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Thermal performances of traditional houses in dry hot arid climate and the effect of natural ventilation on thermal comfort: a case study in Damascus

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Abstract

Traditional houses in hot arid climate of Mediterranean area consist of rooms around one or more courtyards giving a general good comfort conditions especially in hot summer periods. This paper aims to contribution to evaluate the influence of thermal performance of building structures and natural ventilation (cross ventilation, single side ventilation) on the indoor thermal comfort for traditional houses and courtyard located in Damascus old city. The paper shows results of several monitoring data (air temperature, humidity and air velocity) acquired during a summer period, in parallel with occupancy survey for the evaluation of comfort conditions.

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Keywords: traditional houses ; natural ventilation ; thermal comfort ; courtyard ; adaptive model.

1. Introduction.

The oldest heritage buildings in hot arid regions represent good engineering solutions to the external climatic conditions: high temperature and solar radiation in summer (which is the longest period respect to winter period) big thermal excursion between day and night (both in summer and winter).The Damascene settlers, since several centuries ago, responded to all changes of these negative weather conditions through a creative flexible building engineering “harmony” until reaching to balancing the heating and cooling in a marvelous unity. It allows generally

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to mitigate the impact of different climatic variations and to absorb particularly the heating's surplus throughout an integrated texture (thermal mass).

Therefore many researcher by worldwide, especially of the Middle East region, have studied the passive control methods of traditional building which gave comfort conditions over the years. Ahmad E. [1] monitored a traditional courtyard house within a six centuries old indigenous urban cluster and compared it to a modern detached house within a new urban development under summer and winter climates of Ghadames, Libya. Al-Hemiddi and Al-Saud [2] studied experimentally the cooling effects in a building with an internal courtyard in a village house in Saudi Arabia. Changes in the courtyard ventilation were made by opening inner and/or outer windows in alternate ways during the day and night periods; besides he studied the effects of cover and uncover courtyard, closing it at day time and open it at night time by a tent. Abdulhak Mohammed [3-4] studied the effect of climatic factors on people in the Republic of Yemen, also analyzing bioclimatic conditions of some Yemeni cities, presenting contrasting differences in different regions: Sana'a (Cold in Winter), Adan (Hot-Humid) and Say'un (Hot-Dry). Farghal-AMGAD [5]investigated the thermal environment and its effect on the comfort mechanism in the hot arid climate of Cairo, also the natural ventilation effects in spring and autumn periods. Sadafi et al. [6] studied the interaction between indoor and outdoor thermal comfort. The contribution of inner courtyards to the comfort of terrace housing in tropical climate was studied by model and measurements. Other researcher [7-11] studied thermal comfort for traditional building with also courtyard.

This research investigate the thermal conditions for varying Damascus traditional houses depending on the courtyard presence. The combination, in those traditional buildings, of passive cooling techniques with high efficiency in natural ventilation (single sided and cross ventilation), coupled with the effects of massive construction and design assembling, provide a good thermal conditions within most of interior spaces; this strategies allow to conserve energy in a hot-arid region, reducing energy needs for air conditioning.

2. Experimental investigation.

2.1. Field investigation.

The buildings investigated represent two types of typical Damascus traditional houses; the first one is the largest (with two or three courtyards), the second represent the smallest one (with one courtyard) comparable to a part of the first one (in some cases the big houses are divided into small houses, each one with its own courtyard and characterised as a new intervention). Generally they present different room's orientation and various building materials.

These buildings are located in different part of old Damascus city, inside and outside the walls; they consist of two floor levels, with heavy mass (stone and lime) at first level and light mass (timber structure with mud and lime plaster) at the second one. The First type case analyzed (multi-courtyard houses) are located in the same area close together, while the second type (one courtyard houses) are located in a different part of the old city and they are influenced by the old urban fabric specially for narrow streets around houses (effect of wind tunnel).

- First type buildings. BAIT FAKHRY AL BAROUDI (Fig.1); it was recently restored where lime and mud mortar was replaced by concrete, and also hemp and clay replaced by bitumen roll; BAIT AL MOUSLLI: this house still maintains his old configuration and structure.
- Second type buildings. BAIT WARRD: the courtyard is covered with sliding plastic roof; BAB AL SALAM HOUSE: his configuration and structure were subjected to a lot of interventions also in design; every room has been equipped with a bathroom, that means a lot of brick block and plaster used although the concrete slab structure is like the others .

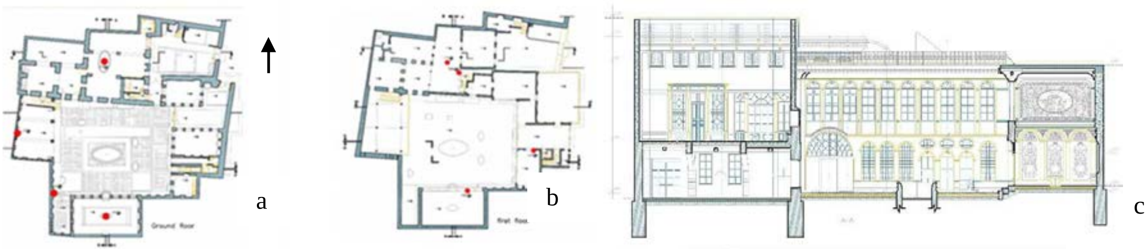

Fig.1; BAIT FAKHRY AL BAROUDI. a; ground floor .b; first floor . c; section AA

2.2. Experimental setup.

Several measurements on microclimate conditions of indoor and outdoor courtyard have been done in summer period 2014 in order to investigate comfort conditions and also effects of natural ventilation (close and open window with different open percentage). All measurements were made in parallel with survey on comfort conditions.

Measurements were made according to ASHRAE standard for temperature, relative humidity and air velocity: all data were recorded every 5 minutes to get good indicator and trends correlated to external climatic conditions. The instruments position is based on three main objectives:

- The first one is related to investigation of thermal comfort according to standard ASHRAE: positions are at 60 and 110 cm height (60 cm high for adaptive comfort model calculation) at the centre of rooms and far away from walls at least 1m (position south wall means far 1m from wall); measurement intervals are 5 minutes.
- The second consideration is related to natural ventilation investigation, to evaluate air velocity behaviour and effect on comfort condition depending on opening windows position (one or two levels). In case of high halls the measurements are divided in two levels: first one to height 3m, the second above 3m.
- The third one is related to analyze room orientation and floor level; besides its protection from direct solar radiation.

Rooms were chosen depending on natural ventilation way: cross ventilation (facing windows or adjacent), single side ventilation at one façade or single side with stack (two levels of windows).

External climatic weather data are collected from the nearest weather station of the faculty of agriculture at Damascus University. It provides many weather data for every hour: temperature, relative humidity, wind speed, dew point, pressure, wind direction.

Operative temperature (T_{op}) is calculated in specific periods using air velocity manual data corresponding with experimental measurements of other physical parameters, in parallel with sensation survey based on PMV scale (7 point scale: from -3=cold, to +3=hot). For personal activity conditions and clothing, data collected from surveys are used for calculations: for relaxing conditions 1.2 met was set; for personal insulation clothes the average thermal clothing resistance for all surveys of student and people (long trouser, short sleeve shirt, socks, and shoes) was used, equal to 0.58 clo.

Comfort analysis was performed using the Adaptive model proposed by ASHRAE-55 2010 Standard [12]: this model allowed to get the effect of outdoor climate (and more specific the effect of natural ventilation) on occupants. This standard introduce the prevailing mean outdoor temperature (T_{mo}) as the input variable for the adaptive model. It is based on the arithmetic average of the mean daily outdoor temperatures over no fewer than 7 and no more than 30 sequential days prior to the day in question: for the period under study, T_{mo} is about 27.2 °C. The relations corresponding to the acceptable operative temperature (ASHRAE 55/2010) according to adaptive model ASHRAE handbook [13] are:

- Upper 80% acceptability limit (°C) = $0.31 * T_{mo} + 21.3 = 29.73$
- Upper 90% acceptability limit (°C) = $0.31 * T_{mo} + 20.3 = 28.73$
- Lower 80% acceptability limit (°C) = $0.31 * T_{mo} + 14.3 = 22.73$
- Lower 90% acceptability limit (°C) = $0.31 * T_{mo} + 15.3 = 23.73$

3. Results.

The most collected data, recorded during of July 15th-22th and August 4th-13th, 2014, can be considered as a representative of a typical summer period. The weather condition during those weeks was sunny, clear and hot. Maximum outside temperature, 39-41°C, was typical values during this period of the year or little bit higher about one or two degrees. The two weeks before this period were also hot and in general sunny, leading to reasonably stable thermal condition during first period, while in the second period was little bit higher. About 1250 measurement was made, the total result about 100 measurements for every house.

3.1. Analysis of thermal performances.

In this paper some comparison of thermal performances between all different Damascus traditional houses under study are shown, in order to evaluate influences of type of building, the dependence on orientation, construction materials (traditional materials and new intervention systems), opening size and position, in order to investigate its impact on internal temperature and the natural ventilation behavior.

- COURTYARD. Typical temperature trends inside courtyard are reported in Fig.2, were houses with traditional structure gives best values for temperature and relative humidity (43%-63%) corresponding to courtyard size. The effect of a cover-up over the courtyard Bait Waard (two days closed) makes it as a greenhouse with high heat storage and a large thermal gradient: at ground level, with surrounding heavy mass, low stationary temperature were recorded, while at first floor very high values are measured due to greenhouse effect and to presence of light mass structure. The use of absorbing materials for wall plaster and roof covering (Fakhry) increase temperature, while the activation of fountain in the same courtyard decreased temperature (min 1°C).
- NORTH halls. Fig.3 shows the difference between two type of halls: Fakhry hall (3 m high, 75 cm underground) presents adjacent cross ventilation at one level windows causing more stationary temperature during day and night periods; Mouslli hall, with two windows level, have more temperature difference between day and night. Very important in this case is the impact of the intervention on structure using new materials (especially concrete) that increased the internal temperature of 1°C at least (Bab Al Salam). In 1st Floor north hall (Fig.4) the effect of cross natural ventilation decrease the temperature of 1°C to 3°C (at Fakhry hall due to high ceiling).
- EAST halls. In this case the kind of structure impacts on the thermal behavior due to stack single side natural ventilation for two levels which gives lower temperature (in Mouslli halls) compared to traditional houses structure Fig.5.
- WEST halls have the same impact as east halls. In the other hand at Bait Warrd, roughly close to Mouslli house, measurements with sliding roof opened give lower temperature caused by the presence of big trees that shaded the whole courtyard and west halls for all days. Fakhry hall (3m high, concrete intervention) increased temperature (min 3°C).

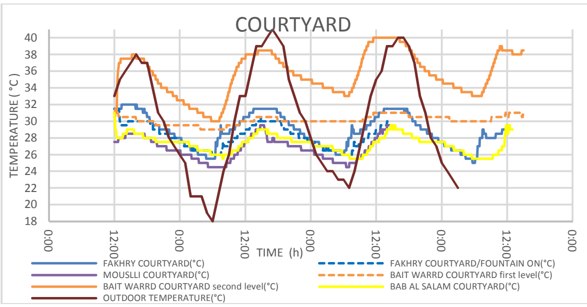

Fig.2; Temperature trends for different courtyards.

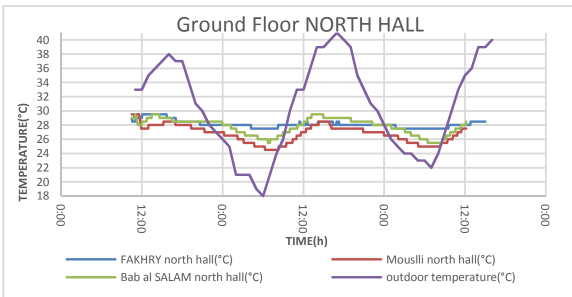

Fig.3; Temperature trends for north halls.

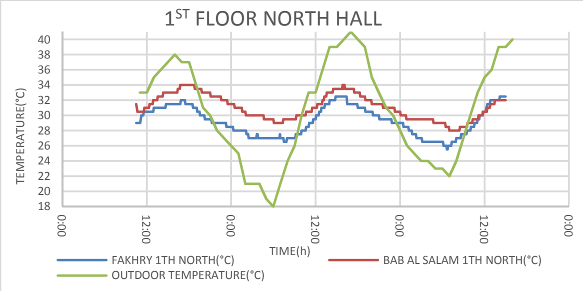

Fig.4; Temperature trends for 1st floor north halls.

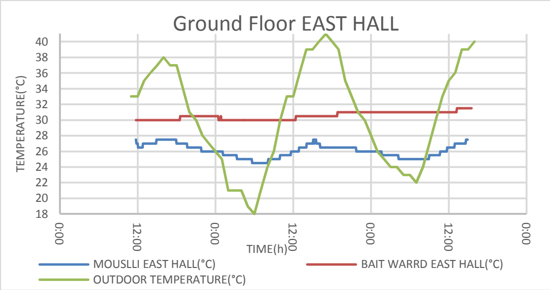

Fig.5; Temperature trends for east halls.

3.2. Analysis of comfort condition.

In this part we analyse the thermal sensation for occupancy based on collected survey data and thermal measurements, and operative temperature T_{op} and acceptability limits calculated as ADAPTIVE model of ASHRAE standard.

Fig.6 shows comfort sensation results from survey data compared to measured temperature, for all Fakhry halls, in two conditions: close and open windows. Significant differences were found between close windows condition (comfort values higher than 2), and open windows condition (values ranging from 0 to 1) due to the effect of kind of natural ventilation (cross “adjacent” ventilation; north hall, single side “stock” ventilation; south hall “two levels of windows”). Otherwise, the adaptive model are too closer to occupancy sensation for natural ventilation effect. Natural ventilation has great effect on human sensation and microclimate of space: in summer period natural ventilation gives at least 2°C lower temperature respect to the closed window, depending on the kind of ventilation, orientation, structure, height and size and opening area.

Figures 7, 8, 9 show results of temperature measurements for different houses that fall within 90% limits of acceptability of the adaptive model of the adaptive model.

For North halls (Fig. 7) all cases fall within the acceptability limits of 90%, but Mouslli house presents better results, depending on structure and materials than Bab al Salam.

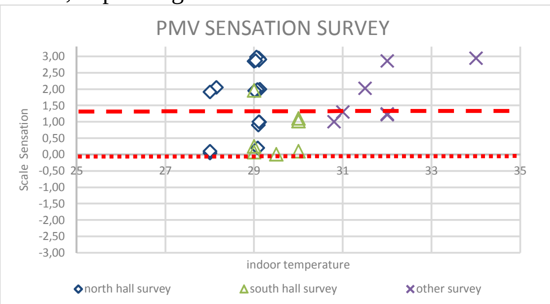

Fig.6; Comfort sensation survey for all Fakhry halls.

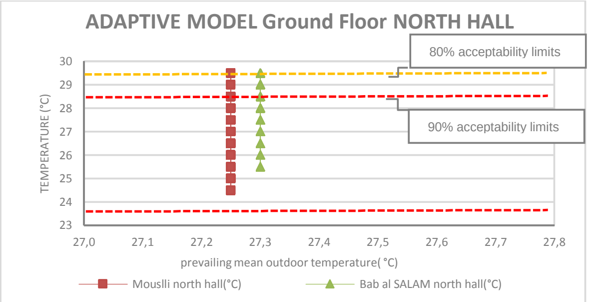

Fig.7; adaptive model for Ground Floor North Halls.

For Courtyard, Fig.8; the periods within the acceptability limits depend on the presence of trees, fountain, kind of building materials, structure (ground floor heavy mass, first floor light mass). The activation of a fountain increase the acceptability roughly of 20%, while the case of closed courtyard create a global worming at top level. Materials add more roughly 20% for acceptable period.

For First floor north hall (Fig. 9) results confirm that cross ventilation increase acceptability limit roughly 20% to 25% comfort period and in East hall the effect of natural ventilation increase 30% to 35% comfort period respect to closed space and also courtyard increase comfort period limits.

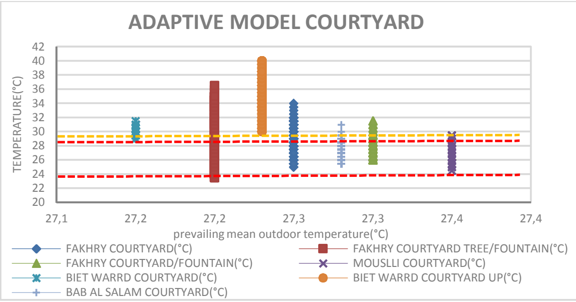

Fig.8; adaptive model for Courtyards.

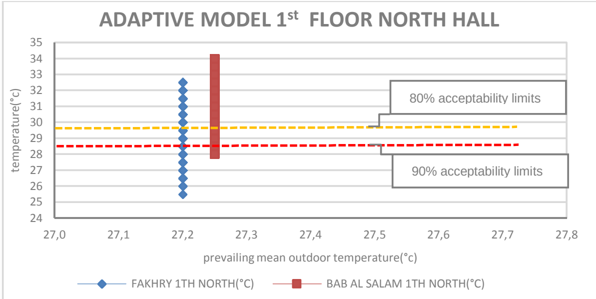

Fig.9; Adaptive model for 1st floor North Halls.

4. Conclusion.

Thermal and comfort investigation on some traditional buildings in the old city of Damascus show the great influence of the presence of internal courtyards as passive cooling techniques used in many region of middle-east with hot-arid climate. Different design factors, materials and operative conditions can influence the thermal performances of buildings and of each different room.

Analysis inside of courtyard shows the importance of the traditional structure and materials (Mouslli), the size and shaded area (Bab Al Salam), the presence of trees and as other important factor the influence of fountain. Building structure (high thermal mass at the ground floor) and ceiling height have main influence on thermal comfort. Opening area and positions have great importance on natural ventilation, in particular the stack effect (two level of windows in Fakhry south hall with elevation of about 8 m), cross ventilation (in west Mouslli hall with cross ventilation adjacent windows) better than single side ventilation (in west Fakhry hall). Using the adaptive model gets results closer to human sensation survey, which show a great variability of subjective sensations, bringing to consider more relevant at adaptive model.

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