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Optimising Ventilative Cooling and Airtightness for [Nearly] Zero-Energy Buildings, IAQ and Comfort

PROCEEDINGS

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INIVE

VENTILATED COURTYARD AS A PASSIVE COOLING STRATEGY IN THE HOT DESERT CLIMATE

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ABSTRACT

Traditional architecture gives ideas to enrich modern architecture. In traditional architecture, local materials and renewable energy resources have been used. The courtyard was one of the traditional architecture solutions as a climate modifier. The inclusion of an internal courtyard in building design is attributed to the optimization of natural ventilation in order to minimize indoor overheating conditions.

The paper investigates the potential of a ventilated courtyard for passive cooling in a small building in a hot desert climate. The analyzed model is one of the low-income housing models in New Aswan City - Egypt. Which was built and provided with main services by the government, these housing models were characterized by their improper design in many cases, especially, concerning with climatic design.

To evaluate the performance of a ventilated courtyard, building simulation software TRNSYS 16 (The coupling between TRNSYS and COMIS) was used. The courtyard parameters considered were the courtyard orientation and the courtyard geometry. To evaluate the performance of a ventilated courtyard, the average monthly indoor air temperature for the purposed building determined in the overheating summer season depended on the weather data for the building site. The results of the investigations of the courtyard parameters indicate that there are some important parameters, and other are of less significance which affects the thermal performance of the courtyard building model.

KEYWORDS: Courtyard, hot desert climate, natural ventilation, low-income housing.

INTRODUCTION

Natural ventilation is one of the natural passive cooling strategies recommended for hot desert regions. In desert areas, this strategy is utilized to conserve energy while maintaining appropriate thermal comfort for inhabitants inside the building.

The aim of this study is to further the understanding and optimization of natural ventilation cooling in buildings that have a ventilated courtyard. The performance of the courtyard was evaluated by using TRNSYS 16 simulation tool, in a multi-story house located in New Aswan City, which is about 850 km South of Cairo, Egypt.

BRIEF LITERATURE REVIEW

Many types of research, such as Dunham, Fathy, Givony, Hinrichs, Konya, Lippsmeier, Olgyay, and Saini reached a conclusion that a building with a courtyard is a desirable concept in the hot, dry climate [1].

In a recent study, Al-Hemiddi describes an experiment to investigate the effect of a ventilated interior courtyard on the thermal performance of a single-family house in a hot–arid region.

Statistical analysis of data recorded during the summer of 1997 was carried out. The results indicate that the courtyard gives high efficiency in providing cool indoor air through cross-ventilation [2].

In another study, a comparison between different geometries of courtyards in terms of wind flow characteristics and indoor air speed is performed based on the Validation of Computational Fluid Dynamics (CFD) simulations with 2D published wind-tunnel experiments. In addition, assessment of thermal comfort is made inside a number of selected dwelling rooms facing different courtyard geometries. It is confirmed that rooms with cross ventilation have higher indoor air speed values and therefore a better thermal comfort than with single-side ventilation. The courtyard dimensions, the position of the room and the orientation are important aspects influencing the indoor air speed and thermal comfort [3].

In their research, Rajapakshaa, Nagaib, and Okumiya investigate the potential of a courtyard for passive cooling in a single story high mass building in a warm, humid climate. From the results of thermal measurements, a significant correlation between wall surface temperatures and indoor air temperatures is evident. A reduction of indoor air temperature below the levels of ambient is seen as a function of heat exchange between the indoor air and high thermal mass of the building fabric. However, this behavior is affected by indoor airflow patterns, which are controlled through the composition between envelope openings and the courtyard of the building. From a computational analysis, several airflow patterns are identified. A relatively better indoor thermal modification is seen when the courtyard acts as an air funnel discharging indoor air into the sky than the courtyard serves as a suction zone inducing air from its sky opening. The earlier pattern is promoted when the courtyard is ventilated through openings found in the building envelope [4].

The passive cooling effects of a courtyard of a small building were determined numerically by safarzadeh and Bahadori in their paper, employing energy-analysis software developed for that purpose. The passive cooling features considered were the shading effects of courtyard walls and two large trees (of various shapes) planted immediately next to the south wall of the building, the presence of a pool, a lawn and flowers in the yard, and the wind shading effects of the walls and trees. It was found that these features alone cannot maintain thermal comfort during the hot summer hours in Tehran, but reduce the cooling energy requirements of the building to some extent. They have an adverse effect of increasing the heating energy requirements of the building slightly. The same savings in cooling energy needs of the building can be obtained through many features such as wall and roof insulation, double-glazed windows, and special sealing tapes to reduce infiltration. They all save on heating energy requirements as well [5].

It is clear from the foregoing review that the courtyard building form, although being described as a suitable solution in hot, dry climate, has not investigated with regard to the multi-story residential building and evaluation concerning the interaction between the courtyard geometry and the orientation. Consequently, the importance and significance of the present study are apparent.

ANALYSIS OF THE CASE STUDY

Climatic features of New Aswan City

New Aswan City is located on the west bank of the Nile, 10 Km north of the present Aswan City and 850 km South of Cairo, so it is located in the south of the Upper Egypt region, which characteristic of a hot, dry climate, with a very wide difference between day and night temperatures. During the summer season, the day-by-day mean of maximum outdoor air temperature reaches 35° C in the north of Upper Egypt and 41° C in the south. In the winter season, the day-by-day mean of minimum outdoor air temperature reaches 6° C in the north of Upper Egypt and 10° C in the south. In general, Upper Egypt has a typical desert climate with significant variations between seasons and between day and night temperatures [1].

The level of humidity in Upper Egypt is relatively low, especially during the summer months. The yearly mean of humidity in Upper Egypt differs from 55% to 20%, north to south respectively. In New Aswan City relative humidity records the lowest value in May and June (12%), whereas reach to the highest value in December and January (36%, 34% respectively). On the other hand, The annual wind rose for New Aswan City indicates that most winds blow from the north, northwest, and northeast (49.2%, 21%, and 12.9% respectively) [1].

Building Description

The use of courtyards in residential buildings in Egypt and other countries in the Middle East is many centuries old. The courtyards provided security and privacy for the residents, and daylight for the rooms, which were built around them. By building a pool, fountain and planting trees in the yard, the architects created a very pleasant space for the residents to spend a portion of their time during summer months in the yard.

In Egypt at present, the courtyard usually employed in buildings to collect sanitary pipes of the service's rooms (w.c, kitchen), which were built around it. Also, provide security, privacy, and daylight for the residents in these rooms.

The original residential building was chosen for the study consists of three floors and has not a courtyard as shown in Fig. 1. It was constructed in 2005 within one of the national housing projects was built and provided with main services by successive governments. Such a policy was adopted and applied since the fifties and is up until now with the main care devoted to producing as many residential units as possible, with less care of units' quality. Consequently, these projects were characterized by their improper design in many cases, especially, concerning with climatic design.

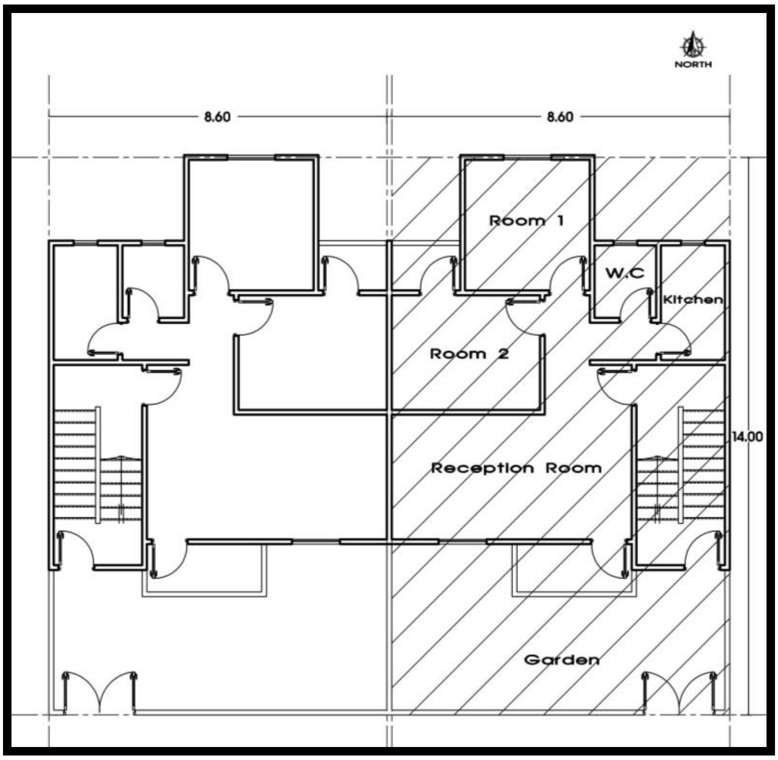


Figure 1. The original residential building

The building does not have insulation on the walls and roof. It is constructed using standard local building materials. The external walls of the rooms are built with only bricks, 16 cm in thickness. The roof is flat and made of a concrete slab, 12 cm in thickness. The external walls are painted light brown.

In a recent study, TRNSYS 16 simulation tool was used to predict the hourly indoor air temperature, which shows that the results indicate that the maximum temperature obtained is 43.6° C on the ground floor. While, on the first floor the maximum temperature obtained is 43.9° C, and on the last floor the maximum temperature obtained is 44.9° C.

In addition, the predicted average monthly indoor air temperature during the summer season (as shown in Table 1) indicates the overheating conditions which exceed the comfort limits to some extent [6].

Month		Jun.	Jul.	Aug.
Temperature (deg. C)	Ground floor	36.6	37.1	37.5
	First floor	36.5	37.0	37.4
	Last floor	37.1	37.7	38.0

Table 1. The predicted average monthly indoor air temperature during the summer season

The previous results declare the need for a cooling system to exceed climatic difficulties, so, the results guide to the importance of employing solutions such as courtyard in buildings to act as a climate modifier.

The modified building has a courtyard in the central area of the house. The same area and dimensions were preserved; the courtyard opened to the sky, and has ventilation openings, and connected to the rooms around it with windows.

In order to determine the efficiency of the courtyard, the simulation process will be carried out on the last floor, which considers the worst case. On the other hand, the courtyard parameters investigated will be in different four scenarios as follow.

Case 1: rectangular courtyard with ventilation openings facing the north orientation (Fig. 2).
Case 2: rectangular courtyard with ventilation openings facing the south orientation (Fig. 3).
Case 3: square courtyard with ventilation openings facing the north orientation (Fig. 4).
Case 4: square courtyard with ventilation openings facing the south orientation (Fig. 5).

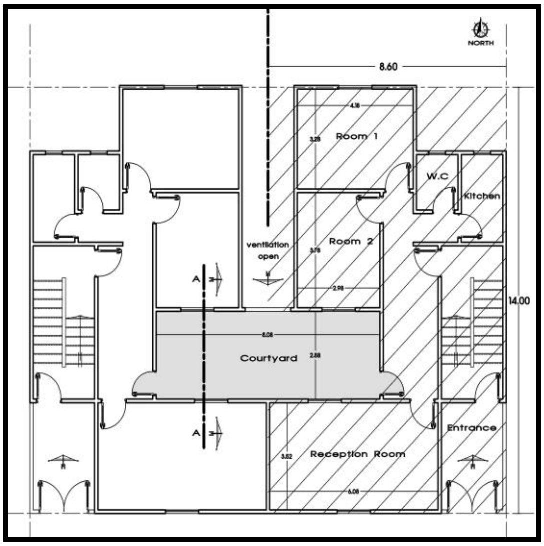


Figure 2. Rectangular courtyard with North orientation

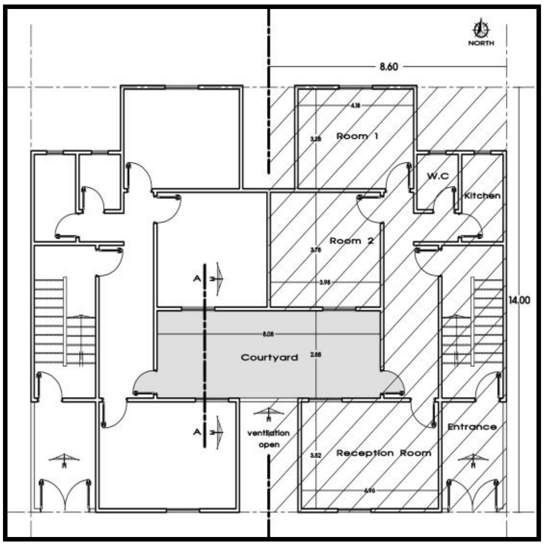


Figure 3. Rectangular courtyard with South orientation

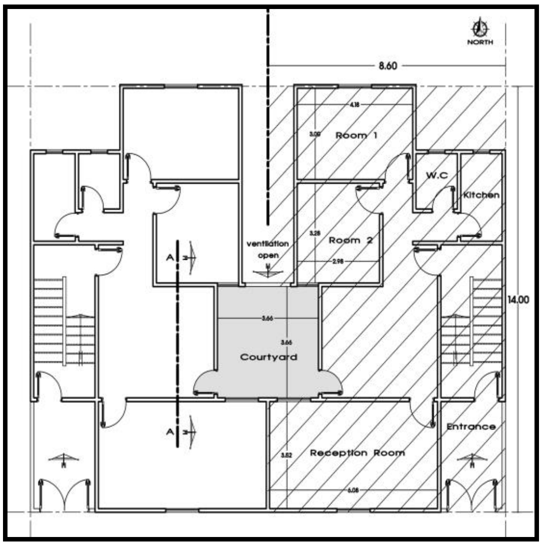


Figure 4. Square courtyard with North orientation

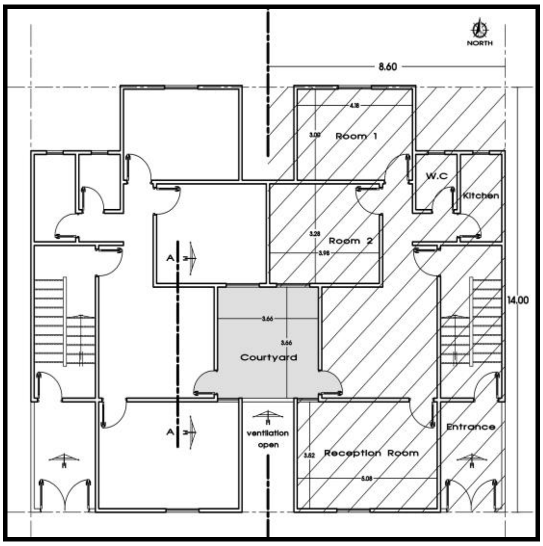


Figure 5. Square courtyard with South orientation

Fig. 6 shows the cross-section of the purpose building.

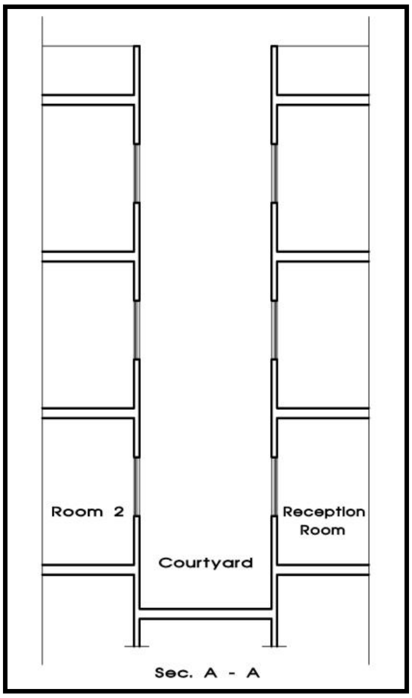


Figure 6. Cross-section through the building

TRNSYS program

The present research uses the computer simulation program TRNSYS 16 (The coupling between TRNSYS and COMIS).

TRNSYS (the TRaNsient SYstem Simulation program) is a flexible tool designed to simulate the transient performance of thermal energy systems. TRNSYS can be connected to COMIS (Conjunction Of Multizone Infiltration Specialists) through the use of an add-on link component called Type157. This type recasts COMIS as a TRNSYS component. In this case, the COMIS input file is generated not using a separate graphical interface but using the TRNSYS simulation studio itself [7].

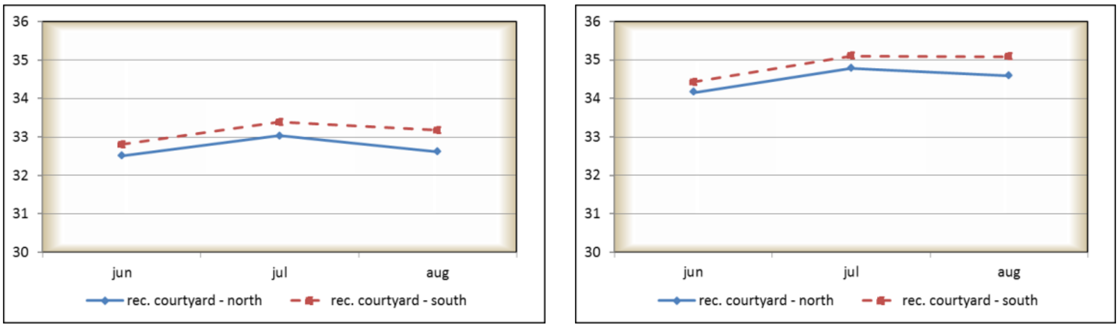
RESULTS

Effect of the orientation

The comparing between the north and the south orientations clear that:

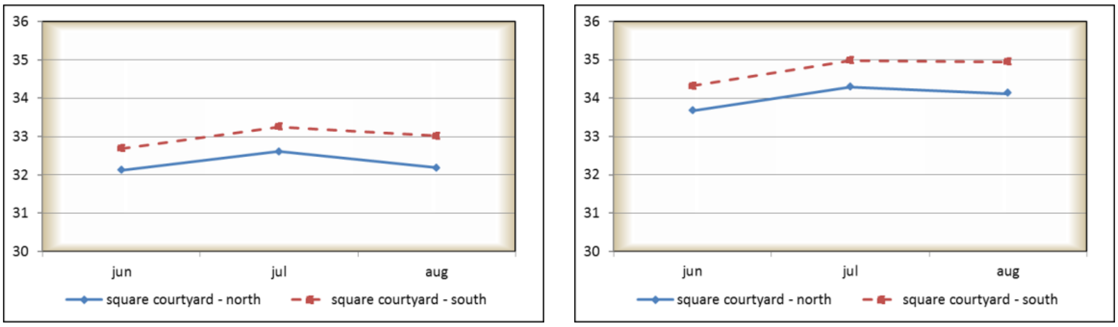
In the case of the courtyard which facing the north, the indoor air temperature recorded either in room 2 or in reception room values less than the indoor air temperature, which recorded in the case of the courtyard facing the south (Fig 7). Also, the same results were recorded in the case of the square courtyard (Fig 8).

The square courtyard is more efficient than the rectangular courtyard.



Room 2 Reception room

Figure 7. Results recorded in the case of a rectangular courtyard



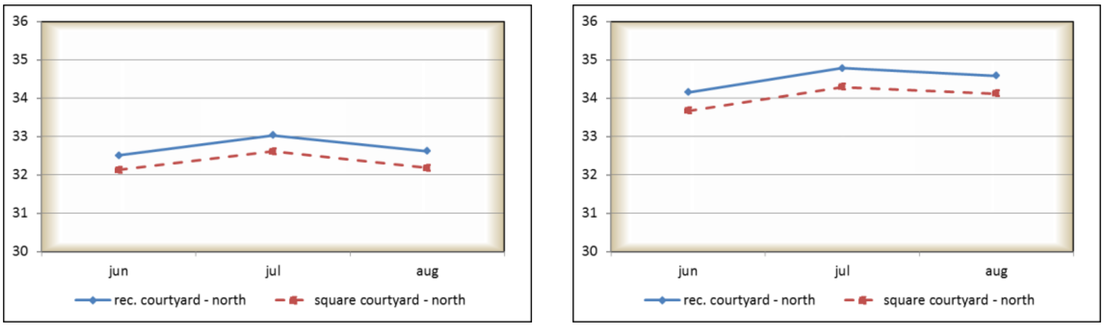
Room 2 Reception room

Figure 8. Results recorded in the case of a square courtyard

Effect of the geometry

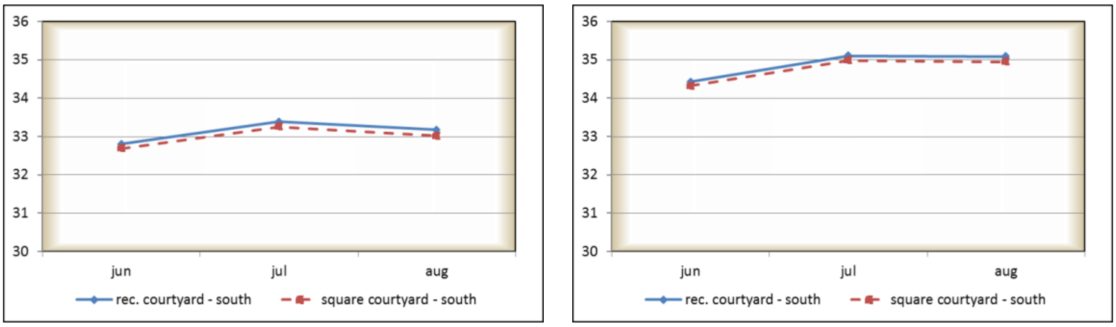
On the other hand, the comparing between the rectangular and the square courtyards indicates that the square courtyard is the best in all cases (Fig 9 – Fig 10).

At the same time, the north orientation is more efficient than the south orientation.



Room 2 Reception room

Figure 9. Results recorded in the case of courtyard facing the north



Room 2 Reception room

Figure 10. Results recorded in the case of courtyard facing the south

In general, it is clear to note that employing the courtyard in the building reduce the indoor air temperature in all cases by 3°C : 5°C (as shown in Table 2).

	Indoor air temperature in room 2			**Indoor air temperature in the reception room**		
	Jun	**Jul**	**Aug**	**Jun**	**Jul**	**Aug**
Building without courtyard	37.1	37.7	38.0	37.1	37.7	38.0
Rectangular courtyard facing the north	32.5	33.0	32.6	34.2	34.8	34.6
Rectangular courtyard facing the south	32.8	33.4	33.2	34.4	35.1	35.1
square courtyard facing the north	32.1	32.6	32.2	33.7	34.3	34.1
square courtyard facing the south	32.7	33.3	33.0	34.3	35.0	34.9

Table 2. The comparison between the four scenarios

The reception room records more values of indoor air temperature than the room 2.

The square courtyard which facing the north orientation is the best case correspond to the rooms around the courtyard.

In all cases, it is noted that the reduction of the indoor air temperature is not enough to achieve the thermal comfort during the summer season.

CONCLUSION

The results showed that it is possible to get a considerable reduction in the indoor air temperature with natural ventilation by using the ventilated courtyard in hot desert climate. However, to ensure good performance designers and other professionals should pay attention to some parameters like the orientation and the geometry of the courtyard.

The courtyard is an appropriate design strategy for building from the perspective of climatic and cost-benefit analyses. These strategies can be applied to a single story or multi-story building. Also, the use of the courtyard with a pond, fountain, and trees could be an appropriate strategy during the hottest periods.

Finally, the development of the above formulae helps designers and architects to predict the thermal performance of courtyard buildings cooled by natural ventilation.

However, this approach only helps to predict the indoor air temperature of the purpose building, under given climatic conditions. Therefore, this approach is not universally applicable, and values and judgments based upon it could change when we explore the effects of other designs and/or climatic conditions on courtyard performance.

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