A parametric study of the thermal insulation of external cavity wall constructed using fired clay hollow bricks

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Abstract: This paper investigates the analytical assessment of the insulation capacity of external cavity walls made with different arrangements of holes with and without insulation material. The thermal analysis of the different fired clay hollow bricks was carried out using a steady state model which was developed by the author. Description and validation of one leaf models were given in earlier publication where, impact of parameters such as; the configuration of the brick recesses, the integration of insulation material, and the emissivity of the surfaces on the thermal insulation capacity of hollow fired brickworks were assessed [1, 2]. The parametric study is extended, in this article, to include more types of hollow bricks with different hole arrangements and two types of insulation material. The insulating material, such as granulated cork or polystyrene, is inserted into brick voids. It was found that it is possible not only to improve thermal insulation capacity but also saving building material and reducing space consumption.

Keywords: parametric, cavity wall, fired hollow bricks, equivalent thermal resistance, equivalent thermal conductivity, insulation, cork, expanded polystyrene.

1 INTRODUCTION

Thermal insulation is an essential element in the building envelope and the control of the environment, not only for the comfort that procure during cold and hot seasons, but also for energy saving. Propelled by the research to improve thermal comfort of the occupants and by the energy conservation in our buildings, our laboratory has been involved since 2003 in developing of new processes to improve building thermal insulation capacity. This was basically by studying thermal performance of fired hollow bricks used for external building walls construction. The impact of parameters, on thermal insulation, such as; configuration of the brick voids, the integration of insulating material within the voids, and the voids surface emissivity were investigated and the findings were published in [1, 2]. A particular interest was given to locally available insulating material such as cork, and this could be enlarged to include other materials. In reducing the energy consuming by the heating mechanical systems, we contribute to environment protection from emission pollutants.

In most traditional buildings, heavy walls from stones and adobe have been used. Their disadvantages can be summarised in: they are heavyweight and cannot be used for multi-storey buildings, they are porous to some degree, and sooner or later, especially with weak, or incorrectly constructed joints that they will let in water. Without a barrier of some kind, there is a chance that water will work its way indoors, however thick is the wall. New modern technology has allowed the production of diverse new material such as fired clay hollow bricks. This material is widely used for construction of cavity walls and partitions in the north of Africa. Figure 1 shows a general view of a building constructed from clay hollow brick.
This material has various advantages such as; it is cost-effective, lightweight, and relatively with improved thermal performance. The manufacturers produce two categories of clay fired hollow bricks, big size or 12-hollow-bricks (denoted here as BB12CE) and Small size or 8-hollow-bricks (denoted here as SB8CE), as shown in figure 2.

Generally, cavity walls are constructed of two skins of fired clay hollow bricks and an empty cavity. The cavity wall was first introduced into buildings to protect indoors from damp, as water cannot travel across a cavity. Insulation can be placed in cavities to improve thermal comfort and energy saving. But because of the problem of its deterioration by the moisture, the cavity is left empty. However, occupants complain from not having sufficient thermal comfort in their dwellings. This can be argued by the intensive use of mechanical and electrical heating and cooling equipments and installations in most buildings especially in winter and summer time.

The primary purpose of the work described here is to investigate the relative insulation thermal capacity for various practical arrangements of external double walls constructed of hollow brick with various void configurations, and try to identify some economical, social and environmental fallout.

2 CALCULATION AND MODEL CONFIGURATIONS

The detailed calculation method for estimating thermal performance of fired clay hollow bricks published in [2, 3] has been generalized to a new program, using Matlab, which is used to simulate a large variety of double wall configurations. The configurations
used for the assessment are as shown by figures from 3 to 5. The models used are double vertical walls with and without cavity. Figure 3 shows the first type of arrangement investigated. It is composed of a cavity wall constructed of 12-hollow-bricks (BB12CE) and 8-hollow-bricks (SB8CE) with diverse void configurations. Figure 4 shows the second type of arrangement investigated. It is composed of a double wall constructed of 12-hollow-bricks with diverse void configurations. Figure 5 shows the third type of arrangement investigated. It is composed of a double wall constructed of 8-hollow-bricks with diverse void configurations.

The model that was used as datum, or reference, for comparison is the traditionally used cavity wall denoted in figure 3 by WC1.

The calculations were made for various circumstances; brick voids without insulation, and inserted with insulating materials such as cork and expanded polystyrene (EPS), having thermal conductivity $\lambda_c = 0.039$ W/m °K and $\lambda_e = 0.03$ W/m °K respectively. The brick voids were varied in forms and sizes, squares, vertical rectangles, and horizontal rectangles. The mortar render and joints thermal conductivity $\lambda = 1.1$ W/m °K. Thermal conductivity for brick material $\lambda = 1.15$ W/m °K. Brick partitions thickness and mortar joint height are equal to 0.01m.

![Figure 3: Cavity wall arrangements constructed of diverse brick configurations.](image-url)
(e) Wall type DW1, render (2cm) + BB12CE (14.5cm) + SB8CE (10cm) + render (2cm)

(f) Wall type DW2, render (2cm) + BB6CV (14.5cm) + SB4CV (10cm) + render (2cm)

(g) Wall type DW3, render (2cm) + BB3CV (14.5cm) + SB2CV (10cm) + render (2cm)

(h) Wall type DW4, render (2cm) + BB4CH (14.5cm) + SB4CH (10cm) + render (2cm)

Figure 4: Double walls without cavity constructed of 12-hollow-bricks and 8-hollow-bricks with diverse void configurations.

(i) Wall type DWE1, render (2cm) + SB8CE (10cm) + SB8CE (10cm) + render (2cm)

(j) Wall type DWE2, render (2cm) + SB4CV (10cm) + SB4CV (10cm) + render (2cm)

(k) Wall type DWE3, render (2cm) + SB2CV (10cm) + SB2CV (10cm) + render (2cm)

(l) Wall type DWE4, render (2cm) + SB4CH (10cm) + SB4CH (10cm) + render (2cm)

Figure 5: Double walls without cavity arrangements constructed of 8-hollow-bricks with diverse void configurations.
The aim of the calculations was to find thermal performance of each type of walls. This will enable us to establish comparison between them and find the optimum one with respect to energy saving, and economical fallouts. The calculation was based upon the general schematic model shown in figure 6. Figure 7 is an appropriate electrical analogy for figure 6.

The thermal resistance of a void or a cavity is given as:

\[
R_v = \frac{1}{\left(\frac{1}{R_r} + \frac{1}{2R_c}\right)}
\]  

(1)

Where \(R_r\) is the radiation thermal resistance that can be expressed by:

\[
R_r = \frac{1}{(Ar*hr)}
\]  

(2)

Where \(Ar\) is the area of radiation exchange in m², and \(hr\) is the radiation coefficient of the void or the cavity W/m² °K. \(hr = hrv\) for voids, and \(hr = hrc\) for cavity. \(R_r = R_{ral}\) for voids, and \(R_r = R_{rc}\) for cavity.

Thermal resistance of render, joints brick partitions, or insulation material is calculated from the following equation:

\[
R_{d} = \frac{e}{(\lambda_{d}*A_{d})}
\]  

(3)

Where \(e\) is the thickness in m, \(A_{d}\) is the area of conduction exchange in m², \(\lambda_{d}\) is the thermal conductivity W/m°K.

\(R_c\) is the convection thermal resistance = \(1/(Ac*hc)\)

Equivalent thermal resistance of a cavity wall including external and internal renders is given by:

\[
R_{eq_w} = R_{eq_ew} + R_{eq_c} + R_{eq_iw}
\]  

(4)
Where Req_el, Req_c and Req_il are equivalent thermal resistances for external leaf, cavity and internal leaf respectively. The equivalent thermal conductivity is calculated from:

\[
\lambda_{eq} = \frac{(e_{er} + e_{ew} + e_c + e_{iw} + e_{ir})}{(A_w * Req_w)}
\]  

(5)

e_{er}, e_{ew}, e_c, e_{iw} and e_{ir} are external render, external leaf, cavity, internal leaf, internal render thicknesses respectively in m. A_w is the area of the wall perpendicular to the direction of heat flow in m².

3 RESULTS AND DISCUSSION

The results are examined to see what light they shed on the relationship between the thermal performance and the configuration of the models with or without insulating material and to what extent the results will help us to get some economical fallouts especially in energy, space and material saving.

3.1 Thermal resistance:

The equivalent thermal resistance calculated values for 12 types of investigated double walls with and without insulation under steady state conditions are presented as plots in Figure 8. It can be seen that for all types of walls, thermal resistance increase when the insulation material is inserted in the brick voids. Changing the cork by polystyrene does not really make significant difference in the results. The discrepancies in the thermal resistances become are significant for walls CW2, DW2 and DWE2. These increase further with CW3, DW3 and DWE3. This is explained by the fact that the more the brick void are higher the less thermal bridges (horizontal brick partitions) we can get, and vice versa.

The equivalent thermal resistance, Req, variation in terms of percentage is plotted in figure 9. It is clear that the highest values are those given with wall types CW3, DW3 and DWE3 respectively.

3.2 Thermal conductivity:

The equivalent thermal conductivity calculated values for the 12 types of double walls with and without insulation are plotted in figure 10. It can be seen that equivalent thermal conductivity decreases when the insulation material is inserted in the brick voids. Changing the cork by polystyrene does not make difference in the results. The discrepancies in the equivalent thermal conductivities are significant for the walls CW2, DW2 and DWE2. These increase further with CW3, DW3 and DWE3. This is explained by the fact that the more the brick void are
higher the less thermal bridges (horizontal brick partitions) we can get, and vice versa.

3.3 Energy, material and space saving:
A first look inspection of the results revealed that we can have better thermal performance with a wall DWE3 and DWE3 than a cavity wall W1. We can also save some material and space. The cavity wall CW1 that has (Req = 0.1289 (°K/W) and \(\lambda_{eq} = 0.4309\) (W/m°K)) can have similar values or higher ones if the void configurations of the bricks are let as described in figure 3 to 5. If the cavity wall CW1 has its cavity eliminated to become a double wall DW3 (BB3CV + SB3CV) without insulation, Req will be more or less the same, 0.12 (°K/W) and \(\lambda_{eq} = 0.394\) (W/m°K). This in fact is important from point of view gaining some space. The thickness of external wall will reduce by 5 cm. If we insert cork into

\[\begin{array}{c|c|c|c|c|c|c} \text{Wall Types} & \text{Variation Percentage in Req (%)} \\ \hline WC1 & -5.5 & 12.7 & 11.7 & 11.8 & 17.1 & 30.3 \\ WC2 & -29.5 & 17.7 & 12.3 & 20.3 & 24.7 & 49.3 \\ WC3 & -6.9 & -11.6 & -11.9 & -6.9 & -24.7 & 56.6 \\ WC4 & -23.2 & -11.6 & -11.9 & -6.9 & -24.7 & 56.6 \\ DW1 & -6.9 & -11.6 & -11.9 & -6.9 & -24.7 & 56.6 \\ DW2 & -23.2 & -11.6 & -11.9 & -6.9 & -24.7 & 56.6 \\ DW3 & -6.9 & -11.6 & -11.9 & -6.9 & -24.7 & 56.6 \\ DW4 & -23.2 & -11.6 & -11.9 & -6.9 & -24.7 & 56.6 \\ DWE1 & -6.9 & -11.6 & -11.9 & -6.9 & -24.7 & 56.6 \\ DWE2 & -23.2 & -11.6 & -11.9 & -6.9 & -24.7 & 56.6 \\ DWE3 & -6.9 & -11.6 & -11.9 & -6.9 & -24.7 & 56.6 \\ DWE4 & -23.2 & -11.6 & -11.9 & -6.9 & -24.7 & 56.6 \\ \end{array}\]

Figure 9: Percentage of change in Req for various walls with respect to that of cavity wall WC1 without insulation.

\[\begin{array}{c|c|c|c|c|c|c} \text{Wall Types} & \text{Equivalent Thermal Conductivity (W/m°K)} \\ \hline WC1 & 0.4309 & 0.3857 & 0.369 & 0.456 & 0.4791 & 0.416 \\ WC2 & 0.416 & 0.394 & 0.416 & 0.5177 & 0.4807 & 0.416 \\ WC3 & 0.394 & 0.416 & 0.5177 & 0.4807 & 0.416 & 0.3931 \\ WC4 & 0.4791 & 0.416 & 0.5177 & 0.4807 & 0.416 & 0.5016 \\ DW1 & 0.2904 & 0.2491 & 0.3844 & 0.4201 & 0.3047 & 0.2456 \\ DW2 & 0.3047 & 0.2456 & 0.4146 & 0.4225 & 0.3089 & 0.249 \\ DW3 & 0.2456 & 0.4146 & 0.4225 & 0.3089 & 0.249 & 0.4207 \\ DW4 & 0.4146 & 0.4225 & 0.3089 & 0.249 & 0.4207 & 0.3089 \\ DWE1 & 0.2907 & 0.239 & 0.3787 & 0.4111 & 0.2941 & 0.2342 \\ DWE2 & 0.3047 & 0.2456 & 0.4146 & 0.4225 & 0.3089 & 0.249 \\ DWE3 & 0.2456 & 0.4146 & 0.4225 & 0.3089 & 0.249 & 0.4207 \\ DWE4 & 0.4146 & 0.4225 & 0.3089 & 0.249 & 0.4207 & 0.3089 \\ \end{array}\]

Figure 10: Variation in thermal conductivity, \(\lambda_{eq}\) for different wall arrangements.
the voids of the latter wall, the Req will increase to 0.1925 (°K/W) or 49.3 % improvement. If the insulation is expanded polystyrene, this improvement is slightly higher of the order of 56.56 %. If the double wall is let as DWE3 (SB3CV + SB3CV), the percentage improvement in Req will be 24.02% and 30.19% if inserting cork and polystyrene respectively. This is important, because we will gain some material and space. We use only two wall leaves of small size hollow brick without cavity, and the thickness will reduce by 9.5 cm.

4 CONCLUSION

The present work confirms the early findings and shows the usefulness of the proposed designs in the improvement of thermal performance of external double walls. It was found that some particular configurations together with the insertion of insulation material into brick voids will have certain economical fallouts especially in energy, space and material saving. It was demonstrated that a cavity wall can be simplified into a double wall without a cavity with reduced thickness and better thermal performance. Our proposed process enables us, for instance, to replace a 0.3m cavity wall into 0.2m double wall without cavity but with better thermal performance and insulation capacity.

5 REFERENCES

