Thermal Bridge Effect of Aerated Concrete Block Wall in Cold Regions

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Abstract. As a self-insulating building material which can meet the 65 percent energy-efficiency requirements in cold region of China, aerated concrete blocks often go moldy, frost heaving, or cause plaster layer hollowing at thermal bridge parts in the extremely cold regions due to the restrictions of environmental climate and construction technique. L-shaped part and T-shaped part of aerated concrete walls are the most easily influenced parts by thermal bridge effect. In this paper, a field test is performed to investigate the scope of the thermal bridge effect. Moreover, a heat transfer calculation model for L-shaped wall and T-shaped wall is developed. According to the simulation results, the temperature fields of the thermal bridge affected regions are simulated and analyzed. The research outputs can provide theoretical basis for the application of aerated concrete wall in extremely cold regions.

1. Introduction

Aerated concrete block enjoys the advantages of light weight and high thermal performance. Thus, it becomes one of the main materials of constructing self-insulation exterior walls in recent years. And it is treated as a preferred filling material of frame-structure commercial or office buildings, as well as a prior load-bearing material of low-rise residential buildings [1]. The low thermal conductivity of aerated concrete makes it capable of meeting the 65% energy-efficiency requirements in cold region of China [2]. However, in the practice of this material in northeast of China, aerated concrete walls often go moldy, frost heaving, or cause plaster layer hollowing at thermal bridge parts due to the restrictions of environmental climate and construction technique. These defects limit the promotion and application of aerated concrete materials in the cold and extremely cold climate regions [3,4].

For the aerated concrete block, recent research mainly focus on its application in hot-summer and cold-winter zone. Little work has been done for its use in cold regions. For the thermal bridge effect in aerated concrete walls, researchers often established numerical methods based on heat transfer models to investigate the temperature fields in affected regions [5]. The results indicated that thermal bridge easily occurs in the aerated concrete block wall containing reinforced concrete or metal beam parts. In this paper, the temperature of the L-shaped and the T-shaped wall is evaluated by field test and simulation, and the influencing range of the thermal bridge in the aerated concrete wall is analyzed.
2. Field test of thermal bridge effect of aerated concrete wall

2.1. Section Headings

The field test was performed in the Comprehensive Teaching Hall of Jilin Jianzhu University in Changchun city of China. The exterior wall of the building was constructed from aerated concrete blocks with the thickness of 460mm and a 10mm insulation mortar layer. The heat transfer coefficient of the exterior wall is 0.32W/(m²·K). The tests were processed in a room located in the northeast corner. The L-shaped and T-shaped part of the exterior wall were treated as the test objects, as shown in Fig.1. In these two wall components, plastering mortar, aerated concrete block and reinforced concrete are the main building materials. Since the thermal conductivity of the reinforced concrete is much higher than other materials in the exterior wall, the thermal resistance of the reinforced concrete region in lower than the other parts. Thus, heat losses easily in these places, making the inner surface temperature lower than other parts of the exterior wall. This phenomenon is the thermal bridge in the aerated concrete wall. Likewise, thermal bridge also easily occurs in the contact regions of the wall and floor, wall and balcony, wall and roof, etc. Considering that the structures and thermal bridge effectiveness in these regions are similar with that in the L-shaped and T-shaped walls, this paper focuses mainly on the thermal bridge phenomenon in L-shaped and T-shaped wall.

![Figure 1. Horizontal profiles of L-shaped and T-shaped wall](image)

Temperature test points were positioned along the inner and outer surfaces of the exterior wall, at the 1.5m height from the ground. From the corner, thermal couples were pasted on both the inner and the outer wall surfaces every 10 cm to measure the wall surface temperatures. The test results were recorded by WJK-E data acquisition instrument. Meanwhile, self-recording thermographs were used to measure and record the indoor and outdoor temperature. The arrangement of the test instruments and the data acquisition instrument is shown in Fig. 2.

The test was carried out on a cloudy day in winter, during which the outdoor wind speed is 3.8m/s on average. During the test of the L-shaped wall, the average indoor and outdoor temperatures are 16.4°C and -6.3°C, respectively. And during the test of the T-shaped wall, these two temperatures are 16.8°C and -6.1°C, respectively. The tests results of the temperatures at different test points of the two wall components are illustrated in Fig. 3.
Figure 2. Layout of the test on L-shaped wall

Figure 3. Measured temperature curves of L- and T-shaped wall

Seen from the temperature curves in the figure, for the L-shaped and T-shaped walls, the lowest inner surface temperature is lowest at the corner and highest at the farthest test point, while the outer surface temperature is highest at the corner and lowest at the farthest test point. As the distance of the test point from the corner increases, the inner surface temperature increases, while the outer surface temperature decreases. But the changing rates declines gradually; after the test point 4, the changing rates of the inner surface and outer surface temperature become invisible. For the L-shaped wall, after test point 9, the inner surface and outer surface temperature remain unchanged. For the T-shaped wall, after test point 8, the testes temperatures no longer change. Thus, it can be concluded that, for these two structures, the influencing region of thermal bridge is within the test point 9 and 8, respectively.

3. Numerical methods of temperature fields in L-shaped and T-shaped wall

3.1. Establishment of the numerical models

The heat transfer in the aerated concrete wall is assumed to be a steady-state conduction process in a multilayer structure without inner heat source. The contact thermal resistance and temperature variation in the height direction are neglected. Two-dimensional models of L-shaped and T-shaped structures are established, as presented in Fig. 4 and Fig. 5 respectively. The governing equation is:

$$\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} = 0$$

(1)

For the L-shaped wall, according to the actual heat transfer condition, adiabatic boundary conditions are acted on the truncation surfaces, and convective boundary conditions are imposed at inner and out wall surfaces, as indicated in Fig.4. Specifically, the boundary conditions are:
For the T-shaped wall, the boundary conditions are similar with those of the L-shaped wall. Adiabatic and convective boundary conditions are imposed at model boundaries, as illustrated in Fig. 5.
In the above equations, \( l, m \) are the lengths at different axis direction; \( \delta, \epsilon \) are the wall thicknesses; \( t_n, t_w \) are the indoor and outdoor temperatures, respectively; \( t_\beta, t_\alpha \) are inner wall surface and outer wall surface temperatures, respectively; \( h_n \) and \( h_w \) are the convective heat transfer coefficients of the inner and outer wall surface.

3.2. Determination of thermal bridge affected region and model geometry

To determine the model geometry of the following numerical study, the influencing region of the thermal bridge should be identified based on the test temperature results. A temperature difference ratio at any points \( m \) of the wall is defined as:

\[
\xi = \frac{t_n - t_m}{t_n - t_w}
\]

And the ratio in unaffected region \( z \) is:

\[
\xi' = \frac{t_n - t_z}{t_n - t_w}
\]

Where \( t_n, t_w, t_m \) represents the temperatures of the indoor air temperature, outdoor air temperature, and the temperature at any point of the wall, respectively. \( t_c \) is the critical temperature between affected and unaffected region.

The affected temperature is defined as [6]:

\[
\xi / \xi' = \frac{t_n - t_m}{t_n - t_z} \geq 1.05
\]

The thermal bridge influencing regions of the L-shaped and T-shaped wall can be determined based on the test results. The results are presented in Table 1. For the L-shaped wall, the locations with temperature lower than 15.875°C are affected by the thermal bridge, that is, the region of 0-0.9m is the thermal affected region. For the T-shaped wall, the critical temperature is 16.275°C, thus, the affected region is 0-0.7m.

| Structure | \( t_n \) (°C) | \( t_w \) (°C) | \( t_m \) (°C) | \( t_z \) (°C) | Affect area (m) |
|-----------|----------------|----------------|----------------|----------------|----------------|
| L-shape   | -6.3           | 16.4           | 15.9           | \( \leq 15.875 \) | \( \leq 0.9 \) |
| T-shape   | -6.1           | 16.8           | 16.3           | \( \leq 16.275 \) | \( \leq 0.7 \) |

Based on the determined thermal bridge influencing regions, the geometry parameters of numerical model can be determined. The values of \( l \) and \( m \) should be larger than the influencing region, to make sure that the simulation result can involve all the affected regions. According to Table 1, for L-shaped wall, \( \delta=0.47m, l=m=1.2m>0.9m \); and for T-shaped wall, \( \epsilon=0.47m, \delta=0.135m, m=1.08m, l=1.2m>0.7m \).

3.3. Model validation

To validate the model accuracy, a simulation was performed to the L-shaped wall based on the field test result. The solution was processed in FLUENT software. The boundary conditions were given in accordance with the actual conditions in the test. The simulation result of the temperature field thus can be compared to the test result to validate the model accuracy. \( h_n \) and \( h_w \) was set to be 8.7 W/(m²·K) and 23.3 W/(m²·K) according to the Specifications for Thermal Design of Civil Buildings. The physical parameters of the building materials are presented in Table 2. The temperature field of L-shaped wall and the comparison of the test and simulated temperature results are shown in Fig. 5.
Table 2. Thermal parameters of concerned building materials

| Material         | Density kg/m³ | Specific heat capacity J/(kg·K) | Thermal conductivity W/(m·K) |
|------------------|---------------|---------------------------------|-----------------------------|
| Reinforced concrete | 2500          | 920                             | 1.74                        |
| Plastering mortar  | 1600          | 1050                            | 0.87                        |
| Masonry mortar     | 1600          | 840                             | 0.7                         |
| Aerated concrete   | 700           | 840                             | 0.25                        |
| EPS plate           | 30            | 1380                            | 0.042                       |

Figure 6. Comparison of simulated and measured temperature results of L-shaped wall: temperature contour and curves

Seen from the temperature contour, the reinforced concrete in the marked rectangular region changes the smoothness of isotherms in the localized region. Similar changing tendencies can be observed for the tested and simulated temperature curves. For the inner surface temperature, the biggest error occurs at test point 9 to be 6.3%; while for the outer surface temperature, the biggest error occurs at test point 1 to be 7.5%. The errors are acceptable; thus, it can be concluded that the established model is capable of predicting the temperature fields at the thermal bridge affected regions of aerated concrete walls.

4. A case study on the thermal bridge of L-shaped and T-shaped wall

To analyze the thermal bridge effect of the L-shaped and T-shaped wall in typical weather conditions of the extremely cold regions, a case study was performed. The indoor temperature was set to be 18°C, and the outdoor temperature was set to be -20.9°C, which is equal to the design temperature of the space heating in Changchun city. The simulation results of temperature fields of the L-shaped and T-shaped wall are illustrated in Fig. 7.
Figure 7. Temperature fields of L-shaped wall and T-shaped wall.

Seen from the temperature contour of the L-shaped wall, in the reinforced concrete region, the temperature is much lower than that in other regions. The temperature field also implies that the temperature in y direction receives a stronger impact of the thermal bridge. For the T-shaped wall, the figure shows the result of the right part, since the temperature field is symmetrical at the x direction. The temperature in the reinforced concrete region is also lower than that in other regions. The thermal bridge influence is weak in the y direction, as the indoor temperature imposes on both sides of this part. Through this case study, we can conclude that, for both the L-shaped and T-shaped structure of the aerated concrete wall, the use of reinforced concrete will result in a thermal bridge in the localized region.

5. Conclusion
This paper investigates the thermal bridge effects in the L-shaped and T-shaped structures of the aerated concrete wall. The field test and numerical simulation results verifies this phenomenon. In the L-shaped wall and T-shaped wall, the inner reinforced concrete can create a lower temperature field in the localized region, since the thermal conductivity of the reinforced concrete is much higher than that of the aerated concrete. The thermal bridge effect should be particularly handled to ensure the service life of this wall system.

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