Comparative study of simulation methods applied to heat transfer calculation of building walls containing phase change materials

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Abstract
Phase change materials (PCM) have great heat storage capabilities, and can achieve energy-saving effects when used in buildings after simulation optimization. This paper adopts the finite element method (FEM) and the finite difference method (FDM) to simulate the heat transfer process of PCM under the influence of outdoor temperature. The differences between the two methods are analyzed in terms of time step, space step and phase transition interval. The results indicate that the FEM has a higher accuracy with less variation of temperature with time-space step and phase transition interval when simulating PCM. Furthermore, a comparative analysis of the differences in accuracy and computational speed between open-source software (FreeFEM++) and commercial software (COMSOL Multiphysics®) is conducted based on the FEM. The results demonstrate that the simulation using open-source software can be effectively used to analyze the thermal effects of PCM, which also reduces the dependence on commercial software and provides better economy and flexibility.

Highlights
- The differences between the FEM and the FDM in the simulation of PCM and the reasons for the differences are carefully analyzed.
- The influence of phase transition interval and space-time step on the calculation accuracy of simulation is considered.
- Open-source software is used in the simulation of composite PCM wall to improve the economy and freedom by programming.

Introduction
Building accounts for an increasing proportion of world energy consumption due to the improvement of living standards (Lei et al., 2011), which is one of the three major industries of energy consumption. The energy used for residential heating and cooling accounts for 61 % of total building demand (Urge-Vorsatz et al., 2015). The energy consumption of buildings brings about energy supply shortage, air pollution, and other energy and environmental problems (Huang et al., 2019).

It is urgent for sustainable development of buildings to improve the efficiency of building energy utilization. With the rapid development of the material industry, it is particularly critical to improve the thermal insulation and energy storage performance of building envelopes. According to statistics, the building envelopes accounts for 50 % of the heating and cooling loads of the building (International Energy Agency and UN Environment Programme, 2019), so it is of great significance to judge the energy consumption demand and carry out energy-saving design.

As the performance and structure of composite walls composed of new materials are affected by hourly outdoor temperature, the heat transfer and heat storage capacity of the walls can be improved by studying the wall temperature change. In addition, temperature attenuation and time delay can also be obtained, providing basis for building energy conservation. In recent years, phase change materials (PCM) have been widely recognized in the building materials industry due to their high latent heat and energy storage density properties.

Extensive studies have been carried out on the application of composite phase change walls (Fan et al., 2022). Experiments found that PCM walls can effectively improve the thermal performance of building and reduce the energy consumption of air conditioning when applied to building envelope (Castell et al., 2010). Lv et al. (2007) experimentally studied a test room consisting of a wallboard containing 26 % PCM and compared it with an ordinary room. The analysis of the thermal performance of the test room showed that PCM could effectively reduce indoor cooling load and energy costs. Akeiber et al. (2017) built the test room by incorporating PCM on the roof and walls. Experiments showed that the room without PCM encapsulation was demonstrated to consume higher energy to maintain an indoor temperature of 24 °C.

For the composite PCM wall, the phase change temperature, thickness and location of the PCM layer have different degrees of influence on the thermal characteristics of the wall (Jin et al., 2016). Fateh et al. (2018) considered different PCM positions and wall orientation conditions, and pointed out that PCM has the best performance when the phase change temperature is close to the internal temperature. Jin et al. (2017) suggested that the optimal position of the PCM layer in the wall was affected by the thermal properties of PCM, such as phase change temperature and latent heat. In addition, the change of ambient temperature has a certain effect on the thermal and energy performance of the PCM wall. Adilkanova et al. (2021) studied the application...
effect of PCM in buildings under different climate conditions through numerical simulation. The studies found that the energy-saving rate of PCM depends on the climate conditions and the thermal insulation characteristics of the envelope. Solgi et al. (2016) adopted the method of combining ventilation and cooling in the night environment with PCM, which effectively improved the energy performance and recycling efficiency of PCM. In conclusion, it is of great significance to simulate the thermal condition of the PCM wall under the change of ambient temperature to determine the parameters and locations of PCM and to combine the PCM wall with other ventilation schemes to improve energy utilization efficiency.

The numerical study of wall heat transfer under outdoor temperature variation mainly adopts the finite difference method (FDM) (Jin et al., 2018) and the finite element method (FEM) (Kishore et al., 2020). At present, researchers mostly use commercial simulation software for numerical simulation of PCM walls. Wijesuriya et al. (2020) adopted popular building energy software commonly used in the construction industry to simulate PCM and showed that several simulation programs have the ability to predict surface temperature. Literatures have simulated the phase change process through ANSYS finite element software (Essid et al., 2022), and then analyzed the influence of material structure and parameters. However, commercial simulation software is expensive and can contain a large number of irrelevant computational components. Open-source software has lower licensing cost and the code is autonomous and controllable. Accordingly, using open-source software to simulate and analyze composite PCM wall has better economy and flexibility.

In this paper, the heat transfer process of PCM is analyzed by FDM and FEM based on the modified effective heat capacity method, which is compared in terms of time step, space step and phase transition interval and calculated by the CodeBlocks and FreeFEM++, respectively. In addition, finite element simulation studies of composite PCM walls are carried out using open-source solver and COMSOL Multiphysics® software, respectively. The results of these comparisons can provide reference for engineering design and energy-saving optimization.

**Numerical models**

In order to simplify the calculation, the following assumptions are considered: The material distribution of each part of the wall is uniform, and the thermal physical property is isotropic; The radiation heat transfer between building envelopes, and the convection in the molten parts of the PCM are neglected; The heat conduction is carried out only along the wall thickness direction.

**Effective heat capacity method**

At present, the heat transfer model of PCM is mainly established by effective heat capacity method (EHCM) and enthalpy method (EM). Studies have shown that although the enthalpy method has relatively accurate results, it requires longer computation time, and the time will increase significantly with the decrease of step size (Jin et al., 2018), which is not conducive to large-scale simulation and calculation. The effective heat capacity method is used to calculate and analyse PCM in this paper and the governing equation is

$$\rho C_P \frac{dT}{dt} = \nabla \cdot (k \nabla T)$$  \hspace{1cm} (1)

Where \( \rho \) is the density, \( C_P \) is the specific heat capacity, and \( k \) is the thermal conductivity.

The \( C_P \) generally adopts the three-stage forms as Equation (2), as shown in Figure 1(a).

$$C_P = \begin{cases} 
C_{ps} & T < T_c - \Delta T \\
\frac{L}{2\Delta T} + \frac{C_{ps} + C_{pl}}{2} & T_c - \Delta T \leq T \leq T_c + \Delta T \\
C_{pl} & T > T_c + \Delta T
\end{cases}$$  \hspace{1cm} (2)

Where \( C_{ps} \) is the solid specific heat capacity; \( C_{pl} \) is the liquid specific heat capacity; \( L \) is the latent heat; \( \Delta T \) denotes half of the phase transition interval.

![Figure 1: The three-stage effective heat capacity method.](https://doi.org/10.26868/25222708.2023.1123)
the temperature at the moment \( t_i + 1 \) is \( T^{i+1} \) when the PCM absorbs the equivalent heat, and the area of region III is the same as that of region III.

Therefore, the three-stage heat capacity method is modified here. Referring to the modified heat capacity of PCM solidification process (Liu et al., 2006), the melting process is divided into six stages by analyzing the relationship between the temperature change of nodes in a time step and the phase transition interval. The heat capacity of the situation is as follows

\[
C_p = \begin{cases} 
C_{p3}, & T^i < T_c - \Delta T, T^{i+1} < T_c - \Delta T \\
C_{p1}, & T^i < T_c - \Delta T, T_c - \Delta T \leq T^{i+1} \leq T_c + \Delta T \\
C_{p2}, & T^i < T_c - \Delta T, T^{i+1} > T_c + \Delta T \\
C_{p3}, & T_c - \Delta T \leq T^i \leq T_c + \Delta T, \\
& T_c - \Delta T \leq T^{i+1} \leq T_c + \Delta T \\
C_{p4}, & T_c - \Delta T \leq T^i \leq T_c + \Delta T, T_c + \Delta T < T^{i+1} \\
C_{p5}, & T_c + \Delta T < T^i < T_c - \Delta T, T^{i+1} < T^i + \Delta T \\
C_{p6}, & T_c + \Delta T < T^i < T_c - \Delta T, T^{i+1} > T^i + \Delta T \\
\end{cases}
\]

When after a time step of two temperatures pass through the phase change range, the calculation by the modified effective heat capacity method allows the heat capacity to be converted to a more exact value based on the heat absorbed by the PCM. By this way the calculated temperature in Figure 1(b) is closer to \( T^{i+1} \). The modified specific heat capacity is easy to use and can calculate the latent heat release more accurately.

**Finite difference method**

In this paper, the unsteady heat conduction equation is used to analyze the boundary temperature and internal temperature of the wall after the outdoor temperature changes. According to the thickness of the wall, the space step is set to divide it into \( N+1 \) nodes, and the corresponding temperature is \( T_j \) \((j = 0.1, ..., N)\). Based on Fourier law and Newton's law of cooling, the Taylor expansion method is used to discretize the region. The boundary is discretized by explicit format, and the temperature node \( T_0 \) of the inner surface can be obtained from the following equation.

\[
(1 + \frac{a_n\Delta x}{k} + \frac{1}{2\sigma})T^{i+1}_j - T^{i+1} = \frac{a_n\Delta x}{k}T_j + \frac{1}{2\sigma}T^i_0 \tag{4}
\]

Where \( a = \frac{k}{\rho c_p}, \sigma = \frac{a\Delta r}{\Delta x^2} \), \( \Delta r \) is the time step, \( a_n \) is the heat transfer coefficient of the interior surface, \( T_j \) is the temperature in the room, and \( i \) is the time step.

The external surface temperature \( T_N \) is

\[
(1 + \frac{a_m\Delta x}{k} + \frac{1}{2\sigma})T^{i+1}_N - T^{i+1}_{N-1} = \frac{a_m\Delta x}{k}T_w + \frac{1}{2\sigma}T^i_N \tag{5}
\]

Where \( a_m \) is the heat transfer coefficient of the exterior surface, \( T_w \) is the outside temperature.

For the nodes inside the wall, the diffusion term adopts the intermediate difference form, and the unsteady state term adopts the forward difference form.

\[
-\sigma T^{i+1}_{j+1} + (1 + 2\sigma)T^{i+1}_j - \sigma T^i_{j-1} = T^i_j \tag{6}
\]

The tridiagonal matrix is established by combining Equation (4), (5) and (6).

\[
\begin{bmatrix}
T^i_0 \\
T^i_1 \\
\vdots \\
T^i_{N-1} \\
T^i_N
\end{bmatrix} = \begin{bmatrix}
\frac{a_n\Delta x}{k}T_j + \frac{1}{2\sigma}T^i_0 \\
\frac{a_n\Delta x}{k}T_j + \frac{1}{2\sigma}T^i_1 & -\sigma & 1 + 2\sigma & -\sigma & \cdots \cdots \\
\vdots & \vdots & \vdots & \vdots & \vdots \\
-\sigma & 1 + 2\sigma & -\sigma & \cdots \cdots & \cdots \cdots \\
\frac{a_m\Delta x}{k}T_w + \frac{1}{2\sigma}T^i_N \\
\end{bmatrix}
\tag{7}
\]

The TDMA algorithm is used to solve the above implicit format through Code::Blocks, which is a free C/C++ and Fortran IDE.

**Finite element method**

Meshing is done in the form of triangulation, and the finite element space is established according to the continuous piecewise Lagrange finite element in the form of P2. The integrand is calculated by summing all vertices and midpoints in the loop of the triangle (Florian, 2013). According to the unsteady heat conduction differential equation, the wall temperature should meet the following equation:

\[
(\nabla \cdot (k\nabla T)) = \partial_x \left( k \frac{\partial T}{\partial x} \right) + \partial_y \left( k \frac{\partial T}{\partial y} \right) + \rho c_p \frac{\partial T}{\partial t} \quad \text{in} \quad \Omega \\
a_n T + \frac{\partial T}{\partial n} = a_n T_f \quad \text{on} \quad \Gamma_f \\
a_w T + \frac{\partial T}{\partial n} = a_w T_w \quad \text{on} \quad \Gamma_i \\
\frac{\partial T}{\partial n} = 0 \quad \text{on other} \quad \partial \Omega
\tag{8}
\]

Where \( n \) denotes the outer unit normal vector of boundary of the geometric region \( \partial \Omega \), \( \Gamma_f \) is the interior wall surface, \( \Gamma_i \) is the exterior wall surface. For other boundaries other than inner and outer walls, the Neumann boundary condition is used, and the heat flux value is set as 0.

Choosing the Euler's implicit form for quadrature, multiplying the Laplace's equation by a smooth test function \( v \) and integrating over the entire domain, applying Green's equation can further obtain the variational formulation:

\[
\int_{\Omega} \frac{1}{k} \frac{\partial T^{i+1}}{\partial t} v - \int_{\Omega} \frac{1}{k} v \frac{\partial T^{i+1}}{\partial t} + \int_{\Gamma_f} k v T^{i+1} \nabla v + \int_{\Gamma_i} a_n \left( v T^{i+1} - T_f \right) v + \int_{\Gamma_i} a_w \left( v T^{i+1} - T_w \right) v = 0 \tag{9}
\]

The built-in functions of the FreeFEM++ (Hecht, 2012) finite element solver are used to integrate the domains and boundaries. The linear system is solved by the column
principal element Gaussian LU decomposition of UMFPACK. Part of the code is shown below. The full code can be obtained by contacting the authors.

```plaintext
real h1=0, h2=0.15, z=0.15;
border a1(t=h2,h1){ x=0; y=t; label=1; }
border a2(t=0,z){ x=t; y=h1; label=2; }
border a3(t=h1,h2){ x=z; y=t; label=3; }
border a4(t=z,0){ x=t; y=h2; label=4; }
mesh Th=
b1mesh( a1(75)+a2(75)+a3(75)+a4(75));
```

The characteristics and differences of the two methods

Since the heat capacity varies with temperature in the effective heat capacity method, both FDM and FEM methods use heat capacity determined by the temperature of the previous moment when calculating the temperature of the next moment in this paper. In addition, the FDM uses Taylor series expansion to discretize the derivative by the difference quotient of the function value; The FEM uses the variation formula, and the loss is approximated by the Euler implicit difference with respect to time. Due to the different functional forms used, the calculation speed and accuracy will be different, so it is necessary to further analyze the calculation results of the two methods.

Results and discussions

The simulation conditions of the PCM board are as follows: the thickness of the PCM board is 15 cm, the latent heat is 179 kJ/kg, the phase change temperature is 27 ℃, the thermal conductivity is 0.2 W/(m·K), the specific heat capacity is 2000 J/(kg·K), and the density is 880 kg/m³. The initial temperature of the PCM board is set to 20 ℃. Considering that the PCM absorbs more heat in the time step when the temperature is high, the higher external temperature can be selected in the simulation. The temperature of one side of the board is maintained at 95 ℃. The differences between the two methods are analyzed in terms of time step, space step and phase transition interval.

Figure 2: Grid independence analysis.
Calculating the central temperature of the wall after 60 min to test the grid independence of the two methods, the time step is 10 s and the results are illustrated in Figure 2. The temperature fluctuation range is less than 0.1 K for both methods when the node number exceeds 16. Since the space step corresponding to this node number is 10 mm, space steps greater than this should be selected to analyze the impact of space step size on the simulated temperature inside the PCM board.

Comparison of two methods applied to PCM board simulation

Figure 3: Temperature variation of the second space node at different time steps.
Figure 3 shows the temperature change of the second space node (a space step away from the heating side of the PCM board) under different time steps. The phase transition interval is 2 °C, and the space step is 2 mm. Since calculation results of the EM are close to the real solution, it is plotted in a smaller time range for comparison, as shown in Figure 3(b). Compared with the EM method, the difference in temperature calculation increases with increasing time step for both methods. The reason is that the larger the time step is, the more heat is transferred when calculating in a time step. The temperature calculated by all methods tends to be stable when the operation time is more than 20 mins.

Figure 4(a) depicts the temperature distribution of PCM board after 60 mins. The temperature values calculated by different methods and time steps are very close. To reflect the difference between the two methods, the node with large temperature difference is analyzed and the results are shown in Figure 4(b). When the time step is 10 s, the temperature calculated by the FDM is 0.9 °C higher than that calculated by the EM, while that calculated by the FEM is 0.27 °C lower. When the time step of 10 s and 2 s is adopted, the temperature difference calculated by the FEM is 0.22 °C, and the FDM is 1.11 °C. Therefore, compared with the FDM, the FEM has smaller variation amplitude with time step and higher accuracy.

The space step of 0.5, 1 and 2 mm is selected for analysis. The time step is 10 s and the phase transition interval is 2 °C. Figure 5(a) shows the temperature distribution of the PCM board after 60 mins, and the nodes with large temperature differences are selected for analysis as shown in Figure 5(b). According to the calculation results, the calculated temperatures of both methods at the same node increase with the increase of the space step. When the space step size is large, the internal phase change process is skipped in the calculation due to the influence of the temperature in the nearby area and the distance between the nodes, which results in a higher calculated temperature.

The temperature difference calculated at the same node increases with the increase of space step. The calculated difference between 0.5 mm and 2 mm space step by the FDM can reach 1.8 °C. The calculated results of the FEM vary relatively little with the step size, with a difference of 0.53 °C.

On the basis of constant time and space step, the phase transition interval of 2, 0.5 and 0.05 °C is selected for analysis, and compared with the three-stage EHCM. The temperature distribution after 60 mins is presented in Figure 6. The EHCM can well simulate the temperature change of PCM when the phase transition interval is greater than 0.5 °C. However, when the phase transition interval is small, the calculated temperature tends to skip the phase transition process, lead to large results. The
three-stage EHCM oversteps the phase change process in the calculation when the phase transition interval is 0.05 °C, and the modified EHCM still has the temperature change affected by latent heat. The calculation results between the FEM and the FDM do not vary regularly with the phase transition interval, and the results obtained by the FEM are more accurate.

**Figure 6: Comparison of temperature calculation results under different phase transition intervals.**

According to the above analysis, the FEM has a higher accuracy with less variation of temperature with time and space steps when simulating PCM compared with the FDM. Since the FEM based on the effective heat capacity method is suitable for phase change intervals greater than 0.5 °C, and commonly used phase change walls have larger phase change intervals (Sun et al., 2022), the method can meet most of the simulation needs and has good applicability. Furthermore, the FEM makes it easier to analyze phase change walls of different shapes, such as corners and arcs. In this paper, we will investigate the simulation of composite PCM wall under outdoor temperature variation based on the FEM using open-source solver and COMSOL Multiphysics® software, respectively.

**Comparison of heat transfer results of simulated composite PCM wall**

![Image](https://doi.org/10.26868/25222708.2023.1123)

The experimental results of the test room in the literature (Pasupathy et al., 2007) are used to analyze. Composite wall (2 m × 2 m × 0.245 m) in the experiment is composed of roof board, PCM board and concrete board, and inorganic salt water compound is used as PCM. The specific parameters are shown in Table 1. The other walls of the test room are insulated with 6 mm plywood. Considering that the total number of measured data is small, the basic fitting function is used as the outdoor temperature condition. The temperature measured in the experiment are shown in Figure 7. The simulation parameters are the same as those in the literature, where $\alpha_n$ is 1 W/(m²·K), $\alpha_w$ is 5 W/(m²·K), and the indoor temperature is stable at 27 °C.

**Table 1: Physical properties of PCM (48 % CaCl₂ + 4.3 % NaCl + 0.4 % KCl + 47.3 % H₂O).**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase change temperature</td>
<td>26~28 °C</td>
</tr>
<tr>
<td>Latent heat</td>
<td>188 kJ/kg</td>
</tr>
<tr>
<td>Solid thermal conductivity</td>
<td>1.09 W/m·K</td>
</tr>
<tr>
<td>Liquid thermal conductivity</td>
<td>0.54 W/m·K</td>
</tr>
<tr>
<td>Density</td>
<td>1640 kg/m³</td>
</tr>
<tr>
<td>Solid specific heat capacity</td>
<td>1440 kJ/kg·K</td>
</tr>
<tr>
<td>Liquid specific heat capacity</td>
<td>1440 kJ/kg·K</td>
</tr>
</tbody>
</table>

Considering that the heat capacity of the PCM used for the calculation in the open-source software is based on the temperature at the previous moment, and that there are differences in the solver, time stepping method, and tolerance within the software, the effect of different step sizes on the results of the calculation method needs to be further explored. The calculation time and RMSE value of the two software under different combinations shown...
in Table 2 are analyzed. Considering that the initial test wall temperature is 26.54 °C, while the temperature set in the simulation is constant, there is a certain deviation between the simulation and experimental results. The laptop's operating system is windows 10, the central processing unit (CPU) is Intel(R) Core (TM) i5-7200 U CPU @ 2.50 GHz 2.71 GHz, and the random access memory (RAM) is 8 GB.

According to the results, the RMSE values at different time-space steps are less than 0.5 °C, which are within the temperature measurement accuracy of the device, so they are in accordance with the allowed error range. The stability of COMSOL calculation is higher under step size variation, and the FreeFEM++ solver is faster when calculating. However, as the number of grids increases and the time step is further reduced, the COMSOL software is gradually faster than FreeFEM++ due to the built-in time stepping method. For building walls in all-day simulation conditions, too much grid and too small time step will not only greatly increase the calculation time but also have no effect on the calculation accuracy. Thus the calculation by FreeFEM++ can be effectively used to analyze the thermal effects of PCM in buildings. In addition, the number and density of the grid can be flexibly modified with a good degree of freedom during the compilation process using the open-source solver.

Table 2: Comparison of calculation methods under different combinations.

<table>
<thead>
<tr>
<th>Number of grids</th>
<th>Time step size [s]</th>
<th>Computing time [s]</th>
<th>RMSE [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>FreeFEM++</td>
<td>COMSOL</td>
</tr>
<tr>
<td>0.8*10^4</td>
<td>1200</td>
<td>&lt;1</td>
<td>5</td>
</tr>
<tr>
<td>0.8*10^4</td>
<td>600</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>0.8*10^4</td>
<td>60</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>1.0*10^2</td>
<td>60</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>2.0*10^2</td>
<td>30</td>
<td>14</td>
<td>18</td>
</tr>
<tr>
<td>5.0*10^2</td>
<td>5</td>
<td>126</td>
<td>107</td>
</tr>
</tbody>
</table>

In addition, the amplitude decay is assumed to be the ratio of the amplitude of the temperature of the inner surface of the wall to the amplitude of the air temperature fluctuation; the time delay is the difference in time between the wall and the outdoor air temperature to obtain the maximum value; the average calculated heat is the average heat dissipation to the room in 24 h. These indicators can be used to analyze the heat transfer and heat storage effects of PCM walls and to control room temperature in combination with other air conditioning devices. According to the calculation, the amplitude attenuation, time delay and average calculated heat calculated by FreeFEM++ are basically the same as COMSOL. Both ways can well simulate the heat transfer of composite PCM wall in the room. The use of the FreeFEM++ open-source solver can effectively reduce the cost and has good economy. Therefore, it is advantageous to apply it to the simulation of PCM walls.

Conclusion

In this paper, based on the modified effective heat capacity method, the heat transfer models of PCM board and composite PCM wall were established using the finite difference method and finite element method. In addition, the internal surface temperature of the composite PCM wall under varying outdoor temperature was simulated based on FEM using open-source and commercial software, respectively. The main conclusions are gained as follows:

1. Compared with FDM, the temperature calculated by FEM has a smaller variation with time step, space step and phase transition interval and has a higher accuracy.
2. The phase transition interval will affect the calculation accuracy of the effective heat capacity method and the smaller phase transition interval is difficult to meet the calculation accuracy. The modified effective heat capacity method is more accurate than the three-stage form. The FEM based on the modified effective heat capacity method is suitable for simulating phase change interval larger than 0.5 °C, which satisfies the conditions of commonly used phase change materials for buildings.
3. The amplitude decay, time delay and average calculated heat are in good agreement between the FreeFEM++ and COMSOL Multiphysics® software results calculated using the FEM. Since in building analysis, energy consumption is usually considered in "hours". For the simulation of building envelopes composed of PCM, finite element analysis using FreeFEM++ can achieve accurate results and fast calculations. In addition, the use of open-source software has good freedom and economy compared to commercial software and can be effectively used to analyze the thermal effects of PCM in buildings.

The instantaneous heat transfer of composite PCM walls can be accurately simulated through the method of independent programming, and then the heat transfer and heat storage performance of walls can be analyzed. The introduction of open-source software in the study of PCM walls, combined with the current advanced technology to develop simulation schemes can economically and effectively realize the simulation of large-scale heat transfer process, which is beneficial for the further study the use of PCM walls in buildings.

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