Study on night heating design of solar thermal storage system in winter based on CFD

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Abstract. With the gradual maturity of solar heating system, more and more houses are equipped with solar heating equipment for heating. In view of the heating effect of the movable plate house, this paper selects the coldest monthly average temperature of -15 °C in Jinan as the external condition, designs the wall embedded heating coil with water as the medium, and uses CFD simulation software to establish the geometric model of the temperature distribution of the house in 7 hours after 10 pm. The simulation results show that when the overall wall is covered with heating coil, the nighttime temperature of the indoor personnel rest area is above 7 °C without considering the heat transfer effect between the personnel themselves and the internal space of the house. If the wall is covered with heating coil, the indoor average temperature will be no less than 12 °C. Solar energy contribution rate can reach more than 43.15 %, energy saving effect is obvious.

1. Introduction

In recent years, people’s demand for building energy efficiency has increased. For the combined board room used for workers’ living in engineering operations, the heating methods are mostly air conditioning, electric heating and other electrical heating equipment. In use, it is easy to cause fire due to excessive equipment temperature, and consumes huge energy. In order to solve this problem, this paper proposes a heating coil fixed on the mobile wallboard, which uses hot water circulation to heat the house. The house model is established by Solidworks and Fluent software, and the night heating of the house is simulated. The heating effect of the heating coil is compared under different areas and positions, and the contribution rate of solar energy in heating is calculated. The advantages and disadvantages of different conditions are analyzed, which lays the foundation for the application of solar heating in mobile board houses.

2. Modeling simulations

In this paper, a single-story temporary slab room built in a construction site in Jinan is selected. The size of the room is 6m×5m×2.8m by Solidworks software. The enclosure structure is surrounded by external walls, and the other is floor and roof. There are two2m×1m×0.5 m single beds attached to the walls on the left and right sides of the door in the house. The 30 mm diameter heating coil is embedded in the wall opposite the door and window of the house. The location range and the overall model of the room are shown in Figure 1.
Figure 1. Building models of heating coils with different heights

Ansys-Mesh software is used to mesh the model, as shown in Figure 2. The unstructured grid is selected to locally encrypt the vicinity of the heating coil. The grid size is gradually increased in the large indoor space, the number of grids is reduced, and the operation speed is improved.

Figure 2. Grid generation near heating coil

In order to simplify the calculation model, the average heating temperature of the heating coil is set to 45 °C, and the wall panels and roofs around the house are insulated by external 100 mm benzene plate. The main parameters of the house are shown in Table 1.

Table 1. Boundary and material property parameters.

| Material      | Density (kg/m³) | Viscosity (kg/m-s) | Thermal Conductivity (w/m-k) | Specific Heat (J/kg-k) | Thermal Expansion (1/k) |
|---------------|-----------------|--------------------|------------------------------|------------------------|-------------------------|
| Air           | 1.205           | 1006.43            | 0.0242                       | 0.593                  | 0.286                   |
| Composite Wall| 160             | —                  | 0.04                         | 750                    | —                       |
| Ground        | 1600            | —                  | 1.74                         | 1750                   | —                       |
| Window        | 2400            | —                  | 6.4                          | 790                    | —                       |
| Door          | 160             | —                  | 1.2                          | 680                    | —                       |

*Boussinesq hypothesis is used to set the air physical properties, so that its density changes with temperature.

In terms of temperature selection, the temperature of roof, wall and doors and windows of the house selects the coldest temperature of Jinan in December as -15°C; The indoor temperature rises due to the solar thermal radiation during the day. Although the night temperature will decrease, it will still be higher than the external temperature. The numerical simulation sets the indoor temperature to 5°C.

3. Analysis of simulation results

The simulation time was from 10p.m. to 5a.m. the next day. In Figure 3, Three XZ profiles at different positions were selected to observe the temperature field distribution inside the house.
The temperature distribution in the plane of figure 3 (b) Y=1m and figure 3 (c) Y=3m is uniform with little difference, and the temperature in most areas is between 282 and 288K. This is because the indoor air simulated in this paper will expand and move irregularly after receiving heat, and the high-temperature air and the surrounding low-temperature air continue to conduct convective heat transfer in of weak laminar flow. This heat transfer mode is conducive to the uniform distribution of indoor temperature, and does not cause local overheating or undercooling in the house due to distance.[1]

Figure 3 (d) The temperature difference at Y=5m is large. This is due to the external wall of the house, affected by the temperature outside the house; The heating coil has been heated by hot water circulation at night, and heat is transferred from the high temperature heating coil to the low temperature indoor air by convective heat transfer. In order to more clearly reflect the effect of heating coil with different heights and heating areas on the temperature rise of the house, the experimental results of three different coil settings are arranged into curves as shown in Figure 4.

![Figure 3. Temperature distribution chart of XZ plane of house](image)

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![Figure 4. Temperature distribution of houses under three heating coil arrangement modes](image)

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- It can be seen from the temperature variation range of the three curves in Figure 4 that when the heating area of the coil is constant, its installation position has no significant effect on the temperature field of the house, and the heat loss at the door and window of Y = 0 m is serious.

- As the XZ surface continuously approaches the heating coil along the Y axis, the change of the average surface temperature shows a trend of first significant increase and then slow decrease. This is due to the low wall temperature, resulting in heat loss in the near-wall region of heat transfer.

- The minimum indoor average temperature of Y>1m in the room is 7°C. Referring to the temperature distribution in Figure 3 (b)(c), the temperature distribution in the human activity area is uniform. Although the surface average temperature is the lowest at Y = 5 m, the temperature near the coil is higher than the surface average temperature. When people in the room lie in bed at night, compared with (b)(c) two different coil installation heights, the coil located at Z=0.45~1.05 m has better heating effect for people.[2]

- When the heating coil is in the position of Z=0.45~1.85m, the maximum average temperature of the section where the heating coil is located is 12 °C. At this time, the heat transfer area is the largest and the heat input is the highest. The heating coil at Z=0.45~1.05m is better than that at Z=1.25~1.85m. This is because the air inside the house will rise forward along the Z axis after heating, which strengthens the effect of air convection heat transfer, thereby reducing the temperature near the wall and reducing the heat loss.
4. Energy-saving analysis of solar heating
The heat obtained by solar ground heating system is stored in the heat storage tank first, and then heated by hot water circulation until night. The house size in this simulation is 6m×5m×2.8m. According to the data given in Table 2, this paper selects the monthly average total radiation in December as the basic data of solar heating.

Table 2. Monthly daily average total radiation in Jinan City

| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|-------|---|---|---|---|---|---|---|---|---|----|----|----|
| Radiation (MJ/m²) | 13.63 | 15.23 | 16.63 | 16.52 | 18.72 | 18.21 | 14.81 | 14.98 | 16.50 | 16.00 | 14.16 | 13.85 |

Replace the relevant values with the following formula to calculate solar heat storage\(^{(3)}\):

\[ Q_s = \frac{A_c f}{J_T \eta_{cd} (1 - \eta_L)} \]  

In the formula: \( Q \) — Solar energy heat storage, KJ; \( A_c \) — aperture area of collector, m²; \( f \) — solar fraction, %; \( J_T \) — Annual average daily solar radiation on the surface of collector, KJ/m²; \( \eta_{cd} \) — Annual average collector efficiency; \( \eta_L \) — Heat loss rate of tanks and pipelines.

The calculation results of solar energy storage, heat supply at different installation positions and solar energy contribution rate under corresponding conditions are shown in table 3.\(^{(4)}\)

Table 3. Comparison of solar energy contribution rate under different installation positions of coil

| Installation position | Z=0.45~1.05m | Z=1.25~1.85m | Z=0.45~1.85m |
|-----------------------|--------------|--------------|--------------|
| Solar energy storage (KJ) | 87250 | 144450 | 202200 |
| Heating capacity | 60.40 | 60.40 | 43.15 |

5. Conclusion
Different installation positions of heating coil have little effect on the overall temperature field in the house, but the coil installation position can be closer to the rest personnel, and the heating effect is better. The increase of installation area helps to improve the overall temperature of the house, and the heat input also increases. When the solar heat storage is constant, the increase of the heat supply to the house will reduce the contribution rate of solar energy. The contribution rate of solar energy in this simulation is not less than 43.15 %, and the energy saving effect is obvious.

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