Energy and Buildings 89 (2015) 213–221

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Assessing and improving the thermal performance of reinforced concrete-based roofing systems in Iraq

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ARTICLE INFO

Article history:
Received 3 November 2014
Received in revised form
23 December 2014
Accepted 29 December 2014
Available online 5 January 2015

Keywords:
Concrete-based roof
Thermal performance
Thermal resistance
Thermal admittance
Dynamic thermal properties
Domestics roofs

ABSTRACT

The aim of this study is to evaluate the existing reinforced concrete-based roofs of residential buildings in Iraq and also to suggest modified roof configurations in order to improve roof thermal performance. Dynamic thermal parameters including thermal admittance and decrement factor beside the thermal resistance and its reciprocal (*U*-value) were used in this evaluation. It was found that using light-weight precast rubberized concrete flags instead of conventional concrete ones has no significant influence regarding thermal behavior. Installing false ceiling as a finishing associated with traditional uppermost roofing layers has been the efficient way in increasing thermal resistance and significantly decrease thermal decrement factor among the other suggested configurations.

1. Introduction

Domestic buildings are estimated to consume about 40% of global energy consumption [1] which contributes for about 30% of the total greenhouse gases emission [2]. It was estimated that 40% of the total consumed energy in residential sector is for air-conditioning [2] while, in Iraq, this figure is about 66% due to the climate conditions coupled with poorly-insulated buildings[3]. Iraq has a hot and dry climate during Summer, where the outside temperature could, sometimes, exceeds 48 °C, while during the Winter a few days the temperature drops below 10 °C [3,4]. This consumption, in Iraq, constantly increases (by about 5% annually [3]) as a result of temperature increase caused by global warming phenomenon coupled with using traditional reinforced concrete slabs which is characterized as poorly-insulated roofing system.

Roof is defined as the uppermost part of a building envelops or shelter which provides protection from the weather conditions in addition to its structural function. It dominantly governs the transferred heat, beside external walls, between external and internal environments and hence they are highly responsible for thermal comfort and energy consumption for air-conditioning purposes [5].

Flat reinforced concrete roofs are widely used in many regions over the world such as Middle East and particularly in Iraq due to materials availability and tradition of structural and architectural design. One of the most concrete drawbacks is its low thermal resistance and this is exacerbated by the hot weather in Iraq over the most of the year which basically increases the energy consumption for air-conditioning purposes. It was estimated that 60–70% of the total gained heat comes from roofs and external walls. As the roofs of the domestic buildings represent about 50% ±10% of the total weather-exposed surfaces, improving its thermal performance could highly contribute in reducing energy consumption in addition to enhance the building thermal comfort. It was stated that thermal resistance of a construction member (such as roof) primarily depends on the thermo-physical properties of its construction material(s) [5,6]. Although there are many sophisticated insulation materials/systems that provide better thermal performance in comparison with the traditional one, it is not widely used in Iraq due to social and cultural attitudes, relatively expensive, and shortage in the skilled workers.

The draft of the Iraqi code for Buildings thermal insulation [7] has limited the thermal transmittance (*U*-value) of roofs by ≤0.5 W/m^2 K and also suggested different configurations for traditional roofing system in the hot and dry regions (which is the case in Iraq) as shown in Fig. 1. In reality, in most cases the water-proof layers are not used and to less extent the polystyrene (Styroboard) due to the lack in skilled workers (appropriate installation) and

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http://dx.doi.org/10.1016/j.enbuild.2014.12.049
0378-7788/

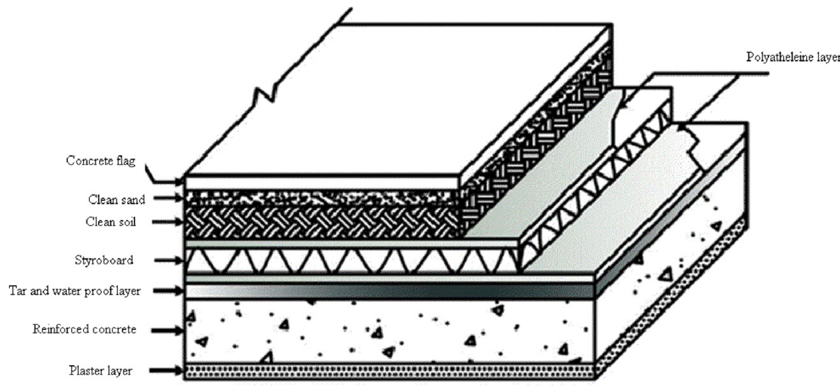

Fig. 1. Typical reinforced concrete-based roof in Iraq [7].

their cost. Construction materials with high 'thermal mass' such as concrete could minimize heat fluctuations as they have ability to absorb and keep heat during the day and then gradually release it during the night within 7–8 h. Hence, such materials could provide a comfortable envelop environment with reducing the required energy for air-conditioning if an appropriate configurations are used [8]. For domestic buildings, the thickness of the reinforced concrete slab is typically about 20 cm that could play an essential role in increasing the fabric thermal mass.

It was reported that there is a gap of knowledge in understanding the thermal performance of the residential buildings although several studies have been conducted to address this issue [9,10]. Some previous studies focused on using smart materials in energy saving which is not affordable everywhere [10–13] while others aimed to improve the construction fabrics thermal performance using different materials as presented by Aldawi et al. [8]. The configurations of reinforced concrete-based roofing systems have not been yet investigated based on the best authors' knowledge in terms of dynamic/thermal behavior. Not only assessing buildings thermal performance is important but also the parameters that used should be carefully considered. Thermal transmittance (U-value) and its reciprocal (R-value) are commonly used in evaluating thermal performance of the construction members (wall/roof) in air-conditioned (A/C) buildings [14–16]. They are used based on the assumption of steady-state heat transfer that provides an acceptable evaluation in climates with small solar gains and small external temperature swing in comparison with the indoor-to-outdoor average temperature difference. It is important to note that these parameters are less efficient to be used in evaluating wall/roofs thermal performance of A/C buildings in a climate with large external temperature swing [5,15,17–19]. In reality, the transferred heat through a construction member occurs under dynamic conditions i.e. non-steady state (dynamic thermal storage); therefore, dynamic thermal behavior parameters were recently suggested to be used in evaluating external load-bearing walls thermal performance in periodic outdoor conditions in A/C envelops [3]. Decrement factor and thermal admittance was frequently used in assessing building envelops thermal performance. They have well-reviewed elsewhere [5].

The domestic buildings, in Iraq, were estimated about 5 million units and this figure continuously increases as a result of population increase. Therefore, improving roofs thermal performance surely will reduce the consumed energy of buildings air-conditioning. The aim of this investigation is to evaluate the existing reinforced concrete-based roofing system in terms of its thermal performance using dynamic thermal admittance parameters beside steady-state parameters (U and R values). Affordable and applicable configurations have also been suggested and evaluated using same parameters.

2. Materials thermo-physical properties and the study limitations

All thermo-physical properties were examined in only dry state to simulate the actual weather conditions, mostly hot and dry, and also to simplify the calculations; therefore, the effect of moisture on these properties was not taken into account. BS 1881-114:1983 [20] was used to measure the dry density of the tested materials while ISO 8301:2010 [21] was used to experimentally measure thermal conductivity λ using a downward vertical heat flow computer-based P.A. Hilton B480 uni-axial meter. The λ-value was computerized calculated using Eq. (1), which deeply explained elsewhere [22]:

$$\lambda = \frac{\left(d \times \left[\left(k1 + k2 \times \bar{T}\right) + \left(\left(k3 + \left(k4 \times \bar{T}\right)\right) \times \mathrm{HFM}\right) + \left(\left(k5 + \left(k6 \times \bar{T}\right)\right) \times \mathrm{HFM}^2\right)\right]\right)}{\mathrm{d}T} \quad (1)$$

where λ = thermal conductivity (W/m K), d = thickness of specimen (m), dT = temperature gradient in the direction of heat flow (°C), $\bar{T}$ = the average of hot and cold plate temperature (°C), HFM = heat flow meter reading (mV), and $k(n)$ = calibration constant with silicone rubber mate.

The ramp rate method was used to determine the specific heat capacity C_p for each ingredient/material using a Differential Scanning Calorimeter, where the mean of five readings across the range −15 °C and 60 °C was taken. For the inhomogeneous materials i.e. conventional concrete, rubberized concrete, reinforced concrete (steel was assumed to have negligible effect due its small portion in comparison with concrete volume), gypsum, and river sand, it was proportionally calculated as the summation of the heat capacities of all ingredients [23]. The air content, within the used materials, was assumed to have negligible effect on the specific heat capacity as it has ∼1.205 kg/m^3 density at ambient temperature and it assumed to have zero mass for gravimetrical material bulk density calculation purpose [24]. C_p was calculated based on the following equation [25]:

$$C_p = \frac{1}{W_{\mathrm{total}}}\left[W_{\mathrm{HCP}}C_{\mathrm{HCP}} + W_{\mathrm{CA}}C_{\mathrm{CA}} + W_{\mathrm{FA}}C_{\mathrm{FA}} + W_{\mathrm{ADD}}C_{\mathrm{ADD}}\right] \quad (2)$$

where W_{total} is the total mass of all ingredients while W is the mass of each ingredient in kg and C is the specific heat capacity of each ingredient in J/kg K. All the used materials' thermo-physical properties are presented in Table 1. Note, the thermo-physical properties of tar has been adopted from Ref. [26] and for acrylic based on