THE MASTERY OF THE TAKHTABUSH AS A PARADIGM TRADITIONAL DESIGN ELEMENT IN THE HOT ZONE CLIMATE

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Abstract

The Takhtabush "A covered outdoor sitting area at ground level" was introduced in the Mamluk period in the 12th century to the traditional courtyard in Egypt (El-Shorbagy 2010). It is located between the shaded courtyard and the backyard, opening completely onto the courtyard and through a Mashrabia onto the backyard which ensures a steady flow of air by convection (Fathy 1986). Several studies investigated the thermal performance of the courtyard and few of them highlighted on the importance of the Takhtabush. No one investigated how far the Takhtabush can affect the thermal performance of the courtyard. The author of this paper doubts the efficiency of the courtyard without the Takhtabush in hot arid zone where the air velocity during the summer is very low most of the time. The current research conducts a comparative study between two scenarios of the courtyard (with and without the Takhtabush) through technical investigation. The investigation is done using monitoring techniques with observation and field measurements. Data is analysed using statistical analysis software. The results showed quantitatively and qualitatively the importance of employing the Takhtabush to enhance the thermal performance of the courtyard.

Keywords: *courtyard, thermal performance, Takhtabush*

Introduction

Houses represent the background or framework for human existence (El-Shorbagy, 2010). Through history, people have tried to adapt their buildings with the harsh climate in the hot-dry zone through reducing heat impacts (Mohamed et al., 2010). They used to open their houses onto a private internal open space that visually and acoustically separated from the outside called Sahn "courtyard" (Afify, 2002). The courtyard helps in maintaining cooled indoor temperatures by employing the phenomenon of the stack effect (Wazeri, 2002). Stack effect occurs when the air inside a vertical stack is warmer than the outside air (provided that there are both inlet and outlet openings). The warmer air will rise and will be replaced at the bottom of the stack by cooler outside air (Szokolay, 2014). With some modifications to the courtyard such as using water and vegetation in its landscape, the benefits of the thermal performance could be maximized.

The phenomenon of the stack effect is employed in the courtyard to enhance thermal comfort by producing cool breezes (Wazeri, 2002). In the evening, the

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warm air of the courtyard, that was heated directly by the sun and indirectly by the warm buildings, rises and is gradually replaced by the cooled night air from above. This cooled air accumulates in the courtyard in layers and leaks into the surrounding rooms cooling them (Oliver, 1997). In the morning, the air of the courtyard, which is shaded by its four walls, is heated slowly and remain cool until late in the day when the solar radiations penetrate the courtyard (Fathy, 1986). According to Wazeri (2002), there are three important factors that affect the capability of the courtyard (Figure 2).

Figure 1
Courtyard of Al-Souhimi house, Cairo, (Captured by the author)

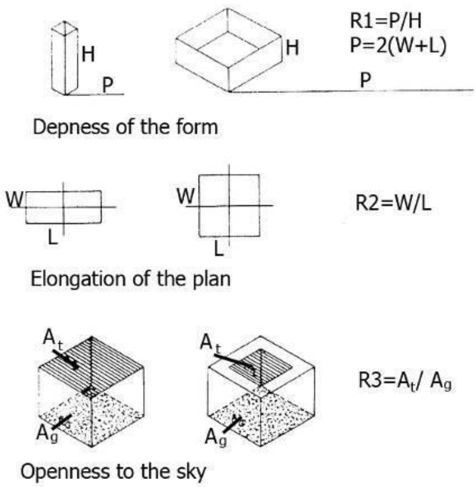

Figure 2
The geometric dimensions of the courtyard (Wazeri, 2002)

The deepness of the form (R1), which is the ratio between the courtyard's perimeters to the height. (R1 should not be less than 3).

The elongation of the plan, which is the ratio between the length to the width of the courtyard. The rectangular shape of the courtyard's plane is better than the square. Wazeri also recommended that the ratio between the length, width and the height should not be less than 1:2:1.4.

The openness to the sky, which is the ratio between the area of the top to the area of the bottom of the courtyard. He added that the best orientation to the courtyard is by orienting the long side to the east west. A recent study, concerned by the effects of surface openings on the air flow caused by wind in courtyard buildings, suggested that openings should be in the upwind and downwind surfaces to achieve the max air velocity. It added that, the larger the upwind surface openings, the more the velocity increases significantly (BMT Fluid Mechanics, 2007).
With the development of architecture and technology people have neglected the traditional architecture in terms of techniques. One of these marvellous techniques is the Takhtabush (Figure 3, 4 and 5).

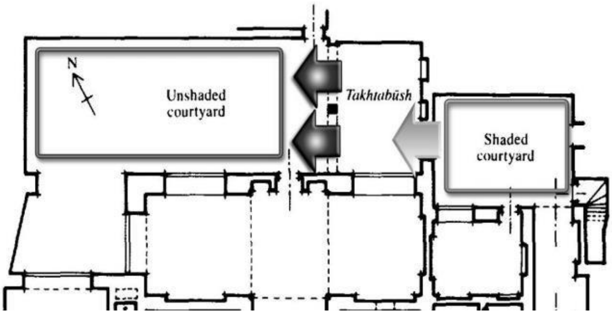

Figure 3
Plan of the part of the ground floor of the Qã 'a of Muhib Ad-Din Ash-Shãf'i AlMuwaqqi at Darb Al-Usta, Cairo, showing two courtyards with a Takhtabush between them, by the author after (Fathy 1986)

Figure 4.*The Takhtabush of al-Souhimi house, Cairo* *(captured by the author*)

Figure 5. *Interior image of the Takhtabush (captured by the author)*

It is an important component of the Arab house which ensures a steady flow of air by convection. Since the backyard is larger and thus less shaded than the courtyard, air heats up more readily there than in the courtyard. The heated air rises up and draws cool air from the shaded courtyard through the Takhtabush, creating a steady cool breeze (Fathy, 1986). Figure illustrates the created air flow through the Takhtabush.

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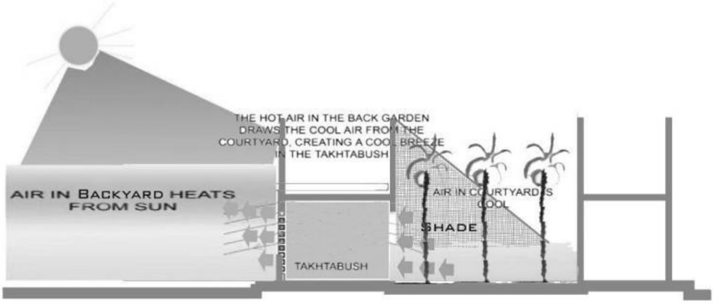


Figure 6
The air flow from the shaded courtyard to the backyard through the Takhtabush, by the author

The original houses could be considered an exception in nowadays urban environment with the high density urban areas. However, the concept of the Takhtabush still can be applied on new small houses through different techniques. Since, the required large area for the backyard could be replaced by the solar chimney. Mohamed (2017) confirmed the effectiveness of utilizing the solar chimney to replace the large backyard in the Takhtabush system.

Research aim and objectives

The research aims at quantifying the effectiveness of the Takhtabush on the thermal performance of the courtyard, through the following objectives:
1. Analyse the importance of the Takhtabush through the literature review;
2. Test the performance of two courtyards representing the proposed scenarios (with and without the Takhtabush);
3. Compare and analyse the results of the two scenarios.

Materials and Methods

The current research conducts a comparison study between two scenarios of the courtyard (with and without the Takhtabush) through technical investigation. Two courtyards of two different precedents representing the two scenarios, located in the same climatic region (Cairo, Egypt) are monitored at the same time to compare their thermal performance. Cairo climate is classified as an arid climate where precipitation rarely occurs. Cairo has a hot desert climate (Köppen climate classification: BWh). Cairo is located in northern Egypt, 165 kilometres south of the Mediterranean Sea and 120 kilometres west of the Gulf of Suezand Suez Canal. The city is along the Nile River, immediately south of the point where the river leaves its desert-bound valley and branches into the low-lying Nile delta region. (Wikipedia 2017). Decimal latitude and longitude coordinates for Cairo is 30.06263, 31.24967. Cairo's climate is a desert climate, which remains mostly dry and arid year round. The hot weather in Cairo means that the humidity can rise at times, particularly during winter (December to February). At this time, precipitation is more likely with less than 25 mm of precipitation annually in most areas and almost never rains in summer, and temperatures drop to 13 to 19 °C. Cairo weather in the summertime (May to August) sees temperatures of 45 to 47 °C (Mohamed

2017). The two case studies are: Buit Al-Souhimi (The one with a Takhtabush) and Gamal El-Din Al-Zahabi House (The one without a Takhtabush) (Fig. 7).

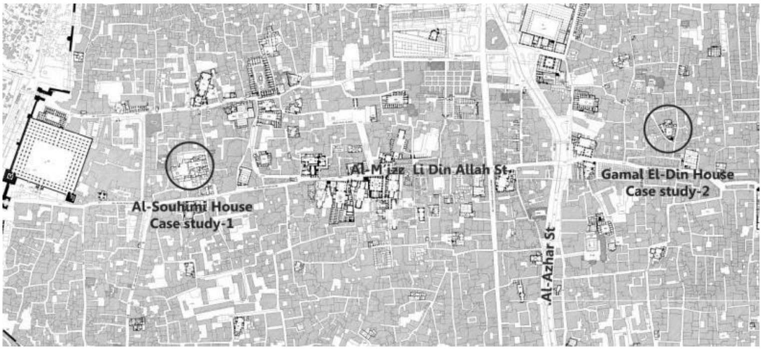
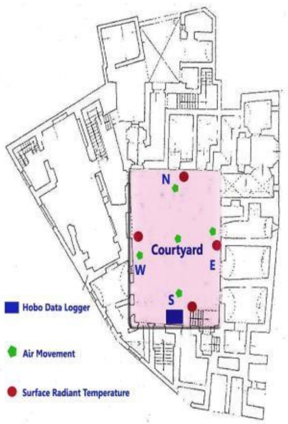


Figure 7
A map of Old Cairo shows the location of the two case studies, after (Warner 2005)

The two courtyards are almost similar also in dimensions, height, and vegetation. This is to assure that the variations in the measurements are affected mainly by the existence of the Takhtabush. Objective assessment was done using observation and field monitoring techniques. Figures 8 and 9 show a ground floor plan for each house with the location of the different measurements inside the courtyards.



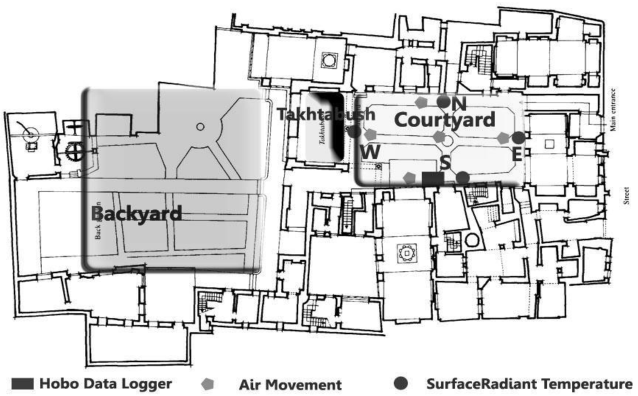


Figure 8. *The ground florr of Gamal El-Din Houseshowing thje location of the measure-ments, by the author*

Figure 9. *The ground Floor of Al-Souhimi house showing the location of the measurements, by the author after* (ARCHNET, 2016)

The measurements included:

1) Monitoring the air temperature of the two courtyards – as the most representative indicator for thermal performance – and the Relative Humidity (RH) using Hobo Data Loggers H12. Hobo Data Logger H12, a device to log the air temperature and relative humidity at certain intervals for a period of time, shown in Figure 10. The Data loggers were fixed at the middle of the two courtyards on the

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same wall orientation (The southern wall: since the courtyard is opened to the sky and receive sun radiation which affect the data logger readings, the only side that is not receiving any solar radiation during the whole day is the south wall that facing the north direction) for the whole summer season (from 21-June to 21-September). The time interval was 15 minutes;
2) Data is analysed using statistical analysis software SPSS to quantify the difference in thermal performance between the two courtyards through Mann-Whitney U test; Mann-Whitney U test is like t-test but does not require the assumption of normal distribution for the values of the two samples (Hague and Harris, 1993).
3) Measuring the Plain Radiant Temperature of the surfaces using MicroRay Pro Infrared Thermometer a device to measure the air velocity at a time (Fig. 11), and the air movement (wind speed) using Hand Held Anemometer- Sky Master, a device to measure the radiant temperature of a surface by Laser techniques (Fig. 12) over different points inside each courtyard for the one daytime on interval of 30 minutes.

Figure 10. *Hobo Data Logger H12*

Figure 11. *MicroRay Pro Infrared Thermometer*

Figure12. *Hand Held Anemometer-Sky Master*

The 21st of June was selected to represent the worst case scenario, since this day is one of the hottest days over the whole year in Cairo. The noon time from 12:30 to 16:0 O clock, was chosen to represent the hottest time during the day. This will help later to measure the Predicted Percentage of Dissatisfied index (PPD) which predicts the percentage of occupants that will be dissatisfied with the thermal conditions (ASHRAE, 2013). It is a function of the Predicated Mean Vote (PMV) using the Psycho Tool. The latter is an electronic version of the psychrometric chart (A psychrometric chart is a graph of the thermodynamic parameters of moist air at a constant pressure, often equated to an elevation relative to sea level) on which human comfort, air-conditioning strategies and statistical climatic data can be overlaid.
The PMV/PPD index predicts the thermal comfort of people in a given environment. It employs both the environmental and human factors that affect the thermal comfort, and has become the most widely used index in recent years (Mohamed, 2009, Mohamed, et al 2009). It has been adopted in the British, European and International standard

(HSE, 2006). According to ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) these indices combine the influence of air temperature, mean radiant temperature, air movement and humidity with clothing and activity levels into one value on the thermal sensation scale (Fig. 13) (ASHRAE, 2005). The PMV index may be defined as the mean value of the votes of a large group of persons, exposed to the same environment with identical clothing and activity (CIBSE, 1999).

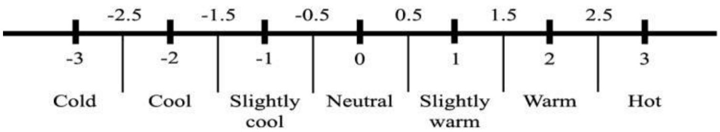

Figure 13
The thermal sensation seven-point scale, after ASHRAE (2005)

Predicted Percentage of Dissatisfied (PPD) predicts the percentage of occupants that will be dissatisfied with the thermal conditions. In the PPD-index, people who vote -3, -2, +2, +3 on the PMV scale, are regarded as thermally dissatisfied (INNOVA, 2004).

Results and discussion

The air temperature degrees of the two case studies were monitored for the whole summer season on 15 minutes' intervals. The temperature degrees ranged from 24℃ to 46℃. The average temperature for case study-1 (Al-Souhimi house) was 28.46℃ while it was 29.56℃ for case study-2 (Gamal El-Din house). On comparing the air temperature degrees of the two courtyards by applying Mann-Whitney U test on the air temperature data for the summer season (21st June to 21st September), the results revealed a significant difference ($P<0.05$)between the two case studies, despite the two sets of data trends being consistent.
In the majority of analyses, an alpha of 0.05 is used as the cut-off for significance. If the p-value is less than 0.05, this confirms the hypothesis that there is a significant difference between the means. If the p-value is larger than 0.05, this proves the Null-Hypothesis of no significant difference exists Hague and Harris (1993). Table 1 presents the statistical analysis output from the SPSS software.

Comparison Item	Al-Souhimi	Gamal El-Din
Mean temperature	29.09	30.57
T- Test	P=0.03	
The difference between the two sets of air temperature at the two courtyards (S=Significant)	S	

Table 1
Statistics comparison between the hourly air temperature degrees of the two courtyards.

Figure 14 shows the air temperature for the two cases on a selected day (21st June). The graph clearly presents the significant difference between the thermal performances of the two courtyards.

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The temperature degrees for case study-1 (Al-Souhimi house) ranged from 25 ℃ to 35 ℃ while it ranged from 27.5 ℃ to 41 ℃ for the other case study. It is obvious that the highest difference between the two case studies is occurred during the noon time. To understand this behaviour, it was important to measure the radiant temperature on the surfaces of the courtyards and the air velocity inside the courtyards.

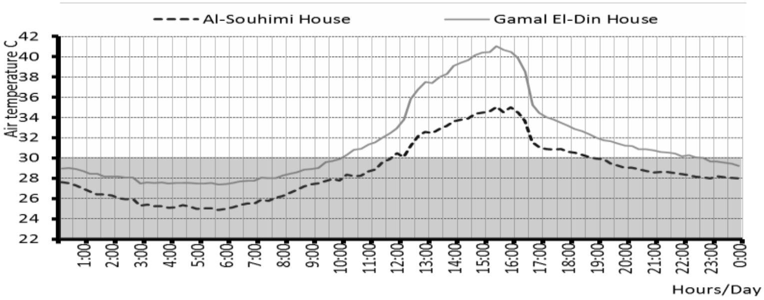

Figure 14 *Air temperature of the two courtyards on 21st June for the whole day*

Table 2 shows the SRT (Surface Radiant Temperature) and the RH (Relative Humidity) inside the two courtyards of the case studies at 12:30 pm. The average Surface Radiant Temperature SRT at Al-Souhimi courtyard is 29.7 °C which is lower than the average SRT at Gamal El-Din courtyard by 1.35. The relative Humidity RH at Al-Souhimi courtyard was 41% while it was 37% at Gamal El-Din courtyard.

Table 2. *Surface RT and RH of the two courtyards at 12:30 pm*

Surface RT	Al-Souhimi House	Average RT	Gamal El-din House	Average RT
North	31.8	29.7	32.6	31.05
East	28.6		30.2	
South	29.7		31.0	
West	28.8		30.4	
Relative Humidity RH	41%		37%	

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Table 3. *Wind velocity at the two courtyards from 12:30 to 16:00 afternoon*

Wind speed	Al-Souhimi								Gamal El-din							
	12:30	13:00	13:30	14:00	14:30	15:00	15:30	16:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30	16:00
North	1.0	0.9	0.7	1.1	1.6	1.4	0.8	0.3	0.6	0.0	0.3	0.5	0.4	0.5	0.5	0.3
East	0.0	0.5	0.6	0.5	1.0	1.1	0.9	0.2	0.3	0.2	0.3	0.6	0.3	0.5	0.4	0.3
South	0.5	0.7	0.8	0.6	0.6	0.5	0.5	0.3	0.0	0.0	0.0	0.0	0.3	0.2	0.2	0.4
West	1.0	1.2	1.1	1.4	1.6	2.0	1.2	0.9	0.0	0.6	0.1	0.0	0.3	0.0	0.0	0.0
Centre	0.9	0.9	0.8	0.9	1.0	1.1	1.0	0.9	0.4	0.1	0.5	0.6	0.5	0.5	0.6	0.2

Figure 15 and 16 present the PMV and the PPD for occupants inside the two courtyards at 12:30 pm on 21st of June. The clothing level was assumed 0.6 clo (clo = 0.155 m^2 °C/W, where m = area, C = degrees Celsius, and W = watts) which refers to light clothes (trousers and shirt), while the occupant activity was assumed 1.5 met (metabolic rate), which refers to standing occupants with light activity with metabolic rates ranging from 1.2 met to 1.5 met. The metabolic rate characterizes the energy generated inside the body due to metabolic activity. The standard unit for metabolic rate is the met, where 1 met = 58.2 W/m² (18.4 BTU /h ft²).

Although both values of the two case studies show discomfort levels for the occupants because of the chosen time from the year and the day, it is clear that the thermal performance of the Al-Souhimi courtyard is better than the other case study.

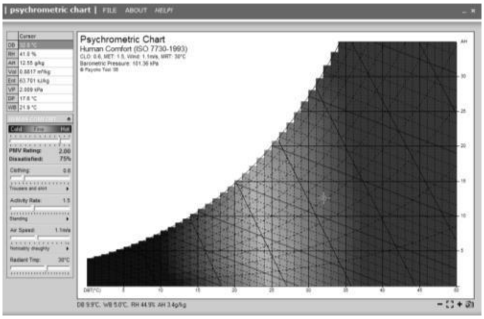

Figure 15. *PMV and PPD for occupants at Al-Souhimi courtyard at 12:30 on 21st of June using the Psychrometric Chart.*

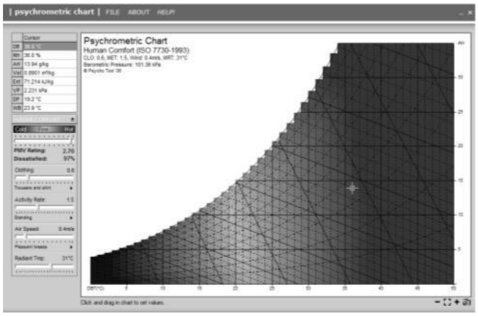

Figure 16. *PMV and PPD for occupants at Gamal El-Din courtyard at 12:30 on 21st of June using the Psychrometric Chart.*

While PMV was 2.7 on ASHRAE Scale for Gamal El-Din courtyard, which represented HOT thermal condition for occupants, it was 2 for Al-Souhimi courtyard which represented WARM thermal condition for its occupants. As for the PPD; it was 97% for Gamal El-Din courtyard which means that almost all occupants would be dissatisfied at the that time, while it was 75% for Al-Souhimi courtyard which means that not all occupants are dissatisfied, where 25% of the occupants are satisfied with the thermal condition.

Conclusions

An objective assessment for two scenarios of courtyards in old Cairo was carried out in this research. The two courtyards were almost architecturally similar to each other except the attached Takhtabush which exists in the first case study (Al-Souhimi house) and does not exist in the second case study (Gamal El-Din house). Air temperature, RH, Air velocity, and Surface RT were monitored and measured during the same times and intervals. PMV and PPD for occupants were evaluated based on the collected data. On analysing the measurements, it was obvious that the thermal performance of the first case study (courtyard attached to Takhtabush) was much better than the second case study (courtyard without Takhtabush). This has been shown clearly through the following results:

- P-Value was <0.05, revealed that there is a significant difference between the air temperature degrees inside the two courtyards during the summer season (21st of

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June to 21st of September);
- air temperature degrees inside case study-1 are much lower than case study-2 and particularly during the noon time because of the steady air flow caused by the Takhtabush;
- PMV and PPD were much better in case study-1 than case study-2 by about 25% which confirms the effectiveness of employing the concept of the Takhtabush in today's designs in the hot zones of the world.

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LA MAÎTRISE DU TAKHTABUSH EN TANT QUE PARADIGME ÉLÉMENT DE DESIGN TRADITIONNEL DANS LE CLIMAT DE LA ZONE CHAUDE

Résumé

Le Takhtabush "Un espace extérieur couvert au rez-de-chaussée" a été introduit à l'époque mamelouke au XIIe siècle dans la cour traditionnelle égyptienne (El-Shorbagy 2010). Il est situé entre la cour ombragée et la cour arrière, s'ouvrant complètement sur la cour et à travers une Mashrabia sur la cour arrière qui assure un flux constant d'air par convection (Fathy 1986). Plusieurs études ont étudié la performance thermique de la cour et peu d'entre elles ont souligné l'importance du Takhtabush. Personne n'a étudié jusqu'où le Takhtabush peut affecter la performance thermique de la cour. L'auteur de cet article doute de l'efficacité de la cour sans le Takhtabush dans une zone aride et chaude où la vitesse de l'air pendant l'été est très faible la plupart du temps. La recherche actuelle conduit une étude comparative entre deux scénarios de la cour (avec et sans le Takhtabush) à travers une enquête technique. L'enquête est réalisée à l'aide de techniques de surveillance avec observation et mesures sur le terrain. Les données sont analysées à l'aide d'un logiciel d'analyse statistique. Les résultats ont montré quantitativement et qualitativement l'importance de l'utilisation du Takhtabush pour améliorer les performances thermiques de la cour.

Mots-clés: *cour, performance thermique, Takhtabush*

LA PADRONANZA DEL TAKHTABUSH COME ELEMENTO DI DESIGN TRADIZIONALE DI PARADIGMA NEL CLIMA DELLA ZONA CALDA

Riassunto

Il Takhtabush "Un salotto all'aperto coperto al piano terra" è stato introdotto nel periodo mamelucco nel XII secolo al tradizionale cortile in Egitto (El-Shorbagy 2010). Si trova tra il cortile ombreggiato e il cortile posteriore, aprendosi attraverso una Mashrabia sul cortile posteriore che assicura un flusso costante di aria per convezione (Fathy 1986). Diversi studi hanno esaminato le prestazioni termiche del cortile e alcuni di essi hanno evidenziato l'importanza del Takhtabush. Nessuno ha studiato fino a che punto il Takhtabush può influenzare le prestazioni termiche del cortile. L'autore di questo articolo dubita dell'efficienza del cortile senza il Takhtabush nella zona arida e calda, dove la velocità dell'aria durante l'estate è molto bassa per la maggior parte del tempo. La ricerca attuale conduce uno studio comparativo tra due scenari del cortile (con e senza il Takhtabush) attraverso un'indagine tecnica. L'indagine viene condotta utilizzando tecniche di monitoraggio con osservazioni e misurazioni sul campo. I dati vengono analizzati utilizzando software di analisi statistica. I risultati hanno mostrato quantitativamente e qualitativamente l'importanza di impiegare il Takhtabush per migliorare le prestazioni termiche del cortile.

Parole chiave: *cortile, efficienza termica, Takhtabush*

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