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Thermal performance of glazed balconies within heavy weight/thermal mass buildings in Beirut, Lebanon's hot climate

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ABSTRACT

The research aims to analyze the thermal performance of what is becoming a very common practice of glazing up balconies in fully exposed heavy weight buildings in Lebanon. Two apartments in one residential building, are monitored simultaneously for four full and consecutive days in late June 2011 one with a glazed balcony the other with a shaded one. Once the building's thermal simulation are calibrated using the EDSL TAS [1] software, parametric runs start by testing different orientations, followed by further shading and spatial manipulation and finishing with construction and thermostatic manipulations, giving an in-depth overview of the thermal performance of those balconies vis-à-vis the internal spaces. The research concludes with practical design recommendation and solutions for keeping with the glazing yet reducing considerably the annual cooling load.

1. Introduction

The paper is studying the environmental impact of a practice that is becoming very common in the built-up fabric in Lebanon: that is glazing balconies. Although not more than 60 km at the widest Lebanon has four distinct climatic zones [2]. The paper deals with the coastal zone which has cool and short winters, hot, humid and long summers [2]. The overwhelming construction type in Lebanon is of exposed concrete slabs, plastered masonry block walls, and an optional natural stone finishing. All those materials are labeled heavy weight or thermal mass referring to their capacity to absorb, store and release heat with a certain time lag [3,4]. The study was conducted simultaneously for five consecutive days in late June in two apartments within the same building: one of which has a glazed balcony whereas the other has a curtained balcony. It recorded the temperature of the dining/living areas connected to the balconies as well as the balconies air temperature. Later thermal simulation results are calibrated against the recorded measurements using EDSL TAS [1]. Once this is done, parametric runs start by testing different orientations, followed by further shading and spatial manipulation and finishing with construction and thermostatic manipulations, giving an in-depth overview of the thermal performance of those balconies vis-à-vis their internal dining/living areas.

1.1. Balconies

The broad name of balcony applies to any transitional covered space between the main building and open to the outside, sharing together at least one wall [5,6]. When the open edges are closed by an added layer of glass, the balconies transform into sunspaces or conservatories. Usually in cold climate where there is a need to enhance solar gains during winter, those glazed balconies are quite frequently used as thermal buffer spaces; whereas in warmer climates it is the open balconies that are used as sub-spaces with an added role of shading the internal spaces [7,8]. But what happens when balconies are glazed in hot climate? Glazing the balconies is becoming more than a common practice in Lebanon, if not the main trend [9]. The Lebanon building code [6] already grants 20% extra areas for balconies, and recently glazing up balconies became a hassle free; fully legal practice with the only condition of having single panels frameless glass. The reasons for glazing up balconies are many; the most obvious is gaining the extra space, other reasons are to reduce noise as well as air pollution.

1.2. Previous studies

In addition to the above theoretical background more targeted studies dealt with different aspect of balconies as well as the calibration of thermal models: Ai et al. [10] studied the balconies' impact on improving internal comfort through more uniform natural ventilation in low rise buildings in the hot and humid tropical

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climate of Hong Kong. Lee et al. [11] studied the positive impact balconies have on reducing noise pollution. Whereas Chan and Chow [12] found that the addition of balconies in any orientation can reduce the annual energy cooling load, with the south/west orientation providing the highest saving of up to 12%, in the subtropical climate of Hong Kong. In a much older study, before the existing of commercial thermal softwares, Raeissi and Taheri [13] showed that overhangs on the entire windows of a house in Shiraz, Iran reduces the annual cooling load by up to 12%. Roux et al. [14] made a full scale model of a glass veranda in the French city of Lyon and compared its temperature against clim2000 thermal modeler and noticed considerable difference in the upper and lower temperature peaks, which they related to the veranda's thermal inertia. Suarez et al. [15] studied the effect of adding a glazed gallery to the overall energy heating demand in northern Spain and found out that such spaces can save between 15% and 30% on heating.

When it comes to simulations a recent study by Bhatia et al. [16] carried out in India calibrated the energy model of a large top floor, more than 600 m^2, by comparing the yearly cooling energy bills to the simulated results and good congruence occurred only after both the coefficient of performance – COP – as well as the roof insulation thickness were altered beyond actual values. Still in India, Dhaka et al. [17] analyzed the positive effect of improved envelop on the yearly cooling load of a single top floor room, and as in the previous study acceptable calibration was not possible without altering the actual constructed envelope dimension. Furthermore there was no reference as of which weather file was used: the recorded or the available typical meteorological year. No measurements were taken in the semi-enclosed walkway which could be compared to a continuous balcony. Nevertheless the study proved that combination of improved envelop can reduce energy of up to 40% and additional 15% can be further achieved through user adaptive behavior. Moving to the UAE in a study to compare the effect of different types of insulation Friess et al. [18], calibrated the thermal model against recorded monthly energy bills of the studied villa without any mention whether or not any or which weather file was used.

2. Field work

The monitored building is located in the Zouk area, 15 km northeast of Beirut, 120 m above sea level within the coastal climatic zone having cool and short winter; hot and humid summer with small temperature fluctuation between day and night all year long [2]. It is a six story residential building including a roof loft, and an additional commercial ground floor and mezzanine. The main living quarters' balconies have a North bearing of 300° (Fig. 1a and b).

Its slabs and columns are concrete. The walls are 15 cm hollow masonry blocks plastered and white painted from the outside and inside. The balcony side edges are made of fair-face concrete having a gray-greenish color whereas the front edge has a glazed balustrade. The windows in all apartments as well as in the glazed balconies are all single glass panels tinted brown. The balcony is 10 m^2, the internal living spaces (entrance, living and dining) sum up to 48 m^2 and the service areas (kitchen, WC and pantry) sum up to 18 m^2. The balcony and the interior have white marble floor tiles finishing. The balcony can be accessed from the dining area which is opened to the main living space (Fig. 1b).

Apartment A has a glazed balcony with internal shades and three occupants with limited activities. Apartment B has full height curtained balcony most of the time closed at 80–85%. The apartment has at least two ladies permanently home (grand-mother and mother) taking care of a new born. In the late afternoons and evenings the living area and balcony are packed with five to twelve people: family of five, extended family of three, friends and up to four neighbors. The TV in the living area is continuously on. Although they have air-conditioning units in the living areas only, they are seldom used around mid July and August. The data loggers were placed in the balcony, protected from direct sun rays and on the dining table inside (Fig. 1b) from June 26th, till July 1st 2011 nevertheless graphs show only the four full days of data recording from June 27th till 30th.

Recorded temperature within the balconies (Fig. 2a) show that peak temperature occurs a couple of hours after the day hottest peak, only when the afternoon sun is directly hitting balconies and external walls. Also temperature within the glazed balcony is constantly higher than the curtained balcony by an average 3.1 K for the day's peak and 1.5 K for the night's lowest. For 1 h only during the observed four days period did the curtained balcony had its temperature above the comfort band, whereas within the glazed balcony this happened for few hours each day. This is in clear contrast with the recorded inside dining/living temperatures where both are within the comfort band (Fig. 2b) with apartment A temperatures slightly higher than apartment B, averaging 0.7 K and 0.8 K for day and night respectively.

3. EDSL TAS thermal model simulation

The Zouk building is modeled (Fig. 3a and b) using EDSL TAS version 9.1 [1]. Thermal simulation results are compared to recorded ambient temperature data. All of the following parameters are taken into consideration: the recorded weather conditions, the building envelope's physical and thermal properties as types of materials, thickness and U-values (Table 1) [19]. In addition to those users' pattern of usage including number or users, length of usage or stay as well as the type of activity conducted are all taken into account and integrated. Finally the electrical lighting and equipments schedule and types are also included into the simulated thermal model.

The 3D thermal model is constructed by placing the glazed balcony, the adjacent dining, the living areas as well as the adjacent services: the kitchen with its glazed pantry, the entrance and one restroom. In addition to that the stair core is also drawn as an empty room. The bedrooms are not modeled as they are not part of the study. Also the ground floor level which is a commercial floor is not drawn. Four typical floors are modeled of which the second and third ones are used for the simulations and calibration. The balcony edges are drawn with window group that can be opened fully for the opened balcony. Shades are drawn on a nil wall detached from the external wall of the building to be considered as curtains on the open balcony. As for the glazed balcony the shades will be drawn when needed as substitute elements and hence can be placed either inside or outside of the balcony proper.

3.1. Thermal model calibration

The calibration results achieved very similar internal temperatures behavior for the two dining/living (gray lines compared to dashed gray lines Fig. 4a). Peaks and bottoms are the same for the first two days with relatively high temperatures; nevertheless they become less than 1 K higher on the third day with outdoor temperature lower than the previous days. As for the glazed balcony (Fig. 4b) simulated temperatures follow closely the recorded temperatures with the same time peaks and bottoms. The only problem is with the open/shaded balcony, where the best results obtained were different from the recorded temperatures (black line compared to dashed black line Fig. 4a).

Based on ASHRAE guideline [20] for a simulated energy model to be acceptable the calculated normalized mean bias error (NMBE)