Passive systems in traditional houses in Middle East areas: solutions and effects of natural ventilation

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Abstract. The Middle East area, has a specific culture and habits, enhanced by adaptation to the environment and local climate through the traditional building constructions where typical design, structures and materials represent the basis for passive strategies. In these hot-dry regions, many traditional houses consist of compact design structures with internal courtyard where the effects of thermal inertia and natural ventilation can be well exploited. This paper focuses on the analysis of passive techniques used in some houses located in Damascus old city, which are renowned for their distinctive adaptability. These traditional houses have a unique structure consisting of two levels: the first floor built with heavy mass stones, while the second has light mass (timber and mud). The presence of an internal courtyard on which several rooms of different size overlook, give rise to an appreciable natural ventilation (single side or cross ventilation) through a proper opening of windows. Based on experimental data (air temperature, air velocity) acquired during a summer period in a traditional house, dynamic simulation for different type of structures and opening are performed in order to investigate the influence of natural ventilation on reducing internal temperature and evaluate comfort conditions using ASHRAE standard. Results also suggest strategies to optimize passive techniques to reduce energy needs.

1. Introduction
The specific characteristics of Middle East climate conditions created a special urban heritage style in a homogeneous harmony with the environment. Traditional houses integrated in a compact urban texture, combining the effects of high thermal mass structures and internal courtyards contribute to mitigate extreme climate conditions during the year, reducing daily thermal excursion and contributing to optimize comfort conditions.

Many researchers by worldwide, especially from the Mediterranean and hot climate regions, have studied the passive control methods of traditional houses, particularly the effect of courtyard ones, which gave comfort conditions over the years and helps to counteract climate change. Philokyprou M, Demosthenous D, Michael A [1] confirm the positive contribution of natural ventilation for cooling in Cyprus. They investigate different ventilation strategies, showing that night ventilation is the most effective strategy for passive cooling, reducing peak indoor air temperatures and also improving indoor thermal conditions during the day. Farzaneh S, Mehdi Sh, Seyed M Sh [2-3] investigate the concept of the traditional central courtyard as a passive cooling strategy for improving indoor thermal comfort in the BS climate of Iran, pointing out the importance of orientation and geometrical design. Moreover, traditional courtyard houses were designed based on a careful attention to climatic requirements in their socio-cultural context, those elements could be considered for future design for saving energy. Ghaffarianhoseini A, Berardi U, [4], optimized the design of courtyards in hot and humid climate in Malaysia towards enhancing their thermal performance characteristics for providing thermally comfortable outdoor spaces according to different design configurations. Domaini A, Halbouni G [5-6] studied the effect of climatic factors on people in the Republic of Yemen and analysed bioclimatic conditions of some Yemeni cities. Sooleyon C, Nooshafarin M [7] and Calcerano F, Cecchini C [8]
studied the influence of courtyard and natural ventilation on thermal performance of indoor space for dry climate and reduce cooling load. Micaleff D, Buhagiar V and Borg S. B [9] investigated by a numerical approach the effect of cross ventilation on a courtyard.

This paper aims to investigate the thermal conditions for Damascus traditional houses. The combination in those traditional buildings, of passive design techniques with high efficiency of massive construction and design assembling beside natural ventilation, provide a good thermal condition within social culture behaviour; these strategies allow to reduce energy consumption. The deep investigation focuses on a typical traditional house integrating results on thermal comfort and energy consumption of a previous work [10].

2. Methodology
This research uses a practical inductive method to investigate the influence of natural ventilation and massive structure of building on indoor thermal comfort and energy consumptions.

The comfort indices are important factors on the thermal performances evaluation of a building since they represent the occupant’s satisfaction; in parallel, the cooling energy need is used as a useful index to analyze building performance and to optimize passive techniques (natural ventilation in combination with thermal mass of structures) in reducing indoor temperature.

Comfort analysis are performed considering the approach of adaptive comfort model and "psychometric-chart " of ASHRAE 55 standard. The last adaptive model developed for buildings, where the cooling and heating system is not required, provides an acceptable degree of comfort in residences and offices over a range of air temperatures from about 27 to 31°C depending on natural ventilation (air velocity and air change rate). ASHRAE 55 psychometric-chart defines comfort zones. The environmental factors addressed in this standard are temperature, thermal radiation, humidity, and air speed. Those two comfort parameters merge in one diagram.

Results are calculated by using energy simulations with Design Builder software after a calibration procedure based on monitoring of weather data and indoor climate conditions (air temperature, air velocity, humidity). The most collected and simulated data are recorded during summer 2016/2017 weeks (July-August), which can be considered as a representative of a typical summer period (peak summer week).

2.1. Case study
A typical large traditional house located in old Damascus city has been investigated. This house is built with the following typical structures: the ground floor with heavy mass (lime stones and basalt) with 50 cm thickness, the 1st floor with light mass (timber and dried mud structure) with 30 cm thickness. Different kind of natural ventilation (single side and cross ventilation) inside rooms are present.

3. Analysis
Building energy simulations have been executed in order to evaluated different indicators. Temperature and humidity results are reported in a psychometric chart allowing the estimation of the discomfort hours and to optimize the passive systems. Energy simulation are also analysed to evaluate conditions to minimize the cooling energy consumptions.

Simulation are performed in the summer period for July and August for two halls with different type of natural ventilation: 1st floor north hall (light mass structure) with cross ventilation, and ground floor south hall (heavy mass structure) with single side ventilation. The following six cases are analyzed:

1- Natural ventilation (NV) during all day.
2- Natural ventilation (NV) during the night.
3- Cooling system during scheduled occupation.
4- Continuous mixed mode with set point temperature at 26 C°.
5- Mixed mode with scheduled occupation.
6- Off-mode, with all windows closed (only infiltrations are considered) and cooling system off.

The “mixed mode” simulation, provides both natural ventilation and cooling system activation, depending on external temperature $T_{ext}$ compared to internal set point: for $T_{ext} > T_{set}$ the cooling system is activated, in other cases only natural ventilation is considered (open windows). Activities options are
scheduled depending on culture behavior and habits in hot climate areas (i.e. take a nap, pause activities from mid-day till sunset).

3.1. Indoor thermal comfort

The relation between indoor and outdoor air temperature for the different cases and for different natural ventilation options, gives information on how natural ventilation and air change rates influences internal comfort. As a general remark we can observe:

- The impact of day ventilation is equal or little higher than the night ventilation.
- Natural ventilation reduces indoor temperature of 3-4 C° degree.
- Thermal mass and inertia of the envelope structure influences the internal temperature behaviour and changes the effects of natural ventilation. For the case 6 (closed windows), it’s evident that the hall with light mass envelope presents higher temperatures than the heavy mass one.

Figure 1 shows the effect of single side ventilation for the south hall. Natural ventilation gives an important contribution in reducing indoor air temperature compared to case with closed windows. On the other hand, we can observe that trend lines for “NV” and “close” cases crossed at a reference outdoor temperature of 34 °C, which means that when Tout >34 °C natural ventilation is not effective.

Figure 1. Thermal performance of south hall for case 1 (only NV), case 3 (cooling), case 5 (mixed) and case 6 (close). Red line corresponds to outdoor reference point for NV and close case.

In Figure 2 results of the two different halls are compared showing the difference between day and night: natural ventilation reduces the indoor air temperature of about 6 °C at night and 3 °C during the day.

Figure 2. Thermal performance. Comparison between south hall (ground floor) and north hall (first floor) and effect of natural ventilation.
The thermal mass behavior is integrated with the effect of air change rate (ACH) due to natural ventilation. Figure 3 shows results of internal temperature for the case of room with light mass structure having cross ventilation, and the case of room with heavy mass structure having single side ventilation. In both cases results are reported with window closed (only infiltration) and open windows.

In case of light mass and cross side ventilation with closed windows, daily temperatures range from 36.6 °C to 31.2 °C while lower temperatures are present for the heavy hall specially during night (35.9 °C to 27.5 °C).

Considering the opening of windows, the different kind of ventilation gives different air change rates: 9.5 h\(^{-1}\) for cross ventilation and 7 h\(^{-1}\) single side ventilation. In the first case the air temperature reduces to 34.8°C (day) and 23.8 °C (night), while in the second case temperatures reduced respectively to 32°C and 23.4°C. Then, heavy mass reduces daily temperature excursion and increases indoor comfort (or reducing discomfort hours).

![Figure 3. Relation between thermal mass and ACH on inside air temperature.](image)

The above results clearly indicate that there is a large potential in natural ventilation, which can be provided by either all-day NV or night NV.

The ASHRAE Standard 55 includes adaptive modelling (AM) and it is intended primarily to apply to sedentary or near sedentary physical activity levels. Figure 4 presents the effect of cross ventilation with a light mass, on 1st floor, which decreases discomfort period less than 40% compared to the case with close windows; this percentage decreased to 25% with the mixed mode system that depends on natural ventilation related to occupant schedule.

In case of heavy mass envelope highest level of thermal comfort can be achieved, because of the more stable temperature. Moreover, a mixed mode system decreases discomfort period to less than 20% during the day.
3.2. Energy performance

A similar analysis is made on the mean energy consumption for cooling in summer period.

Figure 5(a) shows the cooling energy need for the conditioned area that is about 25 kWh/m². By using “mixed mode” rather than the “only cooling system mode” there is a 72% decreasing in cooling energy need. This result is very important and points out the importance of using passive building strategies and natural ventilation.

Figure 5(b) shows a typical daily trend of the internal temperature on 1st floor with cross ventilation. The use of “mixed mode” solution reduce the cooling peak loads during warmest hours: this gives an average energy reduction of 10% and has an important effect on the global efficiency of cooling plant system.

4. Conclusion

Traditional houses in Damascus, combining effects of high thermal mass structures and natural ventilation, show great potential for high comfort conditions. The possibility to use mixed mode cooling systems (combining HVAC and natural ventilation) and considering scheduled activities as culture and occupant habit, improve the energy savings and thermal comfort on occupants.
Natural ventilation presents different advantages, not always generalized. For the case study, the cross ventilation decreases the discomfort hours compared to the single-side ventilation, this depending on effective characteristics of the building and to his thermal mass. Single side ventilation has limit on ACH rate with related effects on temperature. Moreover, the effectiveness of natural ventilation on comfort is limited to outdoor temperatures of 34-36°C, above this range NV has a reverse effect. This investigation also deduced that night ventilation is not as effective as full-day ventilation with low thermal conductance or little thermal inertia.

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