Non-equilibrium Thermal Insulation Analysis of Self-insulation Wall

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Abstract. In this paper, a mathematical model for calculating the cooling load of self insulation wall in unsteady heat transfer process is established. According to the reaction coefficient method based on Laplace transform and inverse transform, a software for calculating and analyzing the cooling load of self insulation wall is developed. The software can not only analyze the dependence of thermal parameters including thermal conductivity on the cooling load of external wall, but also analyze and calculate the self insulation wall. The non-equilibrium thermal insulation thickness of thermal insulation wall in different directions will provide practical calculation basis and data support for dynamic thermal insulation design of self insulation wall in energy-saving buildings.

1. Introduction
Wall external insulation is an important part of building energy conservation. This kind of insulation method of wearing "cotton padded jacket" for buildings has been used in China for more than 30 years, and once became a conventional practice of building insulation. However, with the improvement of people's requirements and standards for residential buildings, the existing external wall insulation technology has exposed more and more problems. In China, the design life of external wall insulation layer is only 25 years, while the average life of buildings is 50 ~ 70 years. Some external wall insulation began to crack after a few years, and the accident of falling occurred; Later maintenance costs are higher, and a large number of construction waste will be generated, which will affect the city image; most of the materials used are flammable and easy to cause fire when they fall off; with the improvement of building energy saving requirements, the thickness of building insulation layer will increase correspondingly. For example, the requirements for external wall insulation of near zero energy consumption buildings are equivalent to increasing from the current 60mm ~ 80mm thickness to more than 200mm, so as to cause greater security risks.

Therefore, the existing external wall thermal insulation technology is not suitable for the development requirements of the times. The new era strongly calls for new technology of both thermal insulation and fire prevention, that is, building thermal insulation and structural integration technology.

Wall self insulation system is a kind of building wall thermal insulation system which uses energy-saving wall materials and supporting special mortar to make the wall thermal performance and other physical performance indicators meet the corresponding standards according to certain building structure requirements. The self insulation technology has the following advantages: there is no additional insulation measures on both sides of the main body of the self insulation wall, the heat...
transfer coefficient of the main part of the wall can meet the limit value of the average heat transfer coefficient of the wall specified in the building energy saving design standard, and it has the characteristics of durability, fire prevention, impact resistance, convenient construction, low comprehensive cost, less common quality problems, and the same life as the building.

The current standard wall thermal insulation design only stays on the minimum thermal resistance value, heat transfer coefficient and other thermal design parameters of the old external insulation, internal insulation and other traditional walls, and lacks the basis of thermal parameters for the design of wall self insulation system. This situation can not meet the needs of building energy saving under the background of new materials and new technologies. The differential equations of unsteady heat transfer are established in the article. According to the reaction coefficient method based on Laplace transform and inverse Laplace transform, the calculation software is compiled. The cooling load caused by dynamic heat transfer of self insulation wall in different directions of energy-saving building under different thermotechnical indexes conditions is obtained, and the curve is drawn. The change law of cooling load of self insulation wall with thermotechnical index is analyzed, and based on the analysis of dynamic heat transfer data, a non-equilibrium heat insulation design method of self insulation wall is proposed, which will provide a strong practical data support for the thermal design of self insulation wall in energy-saving buildings.

2. Mathematical model of heat transfer
According to the heat conduction differential equation and Fourier law, the unsteady heat transfer process in summer can be described by the following heat conduction differential equation, that is, the relationship between heat flux and temperature field is as follows:

\[
\frac{\partial t(x, \tau)}{\partial \tau} = a \frac{\partial^2 t(x, \tau)}{\partial x^2} \\
q(x, \tau) = -\lambda \frac{\partial t(x, \tau)}{\partial x} \\
t(x, 0) = 0
\]

According to the response coefficient method, the disturbance curve which changes continuously with time is discretized into the unit disturbance which is distributed according to the time series; then the response of the wall to the unit disturbance (i.e. the response coefficient) is solved; finally, the result is calculated by superposition integral using the obtained response coefficient. The following formula is the heat transfer reaction coefficient of the wall, where, the root of time, the reaction of the unit disturbance at a certain time will affect the following for a long period of time. Therefore, the superposition integral method must be used to obtain the result under the effect of the whole disturbance. The formula for calculating the design cooling load temperature of an external wall at a certain time is as follows, where, is the outdoor comprehensive temperature, which represents the external wall orientation, is At the time of calculation, a is the area, and the unit area is 1m². The indoor air temperature is 26 ℃.

Then the cooling load through the wall can be obtained as,

\[
\Phi = KA \sum_{j=1}^{N} Y(j) \rho_{j} (n-j,k)-26
\]

\[
Y(0) = K + \sum_{j=1}^{N} \frac{B_j}{\Delta \tau} \left(1 - e^{-\alpha_{3} \Delta \tau}\right), j = 0
\]

\[
Y(j) = -\sum_{j=1}^{N} \frac{B_j}{\Delta \tau} \left(1 - e^{-\alpha_{3} \Delta \tau}\right)^{2} e^{-(j-1)\alpha_{3} \Delta \tau}, j \geq 1
\]
The calculation steps of VB program are as follows: input the physical properties of each layer of building envelope; calculate the root of $B(s)=0$ is $-\alpha_i$; calculate $B\left(-\alpha_i\right)$, get the coefficient $B_i$; calculate the reaction coefficient; input the outdoor comprehensive temperature $\theta_z(n-j,k)$, The discrete time interval is taken as $\Delta t = 1h$, solve the discrete time interval of the reaction coefficient; and according to ASHRAE's suggestion, $j$ equal to 0 ~ 50; calculate the hourly cooling load of each direction and output.

3. The example of self-insulation wall
In this paper, taking Beijing as a typical city, taking the hourly air temperature used in the design of outdoor air conditioning in summer and considering the change of solar radiation, the hourly comprehensive temperature of outdoor air considering the effect of solar radiation on the design day as the input parameter, and taking the autoclaved aerated concrete materials commonly used in self insulation wall as the research object, the mathematical model of cooling load calculation in unsteady heat transfer process is established. The program can not only analyze the dependence of thermal parameters including thermal conductivity on the cooling load of external wall, but also calculate the non-equilibrium insulation thickness of self insulation wall, which will provide practical data support for dynamic thermal insulation design of self insulation wall in energy-saving buildings.

4. Calculation and analysis process of cooling load for self-insulation wall
According to the calculation results in Fig. 1, Fig. 2, Fig. 3, Fig. 4 and Fig. 5, the calculation and analysis process of self insulation wall cooling load is as follows:

- $\delta=0.25m$, $\lambda=0.17W/m.K$

![Figure 1: The cooling load of external wall in each direction changes hourly](image-url)
Figure 2: The cooling load of external wall in each direction changes hourly with \( \delta=0.3 \text{m}, \lambda=0.17 \text{W/m.K} \).

Figure 3: The cooling load of external wall in each direction changes hourly with \( \delta=0.35 \text{m}, \lambda=0.17 \text{W/m.K} \).

Figure 4: The cooling load of external wall in each direction changes hourly with \( \delta=0.4 \text{m}, \lambda=0.17 \text{W/m.K} \).
The fluctuation amplitude, fluctuation phase and peak value of the cooling load of the external walls with different orientations are different, and the time when the cooling load reaches the peak value of the external walls with different orientations is also different.

From the analysis of the cooling load amplitude of the external wall, under the same thermal parameters and the same conditions, the cooling load amplitude of the external wall with different orientations is in the order of horizontal, West, East, South and North.

According to the analysis of the peak value of the cooling load of the external wall, under the same thermal parameters, the peak value of the cooling load of the external wall with different orientations is in the order of horizontal, West, East, South and North.

From the analysis of the corresponding time of the peak cooling load of the external wall, under the condition of the same thermal parameters of the external wall, the order of the corresponding time of the peak cooling load of the external wall with different orientations is horizontal, West, East, South and North.

The software can analyze the dependence of cooling load on thermal conductivity, thermal diffusion coefficient, thermal storage coefficient and thermal inertia index. However, due to the limitation of space, this paper only gives the variation diagram of cooling load peak value with thermal conductivity for five orientations of self insulation exterior wall. When the thermal conductivity increases, the peak value of cooling load increases with the increase of thermal conductivity.

In order to achieve the same wall surface temperature and indoor comfort requirements, under the condition of the same thermal parameters of the external wall, the equal heat flow design method with the same peak cooling load of the external wall in each direction can realize the non-equilibrium heat insulation of the external wall with different thickness in each direction. Qualitatively, the non-equilibrium insulation thickness of self insulation wall from large to small is in the order of horizontal, West, East, South and North. According to the dynamic load curve data in the figure, combined with the thickness modulus of the self insulation wall, the non-equilibrium insulation thickness of the self insulation wall in each direction can be determined quantitatively with the same cooling load peak value of the external wall in different directions as the constraint condition.

5. Conclusion
Taking autoclaved aerated concrete materials commonly used in self insulation wall as the research object, this paper establishes a mathematical model for calculating the cooling load of unsteady heat transfer process, and compiles a program for calculating and analyzing the cooling load. The program can not only analyze the dependence of thermal parameters including thermal conductivity on the cooling load of external wall, but also calculate the non-equilibrium insulation thickness of self
insulation wall. This will provide practical data support for dynamic thermal insulation design of self-insulation wall in energy-saving buildings.

In this paper, Beijing is selected as a typical city, the hourly air temperature for outdoor air conditioning design in summer is taken as the input parameter, and the solar radiation is considered. For other cities, the design parameters of different urban design days can also be obtained, and the calculation software is still applicable.

As long as the dynamic parameters of annual outdoor air comprehensive temperature are input and the calculation software in this paper is run, the hourly data of annual load can be obtained, which provides a practical method for annual load energy consumption analysis of self-insulation exterior wall.

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