Research on Heat Resisting Character of Hollow Building Blocks in Energy Saving Wall

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Abstract: By establishing a mathematical model with the finite difference method, the three-dimensional temperature fields of a new type of asymmetrical hollow building blocks in an energy saving wall are solved in this paper. The three forms of heat resistance of air interlayer, conduction, natural convection, and radiation, are analyzed. To calculate the heat resistance of the air interlayer, an equivalent method is used in this paper. The heat resistance of the hollow building blocks in the energy saving wall is analyzed by electrical simulation, which is compared with experimental results. Compared to the traditional method, the calculation value of this method more accurately reflects the thermal characteristics of hollow building blocks. Results demonstrate that the heat resistance of air the interlayer increases as the thickness of the interlayer increases. However, when the interlayer thickness approaches 45mm, it tends to remain constant.

Key words: energy saving wall; heat resistance; air interlayer; thermal characteristics

1. PREFACE

Because the production of solid clay block can damage tilth, waste resources, pollute environment, we should reduce the use of solid clay block step by step. It is important to the eastern seaboard of our country, especially to the area with more people and less terra. However, concrete hollow building blocks will be more and more widely used in house building. Hollow building blocks attract much attention because of its characteristics of heat preservation, energy-economization and material saving. It becomes to one of the chief materials of house building. Moreover, in “the design standard of building pyrology and heating energy-economization of inhabitancy building”, it puts forward the demand of 50％ to the ability to heat preservation and energy-economization of building exclosure structure, so it is absolutely necessary to lucubrate the thermal characteristics of hollow building blocks of energy saving wall structure.

2. THE PUTTING FORWARD AND ANALYSIS OF PROBLEM

At present, we generally adopt the setted method in “the pyrology criterion of civilian construction” to calculate the thermal characteristics of hollow building blocks, and to calculate the average energy resistance. However, there are some questions in it. For the problem of heat transfer of air interstratification, nowadays, most literatures only have considered its circumstance of heat conduction, but ignored heat convection and heat radiation. Adopting the quantity heat conduction coefficient to confirm the heat conduction coefficient. The fact proves, there is a big discrepancy between the final calculation data and test result. As is showed in table 1.

The course of heat transferring of air interstratification is different to the layer of homogeneous materials, in the layer of homogeneous materials, heat transfer is in the form of pure heat conduction, and sometimes we can solve the problem as one-dimension. However, in the air interstratification, the three modes of heat

Tab. 1 The comparison between traditional calculation and test result

Rows	Heat conduction coefficient of bone material w/m・k	Length of aperture× breadth of aperture mm	Energy resistance m^2・k/w		Error%
			Calculation value [1]	Test value [2]	
Single-line aperture	0.60	290×90	0.354	0.183	93.4
	1.50	290×90	0.198	0.131	51.1
	0.32	290×90	0.532	0.267	99.2
Two-lines aperture	0.32	290×56	0.734	0.332	121.3

transfer—heat conduction, heat convection and heat radiation—are all existing obviously, its course of heat transfer is generally between two surfaces in finite field, including convectional heat exchange and radiative heat exchange. However, if we recognize the whole heat transfer quantity process in the form of heat conduction by mistake, it will make the calculation value of energy resistance bigger than natural value, because if we recognize the whole heat transfer quantity process in the form of heat conduction, it will make the energy resistance R_a bigger than natural value, but in fact, the value of radiative heat exchange is very small, radiative heat exchange shares a part of the ratio yet, this is the main reason why the test value is smaller than the calculation value. For a certain block, the amount of the energy resistance of air interstratification concerns to the size of aperture and the arrangement of it, and it will affect the energy resistance of the whole block structure directly. According to the basic knowledge of heat transfer, for the natural heat convection, when the ratio of breadth and height of aperture $b/h \geqslant 0.28$, it is infinite space natural heat convection; when $b/h < 0.28$, it is finite space natural heat convection, the hollow blocks used now belong to this type basicly. The energy resistance of interstratification chiefly lies on the thickness of air border layer between the two interfaces of interstratification, the intensity of heat radiation between the two interfaces also affects the energy resistance of interstratification. The increase of the energy resistance of air interstratification and the thickness of interstratification is not in proportion; this is the inherent heat insulation characteristic of air interstratification. Because the heat transfer of most building materials works depending on the effect of elastic wave[3], but the heat transfer of the layer of air works depending on the movement of air molecular. Increasing the thickness of air interstratification can reduce the heat loss results from heat conduction, but it increases the heat loss of convection. However, the heat loss of the heat radiation of air interstratification has nothing to do with the increase or reduce of the thickness of air interstratification. Just because the concurrent three modes of heat transfer exist in air interstratification, energy resistance and thickness don't increase in proportion.

3. ANALYSIS OF ENERGY RESISTANCE OF CONCRETE HOLLOW BUILDING BLOCKS

3.1 Mathematical Model of Heat Transfer of Building Blocks of Wall Structure

To make the calculation of energy resistance of hollow building blocks conveniently, take one part of wall structure as the calculation cell. The physical model of wall structure calculated in this paper showed as figure 1, the rectangle apertures of blocks across arranged, because in the course of the heat exchange with adjacent blocks, the gain and the loss of the quantity of heat are equal, we recognize that the four direction sides of the cell are adiabatic boundary conditions. According to literature [4], the heat conduction differential equation showed as follows:

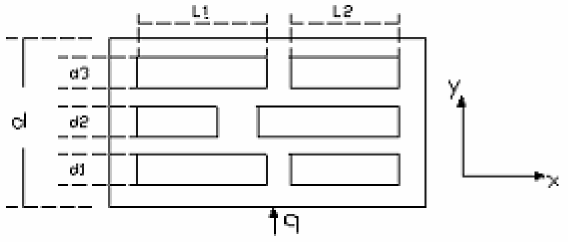

Fig. 1 The physical model of building blocks

X confirmed as the direction of the breadth of blocks

Y confirmed as the direction of the inside and outside wall, also as the direction of heat transfer

$$\begin{cases} t|_{y=0} = t_1, & t|_{y=d} = t_2 \\ -\lambda_x \dfrac{\partial t}{\partial z}|_{x=0} = 0, & -\lambda_x \dfrac{\partial t}{\partial x}|_{x=L} = 0 \\ -\lambda_z \dfrac{\partial t}{\partial z}|_{z=0} = 0, & -\lambda_z \dfrac{\partial t}{\partial z}|_{z=H} = 0 \end{cases}$$

Boundary conditions:

$$\frac{\partial}{\partial x}\left(\lambda_x \frac{\partial t}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda_y \frac{\partial t}{\partial z}\right) + \frac{\partial}{\partial z}\left(\lambda_z \frac{\partial t}{\partial z}\right) = 0 \quad (1)$$

In the formula: t: block's temperature, ℃; λ: heat conduction coefficient, w/m·k; L: the breadth of hollow block, m; L_n: the thickness of air interstratification, m; H: the height of hollow block, m; q: the quantity of heat exchange between hollow block and surrounding, w; d: the thickness of hollow block, m; d_n: the thickness of hollow interstratification, m; with finite difference method, we can gain the temperature field of the block.

3.2 Gain the Energy Resistance of Air Interstratification

In steady condition, the energy resistance of close air interstratification showed in formula (2)[2]:

$$R_k = d/(\lambda_a + \lambda_c + \lambda_r) \quad (2)$$

In the formula: λ_a: heat conduction coefficient of the air in the interstratification, w/m·k; λ_c: convection equivalent coefficient of heat conductivity of the air in the interstratification, w/m·k; λ_r: radiation equivalent coefficient of heat conductivity of the interstratification, w/m·k;

3.2.1 Heat conduction coefficient of the air in the interstratification λ_a

In the interstratification, the heat conduction coefficient of the air changes along with the temperature change of the air itself. Generally, in the calculation of pyrology, confirmming the heat conduction coefficient of the interlayer air in the light of the value of the qualitative temperature inside the interstratification, the qualitative temperature is confirmed by formula (3):

$$t_m = 0.5(t_1 + t_2) \quad (3)$$

In the formula: t_1: the temperature of the inner interface of air interstratification, ℃; t_2: the temperature of the outer interface of air interstratification, ℃; after gaining the value of t_m, we can confirm the value of λ_a by checking table.

3.2.2 Convection equivalent coefficient of heat conductivity of the air in the interstratification λ_c

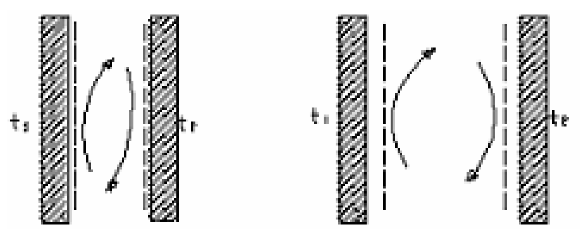

Fig. 2 The schematic of air convection in the layer

The intensity of heat convection in finite space has something to do with the thickness, position, shape and the degree of obturation of the air interstratification. When the direction of heat stream is vertical to the air interstratification, because the difference in temperature exists between the two interfaces of interstratification, the air nearby heat interface will rise, the air nearby cold interface will go down, so a section of air rises and a section of air goes down, and the circumfluence shapes, then the convectional heat exchange produces. If the thickness of interstratification is thin, the rising air current and the going down air current disturb each other, in this time, though the velocity of flow is small, it shapes local circumfluence and attenuates the boundary layer, the effect of heat convection is feeble, the energy resistance of heat convection is also big. When the thickness of interstratification increases, the disturbing degree between the rising air current and the going down air current becomes smaller, the velocity of flow increases along with it. When the thickness gets to a definite degree, the circumstance will be similar to the circumstance of the natural convection produces along the vertical wall in open space. This time, the energy resistance of convectional heat exchange is comparatively small; the effect of convectional heat exchange is comparatively good. Figure 2 shows the two-type circumstances of convection of the interstratification air.

Otherwise, the air's flow in the interstratification chiefly lies on the Grashof number *Gr*, which takes the thickness of interstratification d_n as the characteristic length:

$$Gr_{d_n} = g\alpha\Delta t {d_n}^3 / v^3 \quad (4)$$

When $Gr_{d_n} = 2\times10^5 \sim 1.1\times10^7$, using the formula (5) we can gain the Nusselt number *Nu*[3]:

$$Nu = 0.073\left(Gr_{d_n}\,\mathrm{Pr}\right)^{1/3}\left(H/d_n\right)^{-1/9} \quad (5)$$

The Newton heat exchange formula[3] of the heat convection of interstratification air:

$$q = h\Delta t = Nu\Delta t\lambda_a / d_n \quad (6)$$

However, the form of the equivalent quantity heat conduction of convection is:

$$q = \lambda_c \Delta t / d_n \quad (7)$$

Then

$$\lambda_c = Nu\cdot\lambda_a = 0.197\left(Gr_{d_n}\,\mathrm{Pr}\right)^{1/4}\left(H/d_n\right)^{-1/9}\lambda_a \quad (8)$$

In the formula: d_n: the thickness of air interstratification, m; *H*: the height of air interstratification, m.

3.2.3 Radiation equivalent coefficient of heat conductivity of the interstratification λ_r

The quantity of radiative heat exchange through the interstratification, has something to do with the radiation performance (the black degree or radiation coefficient) of facial material of interstratification and the average temperature of interstratification. For general air interstratification, the space between two interfaces is very small, in a definite temperature, its quantity of radiative heat exchange can takes up more than 2/3 of the whole quantity of heat transfer[2]. According to the course of the radiation between the two interstratification interfaces we can gain the radiation equivalent coefficient of heat conductivity λ_r. The quantity of radiative heat exchange of interstratification is[3]

$$q_r = c_b / \left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1\right)\left[\left(T_1/100\right)^4 - \left(T_2/100\right)^4\right] \quad (9)$$

In the formula, ε_1, ε_2 are the black degree of the two interstratification interfaces. However, shows in the form of equivalent quantity heat conduction of radiation as follows:

$$q_r = \lambda_r \Delta t / d_n = \lambda_r (T_1 - T_2)/d_n \quad (10)$$

Then

$$c_b / \left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1\right)\left[\left(T_1/100\right)^4 - \left(T_2/100\right)^4\right] = \lambda_r (T_1 - T_2)/d_n$$

And then

$$\lambda_r = c_b / \left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1\right)\left(T_1^2 + T_2^2\right)\left(T_1 + T_2\right)\times10^{-8} d_n \quad (11)$$

3.3 Calculation of the Energy Resistance of Block

For the energy resistance of the whole block, we use the circuit simulation method in this paper. For the block model in the figure 1, its simulation circuit diagram shows in figure 3. There is the parallel connection between the part of pure block material and the mixed layer. But in the mixed layer, we can recognize the part of the solid and the energy resistance in air interstratification as being connected in series. In the figure, R_A is the energy resistance of pure block material, R_B is the block material's energy resistance in the mixed layer, R_g is the energy resistance in air interstratification.

Tab. 2 The comparison of air layer energy resistance between calculation and test result

Thickness of interstratification mm	5	10	15	20	25	30	35	40	45	50	55	60
The experimental value[2] $m^2 \cdot k/w$	0.108	0.142	0.158	0.162	0.166	0.175	0.177	0.179	0.182	0.181	0.180	0.180
Calculation method in this paper $m^2 \cdot k/w$	0.116	0.154	0.164	0.174	0.177	0.178	0.182	0.188	0.193	0.188	0.187	0.187
Error %	7.41	8.45	3.79	4.94	6.62	2.28	2.83	5.03	6.04	3.87	3.89	3.89

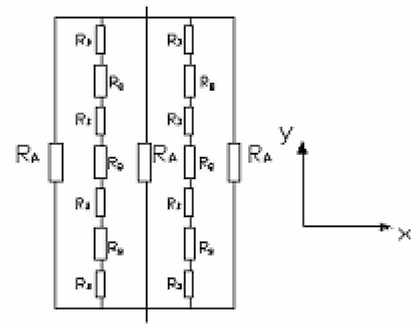

Fig. 3 The scheme of circuit simulation

4. COMPARE AND ANALYSIS OF CALCULATION RESULT AND TEST RESULT

4.1 Compare of the Energy Resistance of Hollow Interstratification

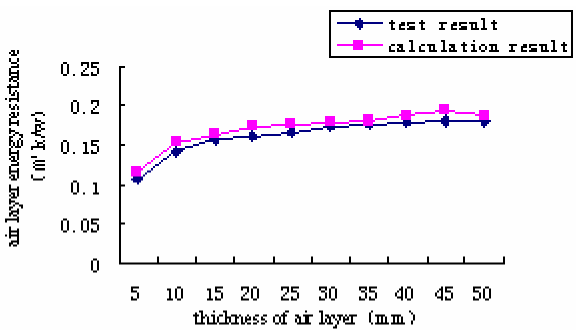

Fig. 4 The comparison of air layer energy resistance between calculation and test result

After calculation compare, we find that relative to the calculation value of traditional method, the calculation value of this paper can approach the experiment test value better, the result is showed in Table 2.

Compare the two groups' data in the table 2, contrast things shows in figure 4. According to the figure 4, we can see after the thickness of close air interstratification reaches 20mm, as the increase of the thickness of interstratification, the increment of the energy resistance of interstratification becomes smaller. Especially when the thickness of interstratification approaches 45mm, the energy resistance of interstratification tends to a constant. Furthermore, during the calculation, we find the radiation energy resistance of air interstratification is very small, but its quantity of heat exchange takes up great amount of ratio. Therefore, if we want to increase the energy resistance of air interstratification, firstly, we should try to reduce the quantity of radiative heat exchange. Generally, comparatively effective method is to paint and stick reflected material whose radiation coefficient is small on the wall of interstratification, now the one chiefly used in building is aluminum foil.

4.2 Compare of the Block's Resistance

We compare the value of block's energy resistance calculated in this paper with the test value; we can consult literature [4] to get the specification and serial number of hollow block. The result shows in table 3.

From table 3, we can see that the calculation value is comparative to the test value. The most error is 6.07％. It shows that the calculation result of this paper has reflected block's thermal characteristics better. Further, through comparison we can see that increasing the lines of aperture can greatly develop block energy resistance, increasing each line of aperture, block energy resistance increase 20％ at least, however, compared to parallel aperture, the obtained increase of energy resistance of stagger aperture is finite. So, on the condition of permission in techniques and mechanics situation, we can increase the lines of hollow blocks properly.

Tab. 3 The comparison of blocks energy resistance between calculation and experiment result

The type of concrete hollow blocks	Concrete capacity kg/m^3	The thickness of air layer mm	The whole thickness of air layer mm	Test value of blocks energy resistance [2] m^2 • k/w	Calculation value of blocks energy resistance m^2 • k/w	Error %
Single-line aperture	2300	130	130	0.183	0.190	3.82
Two-line parallel aperture	2300	50	100	0.268	0.275	2.61
Two-line stagger aperture	2300	75	100	0.295	0..311	5.41
Three-line parallel aperture	2300	25	75	0.346	0.367	6.07
Three-line stagger aperture	2300	25	75	0.382	0.394	3.14

5. CONCLUSION

Aiming at the problem that the gaining energy resistance value by the equivalent coefficient quantity of heat conductivity method has great discrepancy to experiment test value, on the basis of evaluating block's three-dimensional temperature field, this paper through the evaluation of the three aspects of energy resistance (conduction, convection and radiation), then uses the circuit simulation method to the whole blocks, gets the energy resistance of blocks. We can draw the conclusions as follows:

(1) The heat transfer in air interstratification acts with three modes, if we only consider the circumstance of heat conduction and use the equivalent coefficient quantity of heat conductivity method, will make the evaluated resistance value bigger than the test value; therefore, calculate the three aspects of it (conduction, convection and radiation) can get better result.

(2) The energy resistance value increases along with the thickness of interstratification increases, but when the thickness approaches 45mm, the value tends to constant. Furthermore, to develop the energy resistance of air interstratification, we can go chiefly at reducing the quantity of radiative heat exchange, increasing the radiation energy resistance.

(3) After calculating every types of block energy resistance, we can conclude that increasing the lines of aperture can increase block energy resistance

markedly, the increase of block energy resistance from stagger aperture is finite.

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