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A New Energy-Efficient Building System Based on Insulated Concrete Perforated Brick with a Sandwich

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Abstract

The purpose of this research is to put forward a new energy-efficient building system that can meet the energy saving requirement of 65% for public buildings in cold areas based on modified insulated concrete perforated brick with a sandwich. Modified brick was composed of three parts and three parts can be made a whole in brick manufacturing and it was called self-thermal insulation concrete perforated brick and could avoid appearance of cracks. The test was done to obtain thickness of EPS for modified insulated concrete perforated brick with a sandwich in order to meet the requirement of insulation. Thickness of EPS was set to 45, 50, 55, 60, 65 and 75 mm respectively and comparative experiments were also carried out to verify the effect of insulation for modified bricks and unmodified bricks. Field tests were carried out to obtain appropriate masonry methods for modified bricks. Based on the results of analysis and discussion, then obtained: (1) Heat transfer coefficient of wall made by modified bricks was less than heat transfer coefficient of wall made by unmodified bricks when the same for thickness of EPS, it could be reduce by up to 45%; (2) When thickness of insulating layer was 65 mm, heat transfer coefficient of wall made by modified bricks could reached minimum limit 0.45 and it could meet energy saving requirement of 65% for buildings in cold area. (3) Insulating layer, located inside of the wall, could avoid appearance of cracks on surface of wall for modified bricks.

Keywords: Thermal Performance; Improved Brick; Heat Transfer Coefficient; Masonry Methods; Insulation Measures; Thermal Bridge.

1. Introduction

Living environment was very important for the development of humanity and society. In order to meet the comfort requirements of living environment, large amount of energy was consumed by buildings in winter and summer every year for the heat transfer through external walls. Because of the reduction of oil and coal resources, energy saving was urgent for all countries and regions. So it was very important to take measures to improve insulation performance of external wall in buildings.

External thermal insulation system (ETIS) was widely used in insulation of external wall in buildings in cold area. Insulation materials was pasted on surface of external walls of building in ETIS after main structure of building was completed. Good heat-insulation effect and thermal bridge not existed were the advantage for ETIS, so it was widely used in building. But there had been imperfections in ETIS, for example, cracks appeared on the surface of external walls over a long time and it caused rainwater to seep into ETIS, so cracks could reduce the quality of external walls and it made external walls instability [1]. The characteristic of poor fire resistance existed in ETIS also [2].

In view of the imperfections that existed in ETIS, self-thermal insulation system (STIS) was put forward. The STIS

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was split into two classes: one was structural self-insulation (Figure 1), another was material self-insulation. Technology of structural self-insulation was that insulation material was placed inside load-bearing structure during construction. There was great difficulty in construction process for the technology of structural self-insulation [3], so it was rarely used in STIS. Technology of material self-insulation mainly depend on performance of insulation brick and approach to dealing with thermal bridge [4, 5, 6]. The brick itself was insulation material in STIS, so construction process of external walls in buildings could be in parallel with thermal insulation construction process, construction period could be shortened [7].

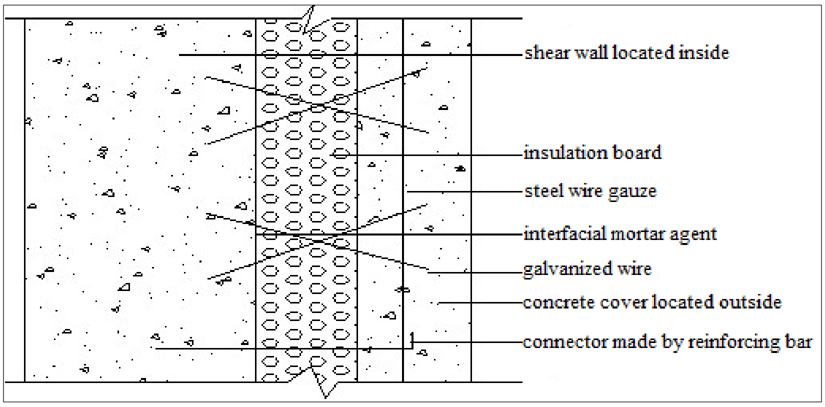


Figure 1. Structural self-insulation system

Insulation bricks or blocks played an important role in STIS [2, 8] so many scholars had paid more attention to numerical and experimental studies on improving insulation performance of insulation bricks or blocks. Zukowski et al studied thermal properties of hollow brick filled with perlite insulation based on numerical methods and experiment methods, it was concluded that high thermal resistance could be obtained without additional layer [9]. Morales et al optimized thermal insulation performance of facades construction with hollow clay bricks by improving geometrical distribution with numerical method [10]. Morales et al studied physical variables of wall thermal transmittance and fired clay conductivity and obtained the linear relationship between them with numerical method [11]. Costa studied how to improving thermal performance of hollow red clay brick by inserting protuberances into holes [12]. Diaz et al investigated thermal properties of light concrete hollow brick with finite-element method and the results showed that engineers could find optimal wall configuration and choose suitable building materials with the help of their comprehensive analyses [13]. Tang et al studied the effect on thermal performance of pasting 10 mm insulation around holes in external walls with the finite-volume method and the results showed that it could reduce equivalent thermal conductivity with the method that authors put forward [14]. Wu et al studied the mechanical and thermal properties of the wall made by rectangular fire hollow blocks and the blocks were made by building waste and industrial waste, the results showed that the blocks satisfied the relevant Chinese standard and it had a high compressive strength and reliable insulation performance comparing with fired common brick or other hollow blocks [15]. Hou et al revealed heat and moisture coupling mechanism of the multilayer energy-saving wall, the results showed that experimental results highlight the important influence of temperature and relative humidity gradient on the hygrothermal properties of the multilayer wall and it also showed that filling compressed straw bricks into hollow concrete block could hinder heat transfer and improve moisture buffering performance of multilayer wall [16].

From the literature cited above, it could be seen that thermal conductivity was one of the important research topic for material self-insulation. Self-insulation brick or block often was used as material self-insulation and it could be broadly divided into two categories based on literature cited above: one was hollow insulation block (Figure 2) another was composite insulation block (Figure 3). Insulating layer was not continuous and thermal bridge existed in brickwork joint on external walls made by blocks that shown in Figure 2 and 3, so the thermal conductivity of external walls was affected and heat transfer coefficient of external walls could not meet energy saving requirement of 65% for buildings in cold area[17]. The cracks also appeared on the surface of external walls made by the blocks mentioned above [7]. Therefore it is necessary to develop self-insulation block which can meet energy saving requirement of 65% and there are no cracks appearing on external wall made by the self-insulation blocks.

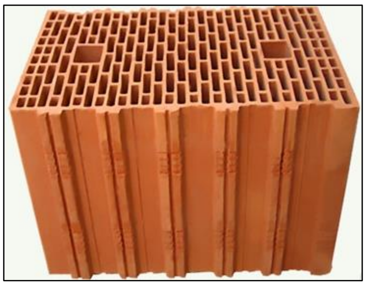


Figure 2. Hollow and microporous insulating brick

Figure 3. Composite insulation brick

A new type self-insulation brick named insulated concrete perforated brick with a sandwich was developed (Figure 4). One patent was granted to the bricks [18]. The insulated concrete perforated brick with a sandwich was different from other self-insulation brick mentioned above in appearance. Wang et al studied the thermal conductivity for insulated concrete perforated brick with a sandwich and results showed that heat transfer coefficient of wall made by the bricks could meet energy saving requirement of 50% in cold area but it could not meet energy saving requirement of 65% for buildings [19]. So, the aim of the present investigation is to modify the insulated concrete perforated brick with a sandwich and make it meet energy saving requirement of 65% for buildings and also the masonry method for the bricks is studied and it can avoid the appearance of cracks on the surface of external wall and insulation measurement at critical thermal bridge positioning is further proposed based on the existing building structure system in this article.

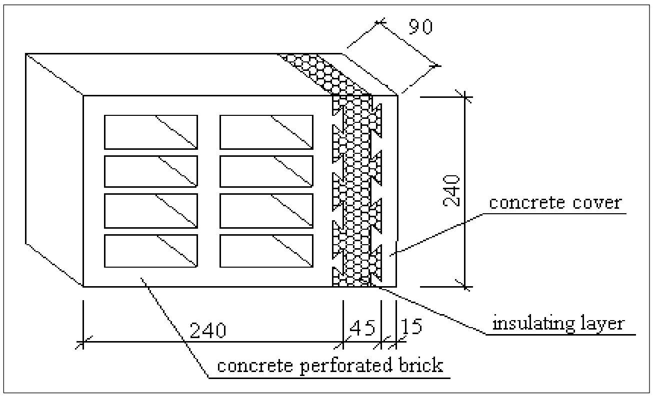


Figure 4. Insulated concrete perforated brick with a sandwich

2. Structural Composition for Brick

Insulated concrete perforated brick with a sandwich was composed of three parts: concrete perforated brick, insulating layer and concrete cover (Figure 5). Evenly distributed porosity existed in concrete perforated brick and it could reduce heat transfer coefficient and it could also resists load. Insulating layer was between concrete perforated brick and concrete cover and it had good heat resistance effect. The shape of swallowtail was applied to insulating layer and it made the connection tightly. In Figure 4 insulating layer was outstretched from the surface of brick, it made insulating layer continuous and could not form thermal bridge between bricks. Concrete cover was used to protect insulating layer. Prestressed steel wire, diameter was 2 mm, was made three parts connect together firmly in brick (Figure 6). The length of prestressed steel wire, anchorage to concrete perforated brick and concrete cover, was 120 and 10 mm respectively.

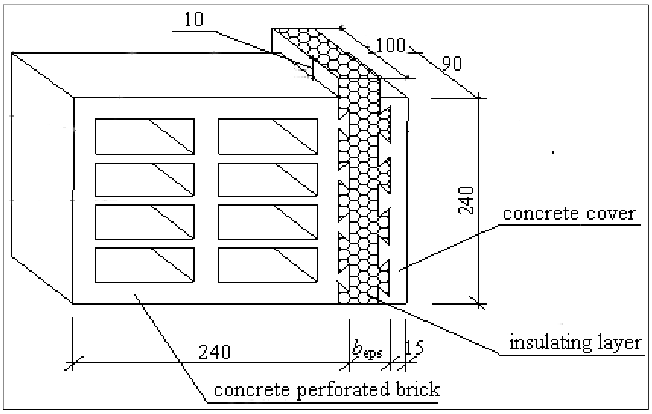


Figure 5. Insulated concrete perforated brick with a sandwich (unit: mm)

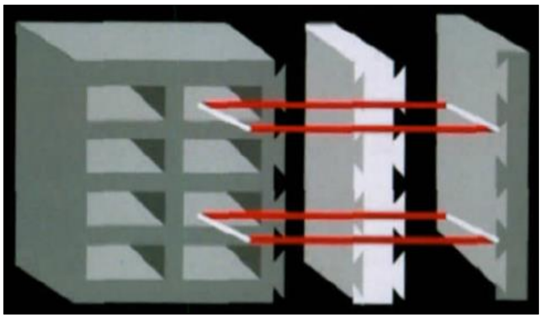


Figure 6. Prestressed steel wire

Concrete perforated brick was made up of fly ash, rock powder, stone fragments and cement and porosity ratio was 40%. The size of concrete perforated brick meet design requirements of masonry structures. Compressive strength of concrete perforated brick could be designed to different strength, for example MU10, MU15, MU20, MU25, MU30 et al.

Material of insulating layer was expanded polystyrene board (EPS) and EPS was good insulation material. The length that EPS outstretched from the surface of brick was 10 mm. The symbol b_{eps} meant thickness of insulating layer in Figure 4 and it determined heat transfer coefficient of wall made by insulated concrete perforated brick with a sandwich. Composition materials and strength grade of concrete cover was the same as concrete perforated brick.

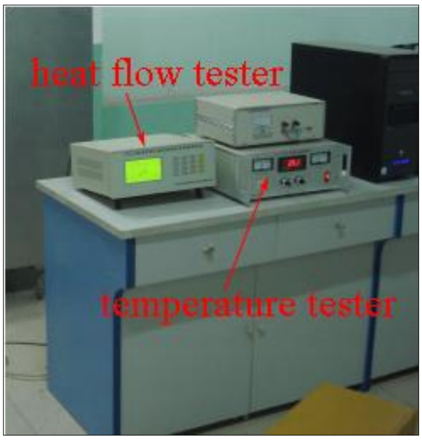
3. Thermal Performance for Brick

In order to study effect of insulating layer outstretched from surface of brick and thickness b_{eps} on conductivity, two types of bricks shown in Figure 3 and 4 were used for testing. Thickness b_{eps} was set to 45, 50, 55, 60, 65 and 75 mm respectively. Density of expanded polystyrene board was 19.5 kg/m^3 and heat transfer coefficient was 0.042W/(m^2 • K). Strength grade of concrete perforated brick was M10.

3.1. Test Equipment

Automatic test system of JTRG—II building thermal temperature and heat flow was used as test equipment (Figure 7). Test equipment was divided into two parts: one was protective box and another was temperature and heat flow automatic tester. Protective box included hot box, cold box and specimen box (Figure 6(a)). Test procedure was shown in Figure 8.

(a) Hot box cold box and specimen box



(b) Temperature and heat flow automatic tester

Figure 6. Automatic test system of JTRG—II building thermal temperature and heat flow

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Figure 8. Test procedure

3.2. Test Method

In order to obtain thermal resistance coefficient of wall made by insulated concrete perforated brick with a sandwich (b_{eps}=45 mm) shown in Figure 5, the wall made by bricks in specimen box. Before pasting heat flow sensors and temperature sensors on the wall, cement mortar was used to paste on the surface of wall [20]. When cement mortar was dried, heat flow sensors and temperature sensors were pasted on surface of cement mortar on both sides of wall (Figure 9).

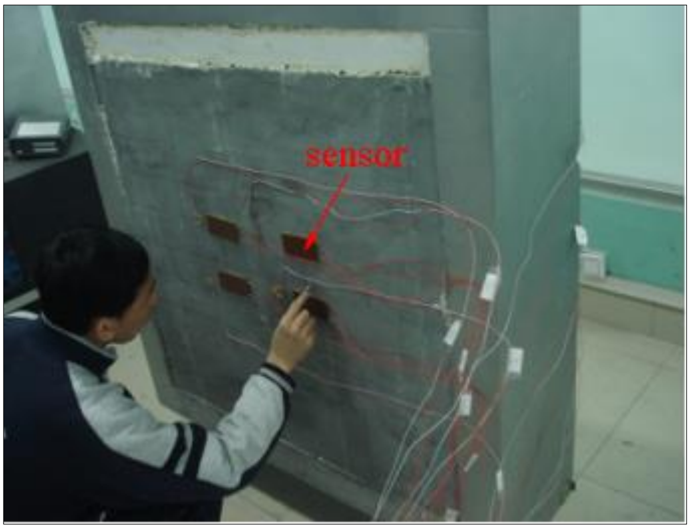


Figure 9. Pasting heat flow sensors and temperature sensors

Temperature was 12°C and humidity was 35％during test in laboratory. Temperature of cold box and hot box was set to -8.0°C and 18°C respectively in automatic test system. Heat flow coefficient was set to 23.26. Temperature circuit number and heat circuit number was set to 8 and 4 respectively. Operation time of temperature sensors and heat flow sensors was not less than 72 hours when temperature and heat flow tended to stabilize, so heat flow and surface temperature of wall which was located in cold and hot box were automatic recorded based on sensors. Mean heat flow and mean surface temperature of wall which was located in cold and hot box were obtained based on test data which were automatic recorded.

3.3. Test Results and Discussion

According to 20 sets of test data shown in Figure 10, mean heat flow q and mean surface temperature θ_e of wall which was located in cold box and mean surface temperature θ_i of wall which was located in hot box were 32.6 w/m^2, −5.637 ℃ and 15.39 ℃ respectively.

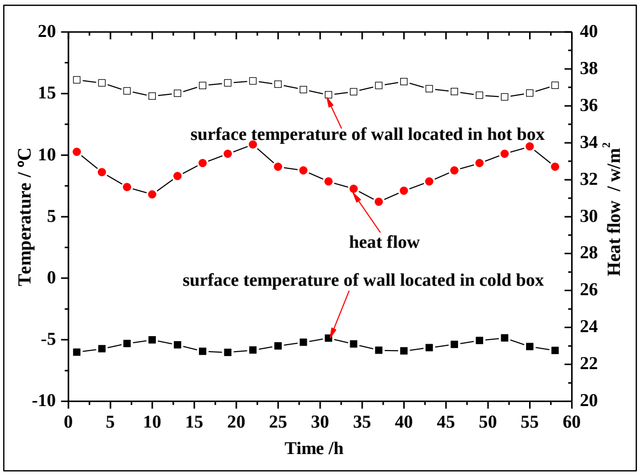


Figure 10. Temperature and heat flow variation relative to time in test

Based on q, θ_e and θ_i, thermal resistance coefficient R of wall made by insulated concrete perforated brick without sandwich could be obtained according to Equation 1.

$$R = \frac{\theta_i - \theta_e}{q} = \frac{19.56-(-9.7)}{20.9} = 1.4 m^2.k/w \tag{1}$$

Total thermal resistance R0 could be obtained according to Equation 2.

$$R_0 = R_i + R_e + R = 0.11 + 0.04 + 1.4 = 1.55.m^2.k/w \tag{2}$$

Symbol Ri meant inner surface resistance of heat transfer; symbol Re meant outer surface resistance of heat transfer in Equation 2. Ri and Re were constants related to the surface features of buildings, Ri and Re were set as 0.11 and 0.04 in this paper.

Heat transfer coefficient k could be obtained according to Equation 3.

$$k = \frac{1}{R_0} = \frac{1}{1.55} = 0.645 > k = 0.45 \tag{3}$$

Heat transfer coefficient k could not meet minimum limit in cold area for insulated concrete perforated brick with a sandwich (b_{eps}=45 mm) [21].

Same test method was applied to insulated concrete perforated brick with a sandwich (b_{eps}=45 mm) shown in Figure 4 and thermal resistance coefficient R and heat transfer coefficient k of wall were 0.689 and 1.192 respectively. So heat transfer coefficient of wall made by bricks shown in Figure 5 reduced approximately 45% compared to bricks shown in Figure 4, but heat transfer coefficient still could not meet minimum limit.

Heat transfer coefficients of wall made by bricks shown in Figure 4 and 5, with different thickness b_{eps}, was shown in Figure 11.

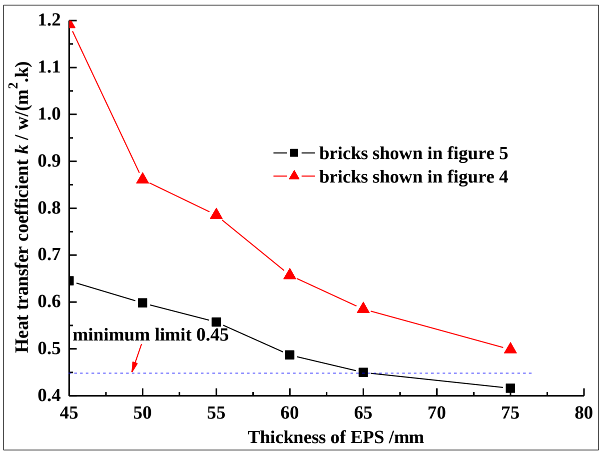


Figure 11. Thickness of EPS effect on heat transfer coefficient

Heat transfer coefficient gradually decreased with increase of thickness of EPS for two types of brick in Figure 11. For heat transfer coefficient, the wall made by bricks shown in Figure 5 was less than the wall made by bricks shown in Figure 4 and it could be reduce by up to 45% when the same for thickness of EPS. When thickness of EPS was 65 mm, heat transfer coefficient of wall made by bricks shown in Figure 5 reached minimum limit 0.45 and it could meet energy saving requirement of 65% for buildings in cold area. When thickness of EPS was 75 mm, it cannot reached minimum limit 0.45 for heat transfer coefficient when the wall made by bricks shown in Figure 4. It could be seen that insulating layer, outstretched from the surface of brick shown in Figure 5, could prevent formation of thermal bridges and reduce heat transfer coefficient of wall. As can be seen from Figure 11, heat transfer coefficient for bricks shown in Figure 4 could reach the minimum limit 0.45 when the thickness of EPS for the bricks shown in Figure 4 was greater than 75 mm, but the thickness of brick could be up to 400 mm and it was difficult to meet design requirements in buildings.

4. Masonry Methods for Bricks

There were two masonry methods for insulated concrete perforated brick with a sandwich. The first method was that concrete cover and insulating layer was located outside of wall (Figure 12). The second method was that concrete cover and insulating layer was located inside of wall. In order to get better masonry method, single apartment, construction area of four layers was 1500 m^2, was built with the first method. A lot of cracks appeared on surface of wall after a period of time and fiberglass mesh was pasted on surface of wall, but cracks still appeared on surface of wall (Figure 13). Above phenomenon indicated that concrete cover could not resist temperature stress caused by big difference in temperature on surface of external walls, therefore it was difficult to avoid appearance of cracks.

Figure 12. The first masonry methods for insulated

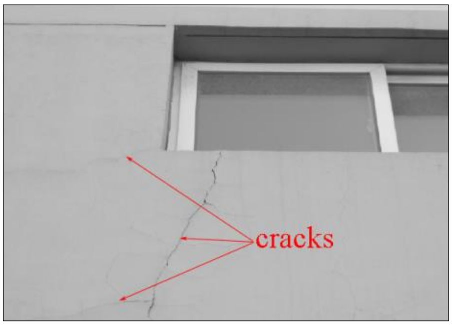


Figure 13. Cracks appeared on surface of wall concrete perforated brick with a sandwich

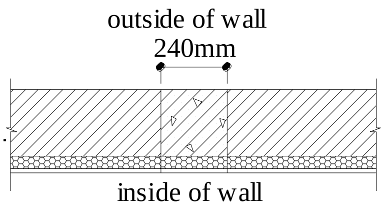
Office building, three layers, was built with the second method and no fiberglass mesh was pasted on surface of wall, no cracks appeared on surface of wall after two years. Project practice indicated that the second method was better than the first method, therefore the method, insulating layer was located inside of wall, was applied to the new energy-efficient building system.

5. Insulation Measurement at Critical Thermal Bridge Position

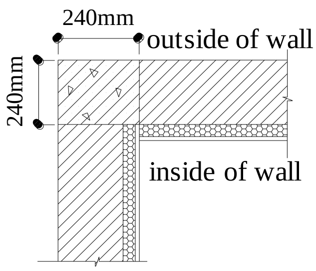
Because load-bearing was applied to the new energy-efficient building system, cast-in-place concrete members, for example, structural concrete columns, ring beams et al, should be set up to meet requirements for seismic resistance based on code for design of masonry structures. Thermal bridges existed at the position of above-mentioned cast-in-place concrete members, insulation measures should be taken to avoid the phenomenon of dewing on surface of inside of the wall.

5.1. Insulation Measures for Structural Concrete Columns

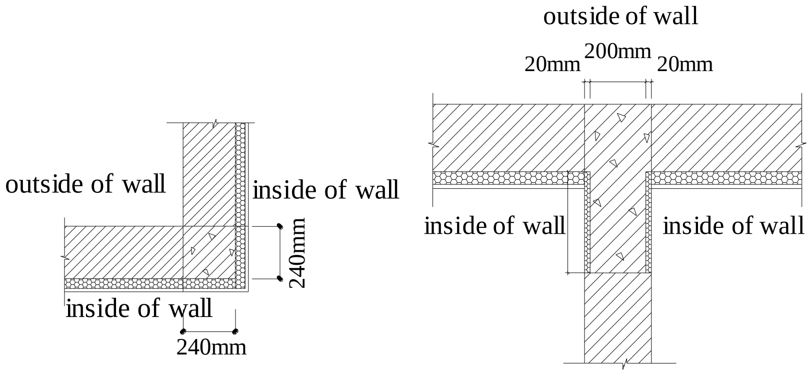
Insulation measures were shown in Figure 14 for structural concrete columns at different location. In Figure 14(a), (b) and (c), expanded polystyrene board (EPS), thickness was same as insulation layer of insulated concrete perforated brick with a sandwich, was pasted on surface of structural concrete columns that was same side as inside of wall. When there were internal partition walls inside of structural concrete column in Figure 14(d), the lengh that structural column extended to internal partition wall was 300 mm. Expanded polystyrene board (EPS), lengh was 300 mm and thickness was 20 mm, should be pasted to the surface of structural concrete columns that located at internal partition walls and it could avoid phenomenon of dewing on surface of structural concrete columns.



(a)



(b)

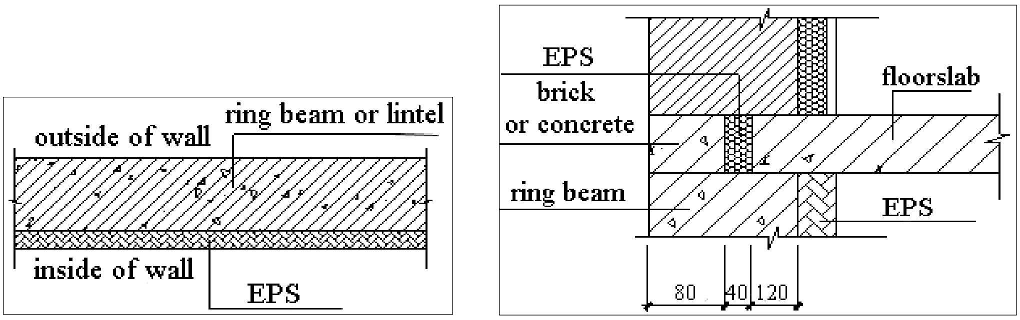


(c) (d)

Figure 14. Insulation measures for structural concrete columns

5.2. Insulation Construction Measures for Ring Beam, Lintel and Floor slab

In Figure 15(a), expanded polystyrene board (EPS), thickness was same as insulation layer of insulated concrete perforated brick with a sandwich, was pasted on surface of ring beam or lintel that was same side as inside of wall. In Figure 15(b), the length, floor slab was placed on ring beam, was not less than 120 mm and expanded polystyrene board (EPS), thickness was 40mm, should be set at the edge of floor slab.

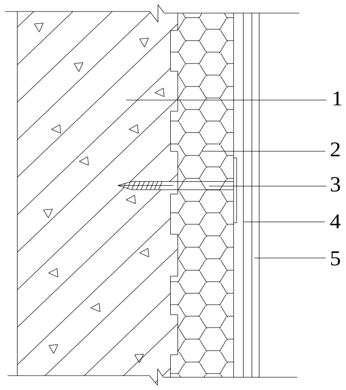


(a) (b)

Figure 15. Insulation construction measures for ring beam, lintel and floor slab

5.3. Combination Method for EPS and Cast-in-Place Concrete Members

Netless cast-in-place system was applied to thermal bridge. Netless cast-in-place system was shown in Figure 16 and it took surface of cast-in-situ concrete as base and expanded polystyrene board (EPS) as insulating layer. The surface of EPS, in contact with cast-in-situ concrete, should be set rectangular slot and anchor bolts were used to fix expanded polystyrene board (EPS). Crack resistant mortar coating was covered surface of expanded polystyrene board (EPS) and fiberglass mesh was placed in it and screed layer was used as protective layer.



1—cast-in-situ concrete member;
2—expanded polystyrene board;
3—anchor bolt;
4—crack resistant mortar coating;
5—screed layer.

Figure 16. Netless cast-in-place system

6. Conclusion

Thermal performance of insulated concrete perforated brick with a sandwich which was improved was studied and insulation measurement was put forward for critical thermal bridge position. The results of the study was:

- Insulating layer, outstretched from the surface of brick, can prevent formation of thermal bridges and reduce heat transfer coefficient of wall. Heat transfer coefficient gradually decreased with increase of thickness of EPS and it was less than the heat transfer coefficient of wall made by unimproved bricks when the same for thickness of EPS, it could be reduce by up to 45%.
- When thickness of insulating layer was 65 mm, heat transfer coefficient of wall made by improved bricks could reached minimum limit 0.45 and it could meet energy saving requirement of 65% for buildings in cold area. When thickness of insulating layer was 75 mm, heat transfer coefficient of wall made by unimproved bricks could not reached minimum limit 0.45.
- Insulating layer, located inside of the wall, could avoid appearance of cracks on surface of wall for improved bricks.
- Insulation measurement, put forward for critical thermal bridge position, could reduce heat loss.

7. Acknowledgements

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