Partial Insulation of Aerated Concrete Wall in its Thermal Bridge 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. In this paper, partial insulation measures of the thermal-bridge position of these parts of aerated concrete walls are designed to weaken or even eliminate thermal bridge effect and improve the temperature of thermal-bridge position. A heat transfer calculation model for L-shaped wall and T-shaped wall is developed. Based on the simulation result, the influence of the thickness on the temperature field is analyzed. Consequently, the condensation inside self-thermal-insulating wall and frost heaving caused by condensation and low temperature will be reduced, avoiding damage to the wall body from condensation.

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 [1-2]. The low thermal conductivity of aerated concrete makes it capable of meeting the 65% energy-efficiency requirements in cold region of China [3]. 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 [4-5].

For research work on the thermal bridge effect of aerated concrete walls, researchers in Sweden suggested that using of advanced building materials and configuration designs would be helpful to mitigate the adverse effect of the thermal bridge [6]. Scholars of USA and Canada carried out investigations on a series of composite energy saving walls. Partial insulation measures were taken at the thermal bridge affected regions to reduce the local heat transfer rate [7]. This work proposes targeted partial insulation designs for the L-shaped part and T-shaped part of aerated concrete walls, and analyzed the influence of insulation thickness on the local temperature fields of the thermal bridge. And the effectiveness of the partial insulation on thermal bridge mitigating is also evaluated.
2. L-shaped and T-shaped aerated concrete wall and their partial insulation strategy

The L-shaped and T-shaped part of the exterior wall are treated as the study objects, since the L-shaped part and T-shaped part of aerated concrete walls are the most easily influenced parts by thermal bridge effect, 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)

1-plastering mortar; 2-aerated concrete block; 3-reinforced concrete

Previous studies confirmed that, for aerated concrete walls, the thermal bridge effect easily occurs in the localized region of the inner reinforced concrete. Therefore, a partial insulation strategy can be designed for this wall system. Specifically, local insulation layers can be designed in the reinforced concrete region, in order to reduce the local thermal transfer coefficient. It’s not necessary to add insulation layer in the whole thermal bridge affected region. The sizes of the local insulation layer should be a little larger than the reinforced concrete region [8]. In this study, EPS plate is employed as the insulation layer. This layer is added to the exterior side of the reinforced concrete region. The sandwich insulation pattern is adopted, as shown in Fig. 2

![Figure 2. Partial insulation strategy for the L-shaped and and T-shaped wall](image)
3. Numerical methods of temperature fields in L-shaped and T-shaped wall

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:

\[
-\lambda \frac{\partial t}{\partial x} \bigg|_{x=x+\delta} = 0
\] (2)

\[
-\lambda \frac{\partial t}{\partial y} \bigg|_{y=y+\delta} = 0
\] (3)

\[
-\lambda \frac{\partial t}{\partial x} \bigg|_{x=0} = h_v (t_v - t_{f2})
\] (4)

\[
-\lambda \frac{\partial t}{\partial x} \bigg|_{x=x+\delta, y=0} = h_o (t_{f1} - t_o)
\] (5)

\[
-\lambda \frac{\partial t}{\partial y} \bigg|_{y=0} = h_v (t_v - t_{f2})
\] (6)

\[
-\lambda \frac{\partial t}{\partial y} \bigg|_{y=y+\delta, x=0} = h_o (t_{f1} - t_o)
\] (7)

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**Figure 3.** Model and boundary conditions of L-shaped wall
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. 4.

![Model and boundary conditions of T-shaped wall](image)

**Figure 4.** Model and boundary conditions of T-shaped wall

In the above equations, $l$, $m$ are the lengths at different axis direction; $\delta$, $\varepsilon$ are the wall thicknesses; $t_i$, $t_o$ are the indoor and outdoor temperatures, respectively; $t_f1$, $t_f2$ 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.

In this study, for L-shaped wall, $\delta=0.47\text{m}$, $l=m=1.2\text{m}$; and for T-shaped wall, $\varepsilon=0.47\text{m}$, $\delta=0.135\text{m}$, $m=1.08\text{m}$, $l=1.2\text{m}$. $h_n$ and $h_w$ was set to be 8.7 $\text{W/(m}^2\cdot\text{K)}$ and 23.3 $\text{W/(m}^2\cdot\text{K)}$ according to the Specifications for Thermal Design of Civil Buildings. For the partial insulation layer of the L-shaped wall, the length of the insulation layer in the x and y directions are 0.3m and 0.4m respectively; and for the T-shaped wall, the total length of the insulation layer is 0.7m with a symmetrical structure. No insulation is made on the y direction. The physical parameters of the building materials are presented in Table 1. The numerical model is validated in our previous study [13].

### Table 2. Thermal parameters of concerned building materials

| Material          | Density $\text{kg/m}^3$ | Specific heat capacity $\text{J/(kg} \cdot \text{K)}$ | Thermal conductivity $\text{W/(m} \cdot \text{K)}$ |
|-------------------|------------------------|------------------------------------------------------|--------------------------------------------------|
| 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                                             |

### 4. Numerical results of the temperature fields

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 is illustrated in Fig. 5.
Figure 5. 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.

Fig. 6 shows the temperature fields of L-shaped wall and T-shaped wall with 0.1m local insulation layers. Compare this figure to Fig.5, it is observed that, adding the local insulation layer can generally improve the temperature in the reinforced concrete region and its neighboring region. Thus, adding local insulation layer would be an effective way to mitigate the thermal bridge effect of aerated concrete walls.

Figure 6. Temperature fields of L-shaped wall and T-shaped wall (with 0.1m insulation layer)

5. Effect of the insulation thickness

Fig. 7 and Fig.8 shows the inner surface temperature curves of the L-shaped and T-shaped walls with local insulation layer with different thickness. The results show that, the larger the insulation thickness, the higher the temperature can be achieved in the thermal bridge affected region. For the L-shaped wall, the main body temperature of the aerated concrete wall is 14.79°C. When there is no insulation
layer, the temperature increases sharply to the main body temperature. when insulation layer is added, a temperature decrease process will occur after the sharp increase. The temperature decrease region locate in the range of 0.7-1.1m, showing that the temperature in this region is even higher than the main body temperature. A 0.1m insulation layer can increase the peak temperature to 15.50°C; while the peak temperature improved by 0.08m, 0.06m and 0.04m insulation layers are 15.36°C, 15.19°C and 14.98°C, respectively. Therefore, adding local insulation layer can greatly weaken the thermal bridge effect of the L-shaped wall.

![Figure 7. Temperature variations of outer-corner wall in y direction](image1)

![Figure 8. Temperature variations of T-shaped wall in x direction](image2)

For the L-shaped wall, the main body temperature of the aerated concrete wall is 14.47°C. A 0.1m insulation layer can increase the peak temperature to 15.53°C; while the peak temperature improved by 0.08m, 0.06m and 0.04m insulation layers are 15.43°C, 15.15°C and 14.94°C, respectively. Therefore, adding local insulation layer can greatly weaken the thermal bridge effect of the L-shaped wall. When the insulation thickness is 0.08m, the temperature in the reinforced concrete region can be maintained at the same level of the main body temperature, indicating that a 0.08m local insulation layer is capable of eliminate the thermal bridge effect of T-shaped wall.

6. Conclusion
This paper studies the effectiveness of adding local insulation layers on mitigating the thermal bridge effect of the L-shaped and T-shaped structure of the aerated concrete wall. The partial insulation strategy is effective to weaken or even eliminate the thermal bridge of aerated concrete walls. The larger the insulation thickness, the higher the temperature can be achieved in the thermal bridge affected region. For the L-shaped wall, adding local insulation layer can greatly weaken the thermal bridge effect of the L-shaped wall; while for the T-shaped wall, a 0.08m local insulation layer is capable of eliminate the thermal bridge effect of T-shaped wall.

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