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The Influence of Urban Geometry on Thermal Comfort and Energy Consumption in Residential Building of Hot Arid Climate, Assiut, Egypt

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Abstract

Designing climatically responsive dwellings not only can achieve thermal comfort for occupants, but also can make a significant improvement in energy conservation. Consequently, interest in the microclimate around buildings in urban areas has increased because its affects other things; outdoor and indoor thermal comfort, energy consumption in heating and cooling, and the spreading of air pollution. This paper aims to investigate the influence of open spaces (outer courtyards) between building "Shallow canyons" with a H/W ratio of 0.24~0.6 in one of the urban patterns of youth housing sectors in New Assiut city and deep canyons with a H/W ratio of 4 in one of the new residential houses (El-Abrahimia and El-Moalemen complexes) in the center of Assiut city on indoor thermal comfort. A comparison was made between the two cases based on indoor thermal comfort, energy consumption and IAQ in hot arid climate.

The study shows a decrease of indoor temperature inside living rooms that overlook the deep canyons in El-Abrahimia complex with a difference of 11°C from the outdoor in the hottest day of July. The design of deep canyons causes a temperature decrease of 6~9.4°C compared to outdoor temperature in different points of the courtyard. Indoor temperature in these cases reach the upper limit of 90% acceptable range of ASHRAE during July with a maximum indoor temperature 32.5°C based on the strategy of using natural ventilation. The findings show decreases of cooling demand and energy consumption in deep canyons. This is considered a basic monitoring method that could be used in the future strategy of sustainable housing design of new cities in hot arid climate.

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Keywords: Urban geometry; Thermal comfort; Indoor temperature; Indoor CO_2 concentration.

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1. Introduction

Climate has a major effect on the performance of buildings and their energy consumption. The variation of temperatures across residential densities in urban areas and its effect on indoor thermal comfort will be taken as an index of the impact of the urban microclimate on the built environment in cities [1]. Compact urban forms in hot dry regions typically found in old city centers are known to be well adapted to the climate [2]. There are, however, few studies from hot dry climates on urban microclimate [3]. In addition, revitalizing outdoor spaces will lead to energy savings inside buildings.

El-Deeb et al. studied the effect of building form and urban pattern on the energy consumption of air-conditioned buildings in different desert environments. Energy simulation was performed for three desert cities: Jeddah (Saudi Arabia), Cairo (Egypt) and Alexandria (Egypt) [4]. Kruger et al. observed and estimated relations between urban morphology and changes in microclimate and air quality within a city center. Two approaches are presented, showing results of field measurements and urban climate simulations. From measured microclimatic data and comfort surveys, carried out in downtown Curitiba, Brazil, the impact of street geometry on ambient temperatures and on daytime pedestrian comfort levels was evaluated [5]. Dalman and Salleh investigated the microclimatic principals of two different fabrics in South East of Bandar Abbas using different thermal comfort indices and microclimate assessment of residential urban canyons and focused on effect of vegetation, building environment & shading [6]. Taleghani et al investigated the effect of courtyards, atria and sunspaces on indoor thermal comfort and energy consumption for heating and cooling. Four building types were modelled and simulated in three different climates using Design Builder [7]. Literature showed that the quantitative analysis for the impact of building and urban forms, orientation, and passive treatments as shading and insulation on indoor energy consumption and indoor thermal comfort in desert environments are not sufficiently addressed and need more investigation concerning physical measurement and indoor and outdoor monitoring. Desert environments are classified as hot-arid desert according to Köppen-Geiger climate classification. However, there are differences between desert environments regards to temperature and humidity ranges despite being of the same classification.

The aim of this paper is to investigate the influence of open spaces dimension (outer court-yards) between buildings “Shallow canyons” with a H/W ratio of 0.24~0.6 in one of the urban patterns of Youth housing sectors in New Assiut city and deep canyons with a H/W ratio of 4 in one of the new residential house (El-Abrahimia and El-Moalemen complexes) in the center of Assiut city on indoor thermal comfort and energy consumption in hot arid climate. The dependence of urban geometry design on indoor condition was emphasized in order to evaluate two different urban canyons on indoor comfort and energy for future design strategies of sustainable city in hot aird climate.box

2. Methodology

Investigation was done in the living rooms of four different flats facing the open urban space with different orientations in New Assiut city, and four points in different locations of the building facing the outer courtyard “deep canyons”. The middle floor of Youth housing sector was chosen, and is occupied by average four occupants. This was seleted in order not to be affected by high solar radiation in the top floor or heat transfer from the ground floor. The air temperature, humidity, and CO_2 were measured using data loggers- Thermo Recorder model TR72Ui with measuring accuracy: ±1%RH, ±0.1°C and TR-76Ui with measurement accuracy ± (50 ppm + 5 % of reading), ±0.5 °C and ±5 %RH and measurement range 0 to 5,000 ppm, 0 to 45 °C, 10 to 90 %RH. Also, four points in different locations of the El-Abrahimia building were chosen facing the outer courtyard “deep canyons”. The datalogger was placed in the living rooms of different flats. Four locations were chosen (end point, middle point, outer point of courtyard, and outside street location). Investigation was carried out during the summer season; July, August, and September, 2014. Also, temperature measurements were conducted inside the outer courtyard deep canyons in the hottest day of June (1pm~pm) and measurement of 15 points inside the courtyard with relation to outdoor temperature. All outdoor data was measured with TR72Ui in the Assiut and New Assiut city to compare indoor and outdoor measurements at the same period and location. Outdoor wind speed is measured inside outer courtyards by hot wire anemometer model AM-4214SD with accuracy ± (5% + 0.1m/s). The research compares the housing prototype built by the government in the new cities and new residential private complex according to different urban geometries and its effect on indoor thermal comfort with relation to energy consumption.

3. Case study location & description

Assiut city is located in Egypt with a latitude of 27°3'N and a longitude of 31°15'E. It has a maximum temperature that range from 41°C to 46°C and a minimum temperature ranging from 16°C to 21°C in the summer months. New Assiut city is located in the east side of the river Nile in desert area. The difference in outdoor temperature between Assiut city and New Assiut city ranges between 2°C to 3°C as shown in fig.1.

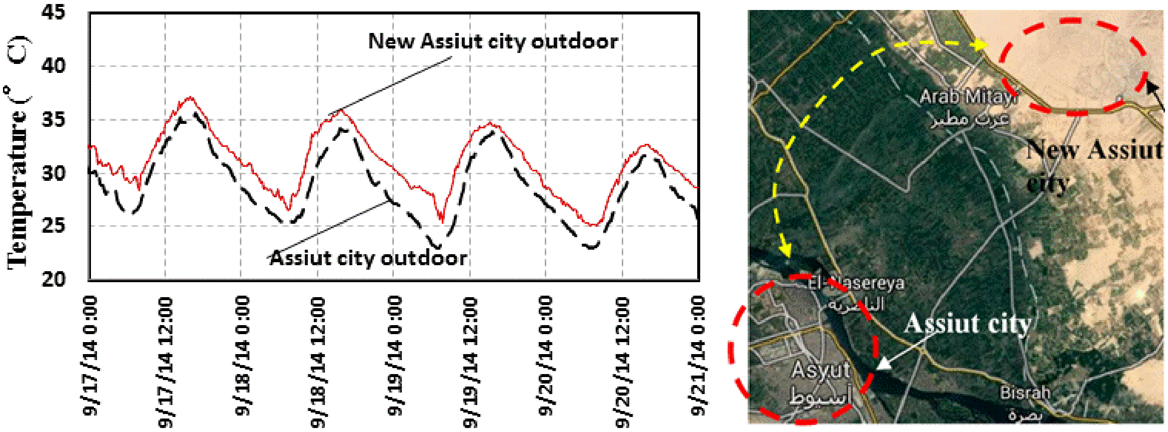


Fig. 1. The satellite image of New Assiut city with relation to Assiut city and the difference in outdoor temperature in the two location, August 2014.

El-Abrahimia housing complex located in Assiut city consists of two big residential blocks with an internal street for pedestrian use as private outer courtyard that support different social interaction and activities. The ground floors are used as different stores and markets with a shaded corridor (Arched). Different urban elements and landscape items (green area, tree,…etc) are used in the outer courtyard to decrease court temperature and act as an internal view for all internal residential flats. The complex has a compact urban form. Buildings occupy the whole plot, with the exception of space used for courtyards, and streets are narrow.

Most of the houses in New Assiut city were built according to a fixed prototype without taking into account building orientation, materials, indoor comfort, and passive ventilation strategies. The urban geometry of the outer courtyard in Youth housing sector is wide and provided with wide pavements. The street pattern is regular and, there are few trees providing shade at the outer courtyard level as shown in fig. 2 and 3.

The new residential complex (El-Abrahimia and El-Moalemen complexes) was selected for this study because this new complex was built with narrow and cut deep canyons "outside open courtyards" with the concept of old traditional building and compact design. This outside courtyard was used as a place for social activities and supports social interaction for people as shown in fig.4.

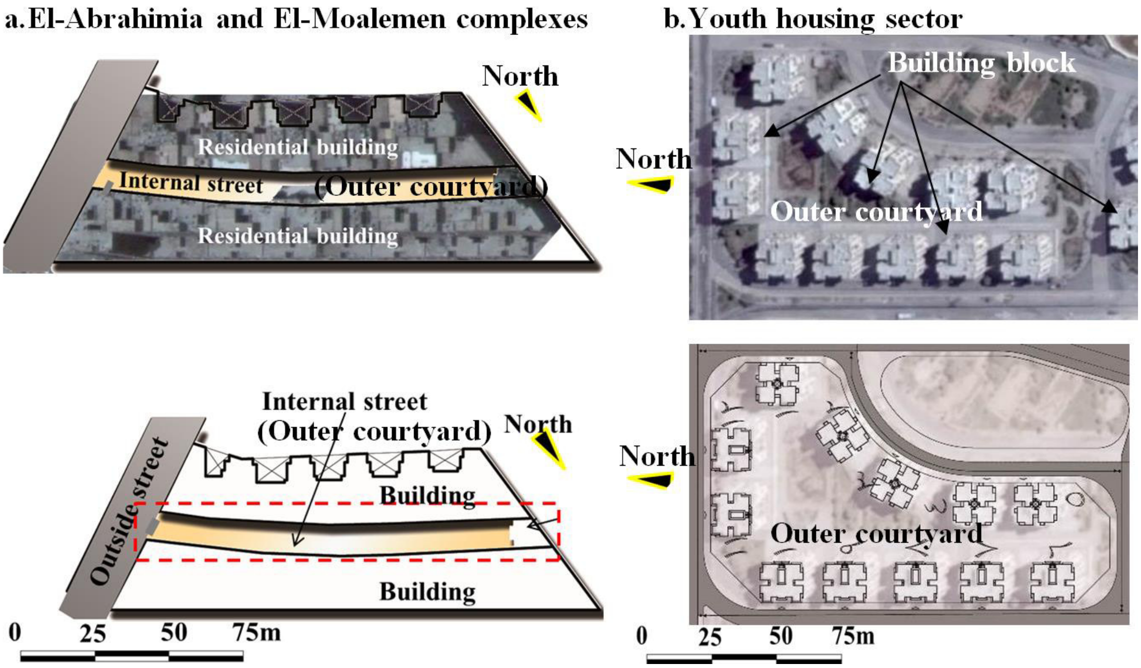


Fig. 2. The urban geometry of the two building complex and the location of the outer courtyard.

Fig. 3. The overall view of the outer courtyard of Youth housing sector complexes.

Fig. 4. The overall view of the outer courtyard of El-Abrahimia and El-Moalemen complexes.

4. Results and discussion

Urban geometries and thermal properties of urban surfaces were found to be the two main parameters influencing urban climate [8]. The ratio between the height of buildings (H) and the distance between them (W) influences the amount of both incoming and outgoing radiation. It can be seen from the fig.5 that the temperature does not fluctuate inside the houses facing the outer courtyard “deep canyon” with a H/W ratio of 4. Indoor temperature doesn’t exceed 32.5°C, even in the hottest days.

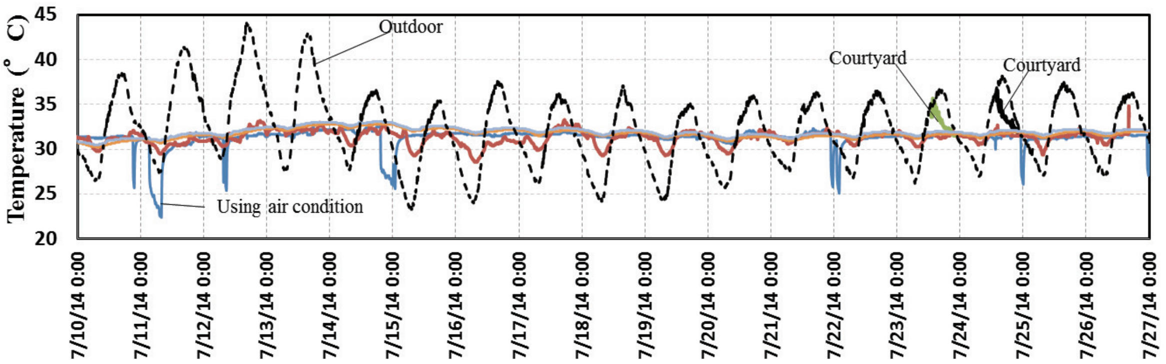


Fig. 5. Temperature profile of four locations in the residential flat of El-Abrahimia relative relation to outdoor and courtyard temperature during July 2014.

Also, the temperature distribution inside the outer courtyard decreases between 6~9.4°C compared to outdoor temperature in different points in the courtyard as shown in fig.6. This is due to the two buildings cast shadows on the courtyard during most of the daylight hours. The effect of the outside temperature is minimized and a cool internal area can be obtained during the day. This causes small fluctuation of temperature inside the courtyard and houses.

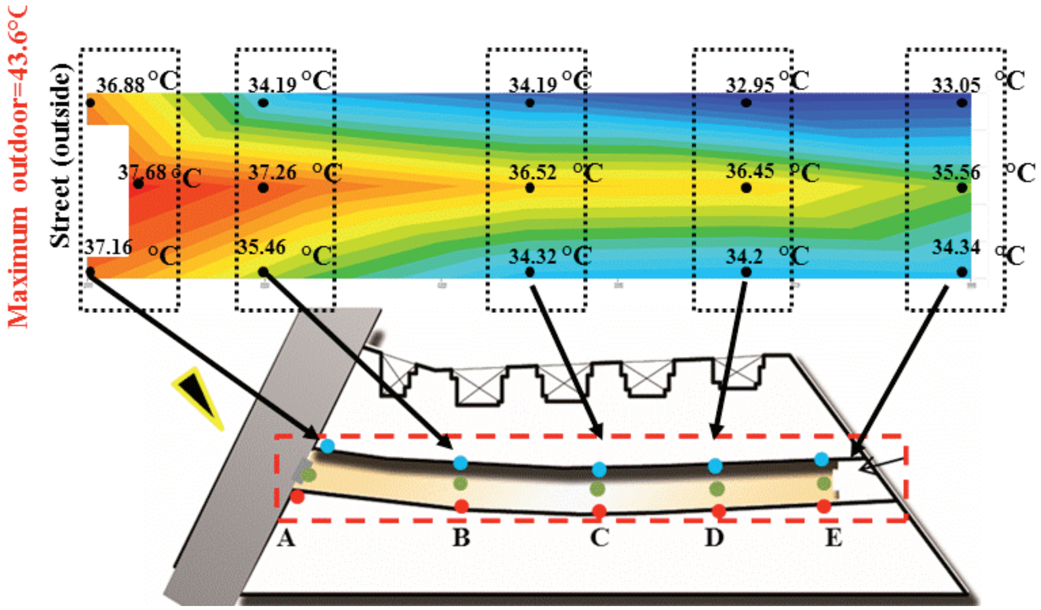
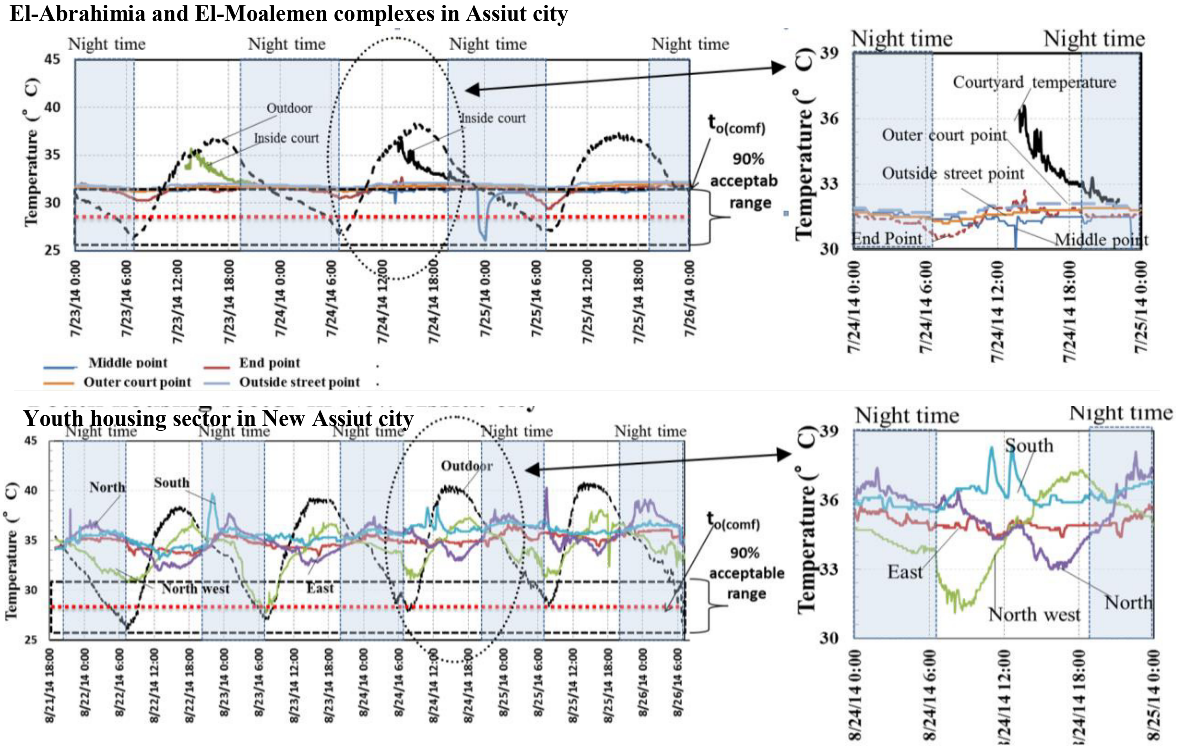


Fig. 6. The temperature distribution in the plan of the outer courtyard of El-Abrahimia and El-Moalemen complexes 4/6/2014 (Average between 1~3pm).

According to Steemers et al., the geometry of the urban form has an influential impact on urban microclimate. The urban geometry is defined by density, surface-to-volume ratios, height-to-width ratios of urban buildings and spaces. A line of analysis of the interaction between form and microclimate discusses temperature difference by the way of the urban heat island effect [9].

In Youth housing sector, occupants used natural ventilation (single side ventilation) as a ventilation strategy inside these houses. The indoor temperatures in the living room of four different directions (north, south, east, N.west) are far from the 90% acceptability limits of Adaptive Comfort Standard (ACS) of ASHRAE except in the north west flat due to using the cross ventilation strategy. The urban geometry between building is a shallow canyon with a H/W ratio of 0.6~0.24 according to different points between building as shown in fig.7. According to Givoni, when the ratio H/W≤1 in the urban canyons of the hot desert areas, the solar radiation is implemented inside the building and causes high heat gain [2]. The outer façade of the building is exposed to solar radiation without any shade from other buildings or trees. This causes high internal gain and increase in indoor temperature. There-fore, high energy consumption will be achieved when using air condition to reach thermal comfort. Also, the relative humidity fluctuates strongly with high indoor relative humidity values due to using natural ventilation strategy and mechanical fans with occupants existing most of the time in the living room. Meanwhile, the profile of the relative humidity in the N.west living room follows the same pattern as that of outdoor as shown in fig.8.

In El-Abrahimia and El-Moalemen complexes, the indoor temperatures in the four measurement points (the end point, the middle point, the outer court point, the outside street point) are close to 90% acceptability upper limits of the Adaptive Comfort Standard (ACS) of ASHRAE with maximum temperature 32.5°C as shown in fig.7. Indoor temperature appeared to be stable most of the time even with the increase of outer temperature without using aircondition. Also, monitoring of courtyard was done from 1 pm until 9 pm to evaluate the pattern compared to indoor and outdoor temperature. A small fluctuation is appeared for indoor relative humidity due to decrease of courtyard relative humidity while occupants were inside the house most of the time during the fasting month, July (Ramadan).


El-Abrahimia and El-Moalemen complexes in Assiut city

Youth housing sector in New Assiut city

Fig. 7. Temperature profile of indoor and outdoor environment in the two complexes.

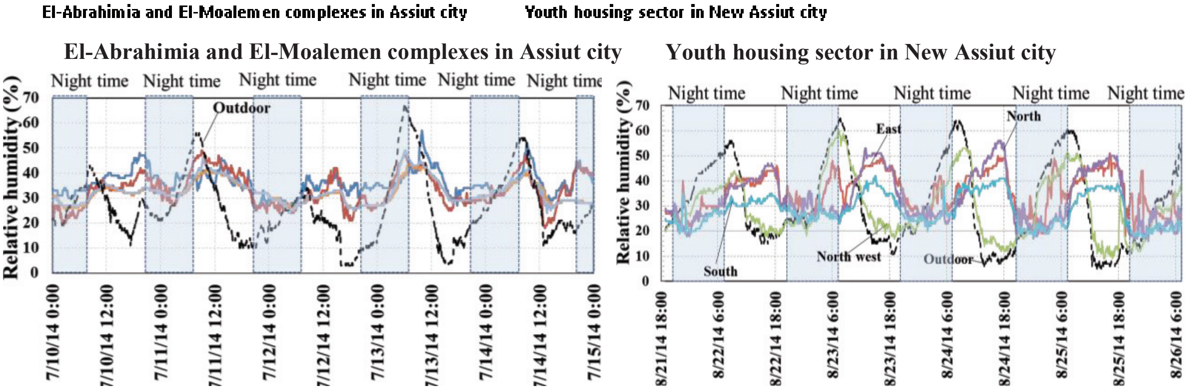


Fig. 8. Relative humidity profile for two housing complexes in different urban geometry.

Fig.9. shows the regression lines between the daily outdoor temperature in the shallow canyons and indoor temperature in Youth project, and the regression lines between the daily outer courtyard temperature inside deep canyons and indoor temperature in El-Abrahimia project. It can be concluded that significant linear relationships with R2 range between 0.43~0.54 in the living room overlooking the deep canyons. Therefore, courtyard low temperature greatly affects indoor temperature inside the house due to the design of the outer courtyard that provides shade for its wall. On the contrary, the correlation coefficient in the living room overlooking the shallow canyons in new Assiut city was very low and ranged between 0.008~0.18 with the effect of high heat gain. Only temperature of the living room in the south orientation was high due to using cross ventilation strategy and opening the windows during daytime and nighttime. This shows the importance of using deep canyon as a strategy in hot arid climate.

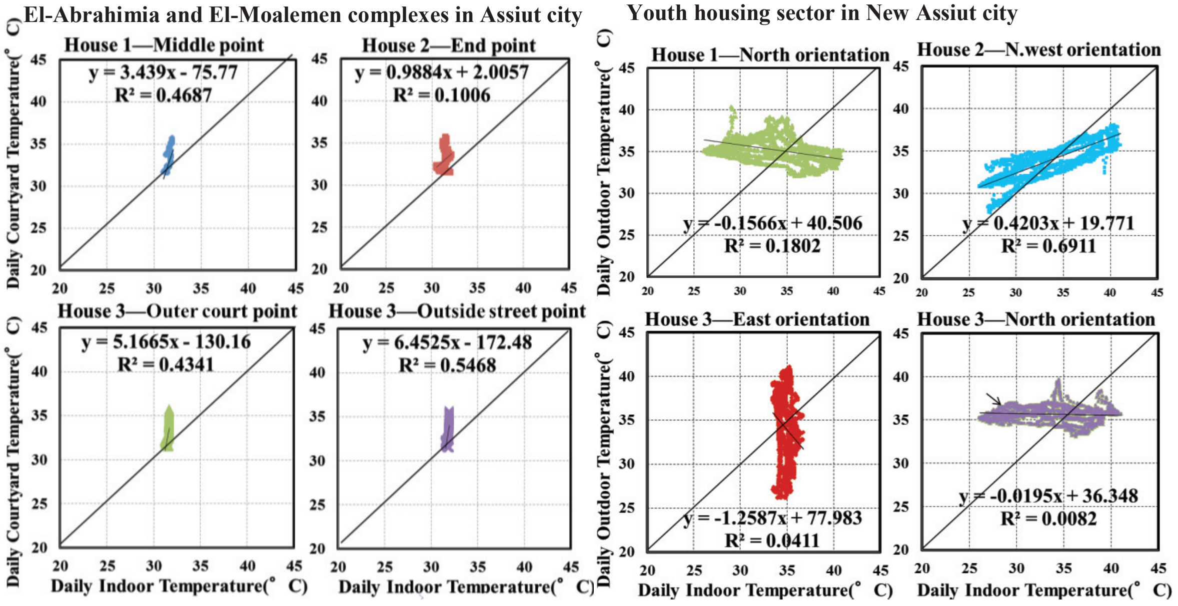


Fig. 9. The regression lines between daily outdoor and indoor temperature in different urban geometry.

CO_2 can act as an index of ventilation efficiency, showing whether the supply of outside air is sufficient to dilute indoor air contaminants. Measuring CO_2 concentration in the living room of the two complexes helps to understand the effect of different urban geometries (canyons) on carbon dioxide concentration for ensuring indoor air quality (IAQ) and a safe living environment. The concentration of CO_2 inside the living room of youth housing project was lower than the concentration inside the living room of El-Abrahimia project as shown in fig. 10. This is due to the increase of average outdoor wind speed inside the shallow canyons that affects CO_2 concentration. The average outdoor wind speed was 2.8m/s and 1.7m/s inside the courtyard of shallow canyons and deep canyons respectively.

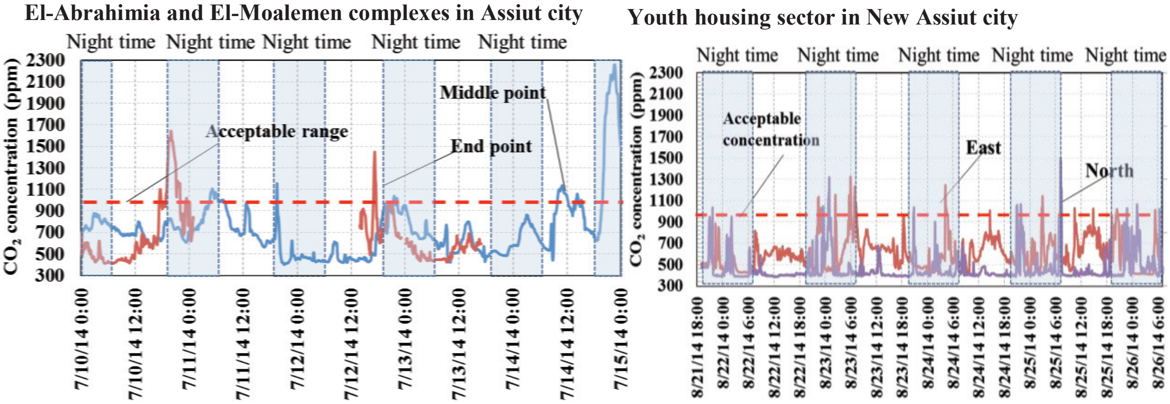


Fig. 10. CO_2 concentration in the living rooms of two different houses under the effect of different urban geometries and wind speeds.

4. Conclusion

The study shows a decrease of indoor temperature inside the living room that overlooking the deep canyons in El-Abrahimia complex with a difference of 11°C from the outdoor in the hottest day of July (12/7/2014). The effect on indoor thermal comfort is an index of the impact of deep canyons with a H/W ratio of 4 in the hot arid climate of Assiut. Such deep canyons cause decrease in temperature between 6~9.4°C from outdoor temperature in different point of the courtyard with low wind speed and without using aircondition. Also, the courtyard low temperature greatly affects indoor temperature inside the house due to the design of the outer courtyard. It is concluded that indoor temperature in the cases reach the upper limit of 90% acceptable range of ASHRAE during the month of July with a maximum indoor temperature of 32.5°C. This causes reduction of cooling demands in the house and energy consumption.

Deep canyon is fairly comfortable and helps to minimize the façade area affected by solar radiation and causes low heat gain from outdoors, whereas the shallow canyons with a H/W ratio of 0.24~0.6 is uncomfortable. The internal temperature in the living room of four different directions (north, south, east, N.west) are far from the 90% acceptability limits of Adaptive Comfort Standard (ACS) of ASHRAE with high wind speed. Therefore, high energy consumption will be achieved when using air condition for attaining comfort. This results based on canyons orientation and geometry. More work is needed to study the optimum H/W ratio for deep canyons. The study stresses the importance of the revising the current strategies for planning cities in hot arid climate to consider deep canyon as a strategy for new cities.

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