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External load-bearing walls configuration of residential buildings in Iraq and their thermal performance and dynamic thermal behaviour

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ABSTRACT

Improving thermal performance of external load-bearing walls in residential buildings could be the most effective way in reducing energy consumption for air-conditioning purpose in housing sector. The aim of this study is to characterize the already existing external load-bearing walls in the residential buildings, in Iraq, in terms of the thermo-physical properties of the used materials. In addition to that, the assemblies of these materials, i.e. wall configurations have been evaluated regarding the steady-state thermal performance and dynamic thermal admittance parameters. Different scenarios were suggested in order to improve the thermal performance of the existing walls. The effect of the binding material (cement mortar) on the global thermal performance of the wall fabrics has also been investigated by utilizing image analysis to calculate the percentage of this material from whole wall. The results showed that binding material has no significant effect on the thermal performance for the studied walls. Gypsum coating layer can be removed as it has marginal effect on the evaluated properties. It was found that involving two air-cavities (internally and externally) has much effect on the walls thermal performance than other approaches.

1. Introduction

Iraq is located in a hot and almost dry climate conditions region during summer, where the outer temperature, sometimes, exceeds 48 °C, while it drops below 10 °C only few days during winter [1]. Iraqi residential sector has about 5 million houses and this number is continuously increasing due to the fast population increase. These houses have mainly constructed using load-bearing walls technique with normally two floors. The external walls are mainly responsible for the transferred heat from/to the houses envelops as they represent more than 50% of the exposure surfaces (walls, roofs, and grounds). The housing sector globally consumes more than 40% of the total energy consumption [2], which contributes for about one-third of the total greenhouse gases emission. This sector, in Iraq, is estimated to consume more than 60% of the total consumed electricity mostly for air-conditioning purpose. The electricity demand has been continuously increasing (by about 5% annually) due to the improvement in living standards and population increase which obviously need more energy especially for air-conditioning during the summer season. This exacerbated by the large increase in temperature caused by global warming phenomenon coupled with using poorly insulated walling system as the single-skin system is still dominant.

The draft of Iraqi code of Buildings thermal insulation [3] has suggested different configurations for load-bearing walls to improve the thermal insulation; however, materials such as polystyrene and mineral wool suggested to be included as internal layers. These materials seem to be expensive and unaffordable for all the people in addition to the traditional mentality that does not accept change/modify the conventional design of the existent walling systems. Therefore, simple, applicable, and acceptable walling systems with better thermal performance/insulation should be designed and examined from both economic and environmental view, if the long-term benefit is taken into account. It was previously concluded that the thermal performance of a wall fabric mainly depends on the thermal properties of the used materials in constructing this wall [4] in addition to its thickness. It is

Abbreviations: System (a), wall configuration with stone as a load-bearing leaf; System (b), wall configuration with clay brick as a load-bearing leaf; System (c), wall configuration with concrete block as a load-bearing leaf; S_{x-1}, internal environmental temperature for system x where x is a, b, or c; S_{x-2}, internal surface heat flux for system x where x is a, b, or c; S_{x-3}, external surface heat flux for system x where x is a, b, or c; ρ, density (kg/m^3); λ, thermal conductivity (W/m^2 K); C_p, specific heat capacity; α, thermal effusivity (m^2/s); β, thermal diffusivity (j/s$^{0.5}$ m^2 K); *R-value*, thermal resistance (m^2/KW); *U-value*, thermal transmittance W/(m^2 K); *Y-value*, thermal admittance W/(m^2 K); Ø, thermal admittance time lag (hr); *f*, thermal decrement factor; *Ω*, thermal decrement factor time lag (hr); *F*, surface factor; *Ψ*, surface factor time lag.

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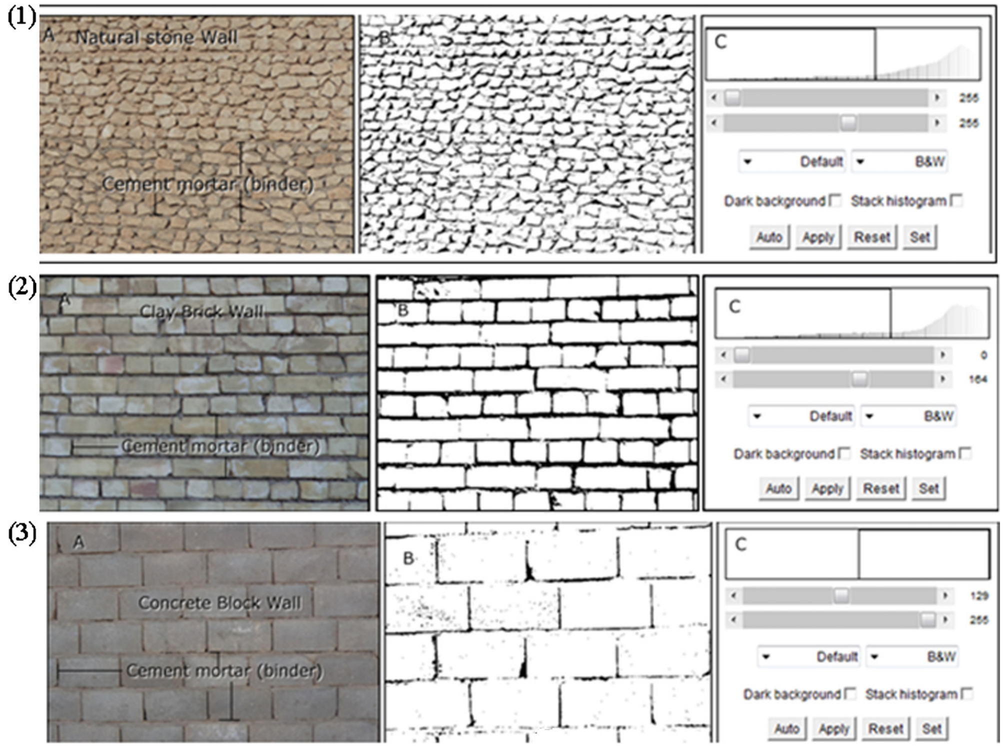

Fig. 1. External wall fabric using natural stone, clay brick, and solid concrete block.

known that air thermal conductivity is much lower than that for the construction materials such as concrete, stone, gypsum, and clay brick; therefore, the dominant walling systems could be improved by involving air-cavity somewhere into the constructed external walling systems.

A few researchers [4–6] have studied the thermal performance of different fabric walls (multi-layered structural element); however, they mostly studied the steady-state-transmittance, i.e. *U-value*. Based on the best knowledge of the author, just one study [5] assessed the stabilized earth walls using the cyclic-response admittance method, which is not widely applied. It was stated that the calculated *R-value* does not precisely reflect the wall thermal resistance as it does not reflect the change in behaviour of the entire system where it does not take into account the benefit of the thermal mass of the wall layers on the wall's behaviour [7]. Regardless the assessing parameters/approaches, envelop building walls are usually evaluated/modified to reduce heating/cooling energy consumption [8]. However, as the temperature is almost continuously changing over the day/night time (at least in Iraq), studying the dynamic thermal properties of admittance is important to be carried out. This could perhaps simulate the real situation better than steady-state thermal transmittance. The aim of this investigation is to characterize the existing load-bearing external walls fabric, for residential buildings in Iraq, in terms of their thermo-physical properties and dynamic thermal behaviour. Also, different simple and applicable scenarios were suggested and evaluated to improve the residential building envelops thermal performance.

2. Characterization of existing and modified external load-bearing walls

There are mainly three external walls configurations (load - bearing walls) in Iraqi residential buildings that depend on the availability of the main construction materials. These walls configurations can be briefly described as follow:

- System (a): It is built using uncut natural stone (limestone) or random rubble that having different shapes and sizes that bound together using mainly cement mortar (1:3 or 1:4 cement:sand) and to less extent gypsum mortar as seen in Fig. 1(1-A). The thickness of this wall fabric is usually 40 cm and to less extent is 30 cm. There are many finishing types for walls outer face including natural stone, ceramic, and marble, but, for normal residential buildings, using about 1 cm thickness of cement mortar in addition to a thin layer of either white or coloured cement is dominant. Regarding the internal face, the wall is coated with a layer of 2–3 cm of normal gypsum (rendering coat) class B based on BS EN 13279-2:2004 [9], which aims to level the wall's face before coating it with a layer of 2 mm of Paris gypsum as a finishing coating layer [10], (see Fig. 2). This system is used in the west of Iraq and needs skilled workers.
- System (b): It is built using clay brick with standard dimensions of 240 × 115 × 75 mm, as shown in Fig. 1(2-A). The thickness of this wall is usually 240 mm and rarely 120 or 360 mm are used. As in system (a), the binding material is mainly cement mortar (1:3 or 1:4 cement:sand) and rarely gypsum mortar is used. The finishing materials are almost same as that used in system (a), as seen in Fig. 2. This system is used in the middle and south of Iraq which is described as expensive and more popular over the other walling systems.
- System (c): It is built using solid concrete blocks with dimensions of 400 × 200 × 200 mm and cement mortar is normally used as a binding material and the width is 200 mm, as shown in Fig. 1(3-A). As same as for system (a), cement mortar and gypsum were used in same manner (see Fig. 2). This system is mainly used in the north and middle of Iraq, which is regarded the fastest and cheapest one over the other systems.

In order to calculate the percentage of binding materials (cement mortar) from the whole wall area, which is important in determining the thermal properties of the wall, image analysis technique has been utilized. ImageJ software tool vl.44p was