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Abstract

This paper studies a newly heating system applied in rural residences in order to improve the thermal environment comfort and the reliability of this system. Propose an integrated heating system with solar energy, capillary network and phase change energy storage technology in it, comparing the orthodox heating system mode with this newly heating system method. Then makes a simulation analysis to this integrated heating system with FLUENT software. The results shows that this integrated heating system can make the indoor temperature distribute uniform, offer better thermal comfort as well as reduce commercial energy consumption in rural houses. This combined heating system can lay a fundamental to the further study of integrated heating system in rural residences and seek for a reasonable method to the renewable of rural residential heating technology.

Keywords: Rural residence; Solar energy; Capillary network; Phase change energy storage; Integrated heating system

1. Introduction

For many years people who are living in northeast rural areas of our country have adopted to use heated kang heating system. This way of heating makes the utmost of residual heat produced by fuel burning in the stove with the characteristics of lower expenditure. However people’s demand to the thermal comfort of indoor environment have
risen with the improvement of their life quality. The drawbacks of the heated kang which lacks continuous heating to the indoor surroundings has beyond people’s necessity. Normally, indoor air temperature has to be kept by increasing the quality of fuels or the amount of radiator facilities [1]. In this way lots of disadvantages appear, such as the increasing expenditure, the wasting of resources and the sever contaminant to the environment. Therefore, it is urgent to make an integrated heating system in settling the problem of high energy consumption in rural residential buildings [2].

Solar energy, as a sort of clean energy, is widely used to individuals all around the world. Solar energy hot water system, as a well-known energy conservation and environmental production, is broadly applied in the domestic and overseas. It is estimated that solar energy hot water system can provide up to 80 to 95 percent of hot water dosage in summer during which period other source of energy can be saved. In the sunny days of transition season and winter, the water which is heated by the collectors can reach 50–70°C. Even in rainy days the water’s temperature can meet the demand of daily household by auxiliary heating source. While in the capillary network terminal heating system, it can distribute energy efficiently as long as the water in the collectors reach the temperature of about 40°C. This can also make a great efficiency improvement of collectors as well as thermal comfort in the room.

Phase Change Material, applied in the heated kang, can storage the redundant heat from the procession of heating the kang in order to diffuse heat to the indoor environment more durable. Moreover, it can alter the uniformity of kang’s surface temperature and diminish its surface temperature fluctuation to improve the indoor temperature [3-4].

2. Methodology

The integrated system combine phase change material (PCM) and clean solar energy with orthodox heating method. The system consists of several following parts: solar thermal collector, storage water tank, pipe and pump, terminal capillary network, phase change heated kang, firewall, and soil heating. The principle of the operation can be illustrated as follows. As the picture depicts, hot water which generated by the collector is stored in the storage tank and supply the water to the capillary network in order to release the heat to the room through the pump installed the water supply pipe between storage water tank and capillary network.

![Fig. 1. Sketch of solar energy, capillary network and phase change energy storage heating system. (a) solar thermal collector; (b) storage water tank; (c) pipe; (d) pump; (e) terminal capillary network; (f) phase change heated kang; (g) firewall; (h) soil heating.](image-url)

Making the heated kang, firewall and soil heating stove as the heating source. Exhaust gas heat the coil pipe in the stove to supply hot warm in the radiators via the pump installed in the water supply pipe of the soil heating, then the gas goes into phase change storage heated kang and firewall chimney flue to heat the heated kang’s surface and wall surface to make use of the waste heat of it. PCM in phase heated kang is able to absorb and store much more heat in order to increase the temperature indoors. When the temperature gets lower, the heat which stored in the PCM release to keep the indoor temperature constant.
Making simulation analysis to this integrated heating system with FLUENT software. The study aims to analyze the heating system to the indoor temperature distribution, which has a mathematical expression of partial differential equation. The equation is subject to mass conservation, momentum conservation and energy conservation. Followings are the basis control equations of flow and thermal dissipation:

- **Continuity equation**
  \[
  \frac{\partial \bar{\rho}}{\partial t} + \frac{\partial}{\partial x_j} (\bar{\rho} v_j) = 0
  \]

- **Momentum equation**
  \[
  \frac{\partial}{\partial t} (\bar{\rho} v_j) + \frac{\partial}{\partial x_j} (\bar{\rho} v_j v_i) = -\frac{\partial \bar{p}}{\partial x_j} + \frac{\partial}{\partial x_j} \left[ \mu_t \left( \frac{\partial v_j}{\partial x_i} + \frac{\partial v_i}{\partial x_j} \right) \right] - \rho_c g_i \beta (T - T_c)
  \]

- **Energy equation**
  \[
  \frac{\partial}{\partial t} (\bar{\rho} c_p T) + \frac{\partial}{\partial x_j} (\bar{\rho} c_p T v_j) = \frac{\partial}{\partial x_j} \left[ \left( \lambda + \frac{\mu_t}{\sigma_T^2} \right) \frac{\partial T}{\partial x_j} \right] + s_f
  \]

A general equation can be expressed to the fundamental equations above, namely

\[
\frac{\partial \rho \phi}{\partial t} + \text{div} (\rho \vec{U} \phi) = \text{div} (\Gamma_\phi \text{grad} \phi) + S_\phi
\]

The intensity of radiant heat exchange of each heating body’s surface use \( E_q \) to indicate.

\[
E_q = \varepsilon \sigma_q T^4
\]

Where \( \phi \) is universal variables, which can replace solved variables such as \( u, v, w \) and \( T \) and \( \Gamma_\phi \) is generalized diffusion coefficient and \( S_\phi \) is generalized the source term. \( E_q \) is radiant intensity, and \( \varepsilon \) is the emissivity of actual object surface, and \( \sigma_q \) is Stefan Boltzmann constant, and \( T \) is thermodynamic temperature.

In this paper an actual residential house is selected to make the analysis. Choose the room in the size of 6000mm×5000mm×3000mm, the heated kang in size of 3000mm×2000mm×600mm, PCM layer can be simplified to a box encapsulation layer in the size of 3000mm×2000mm×5mm, capillary network layer can be simplified in the size of 2000mm×1500mm×5mm. Establish the model based on the geometries above.

Setting the calculating parameters in FLUENT. Select single precision 3d solver, check the meshing after reading the mesh file, and choose pressure solver and standard k-\( \varepsilon \) double-equation in calculating simulation turbulent flow. Surrounding pressure to 101325Pa, gravitational acceleration is 9.8, unfold the energy equation modeling and radiator modeling, and choose “DO” in the radiator modeling.
Table 1. The physical property parameters of various materials.

<table>
<thead>
<tr>
<th>Material type</th>
<th>Density ($\text{kg/m}^3$)</th>
<th>Specific heat at constant pressure ($\text{J/kg·K}$)</th>
<th>Coefficient of heat conduction ($\text{W/m·K}$)</th>
<th>Air viscosity ($\text{kg/m·s}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air of 10°C</td>
<td>1.2428</td>
<td>1005</td>
<td>0.0252</td>
<td>1.765×10^{-3}</td>
</tr>
<tr>
<td>Air of 15°C</td>
<td>1.2260</td>
<td>1005</td>
<td>0.0255</td>
<td>1.785×10^{-3}</td>
</tr>
<tr>
<td>Air of 18°C</td>
<td>1.2134</td>
<td>1005</td>
<td>0.0257</td>
<td>1.800×10^{-3}</td>
</tr>
<tr>
<td>Air of 24°C</td>
<td>1.1890</td>
<td>1005</td>
<td>0.0262</td>
<td>1.830×10^{-3}</td>
</tr>
<tr>
<td>Water of 36°C</td>
<td>993.70</td>
<td>4178</td>
<td>0.6000</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Utilize velocity inlet boundary type and the velocity is 0.3m/s, inlet exhaust gas temperature is 400K, inlet turbulence intensity $I$ is 3.56%. Hydraulic diameter $D_H$ is 0.218m, outlet wall rough thickness $K_s$ is 0, and Roughness of constant $C_k$ is 0.5. In pressure difference format and Simple method, First Order Upwind is used in momentum equation, turbulent kinetic energy equation and turbulent dissipation rate equations. Other parameters are default settings.

3. Results and discussions

Followings are the simulation outcome by setting the boundary conditions and iterative computations. Given the cloud chart to the whole room space and the distance of 50mm, 1500mm and 2000mm from the ground.

![Fig. 3. The simulation room chart of solar energy, capillary network, soil heating, phase change energy storage heated kang, firewall heating system.(a) one side; (b) the other side.](image)

![Fig. 4. (a)Temperature field cloud chart of 0.05m from the ground; (b) Temperature field cloud chart of 1.5m from the ground; (c) Temperature field cloud chart of 2m from the ground;](image)

Seen from the simulation outcome, the temperature has a uniform distribution except the corner in the room. The high temperature can arrive at about 26°C with a temperature of approximately 21°C. At the front of the phase change heated kang, the average temperature can reach 103°C, in the middle it can get 87°C, and at the end it is 78°C, which also have a uniform distribution with small difference in temperature gradient. The mean temperature of the distance 5~10cm from the heated kang is 28°C. Indoor average temperature is about 23°C, consequently it can meet the demand to daily life.
In this paper, the working principle of rural kang in northern China has been studied and analyzed. Applying this integrated heating system in rural areas has significant advantages and competitiveness in such aspects as technology, economy, and environmental protection, which can greatly improve the indoor thermal environment. This combined heating system can lay a fundamental to the further study of integrated heating system in rural residences and seek for a reasonable method to the renewable of rural residential heating technology.

The most notable energy-saving efficiency system is solar energy, capillary network and phase change energy storage heating with its saving about 1073 kg coal. In terms of economy, supposed 10 years of utilization, the best economic effect is also solar energy, capillary network and phase change energy storage heating system with 63,000 Yuan. Phase Change Material, applied in the heated kang, can storage the redundant heat from the procession of heating the kang in order to diffuse heat to the indoor environment more durable. Moreover, it can alter the uniformity of kang’s surface temperature and diminish its surface temperature fluctuation to improve the indoor temperature. This integrated heating system can make the indoor temperature distribute uniform with approximately 23°C, offer better thermal comfort as well as reduce commercial energy consumption in rural houses.

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References