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Performance of the Wind Catcher in Hot Dry Regions, Khartoum - Sudan

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Abstract

The People of Sudan are faced with a growing problem with indoor climate conditions in the houses because of high outdoor temperature in the house during dry seasons. Daily temperature can reach up to 47 degrees in the dry season of summer. The Windcatcher is a ventilation technique for natural cooling. Wind catchers have been used for years in several countries with hot-dry climates in the Middle East. Even so, it is never been used in Sudan. This paper aimed to examine the effect of the different criteria that effecting on the designs of the wind catchers and determines how they affect the internal air temperature in Khartoum/Sudan. The addition of water spray increases the relative humidity and decreases the air temperature inside the houses. This old traditional technique could be merging with new building designs in Khartoum-Sudan to raise the green concept in the buildings located in the hot dry areas.

1. INTRODUCTION

The Climate has a great effect on the condition of the buildings with estimation to its energy consumption and air conditioning. The shortage of energy and water resources in hot and dry areas obliged people to build their houses with some strategies based on minimum energy consumption. The energy consumed in the buildings for the heating, cooling systems and ventilation account for more than 60% of the total energy consumption of our buildings. Therefore, the attention of the designer and architect focuses on the natural ventilation systems to reduce energy consumption and has started a new field study known as low energy architecture[1]. The wind tower or the windcatcher sometimes called (Bâdgir, Persian), is a traditional design that has been used for centuries to supply buildings with natural ventilation in the hot and dry climate. The windcatcher structure is a part of the buildings in Iran and some countries of the middle east [2]. Traditional buildings always express the architectural environment in their buildings that take into account the different climatic conditions. Traditional building shapes in hot dry areas were constructed and designed from the resources available in nature, which helped to create buildings with natural ventilation and moderate humidity. Throughout history, many architectural techniques have been used to cool interior spaces of buildings, such as the use of local materials, the inner courtyard, and the wind catcher. The wind catcher is one of the most important architectural techniques used to provide thermal comfort. The idea of the windcatcher appeared in Persian architecture, but there is evidence of its use in the Pharaonic age also[3]. The painting depicted on the tomb of Nabe-Amon (fig.1), and dating back to the Nineteenth Dynasty (1300 BC), shows the Pharaonic house, had a wind catcher with two holes, one facing the prevailing direction of the wind and the other for expelling the hot air from the house, other examples can be found in the Eighteenth Dynasty houses of Tal Al-Amarna [4].

The impact of traditional Persian architecture can also be seen in the architecture of India, Pakistan, and, Middle East (fig 2, 3).

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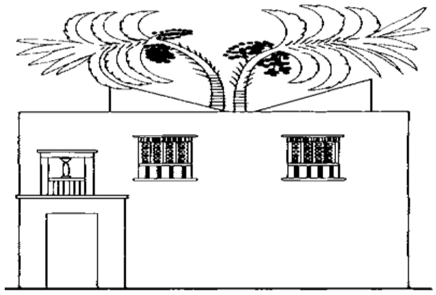


Figure 1. *Malqaf of the Pharaonic, house of Neb-Amun, (c.1300 B.C.), [4]*

Figure 2. *windcatcher YAZD [5]*

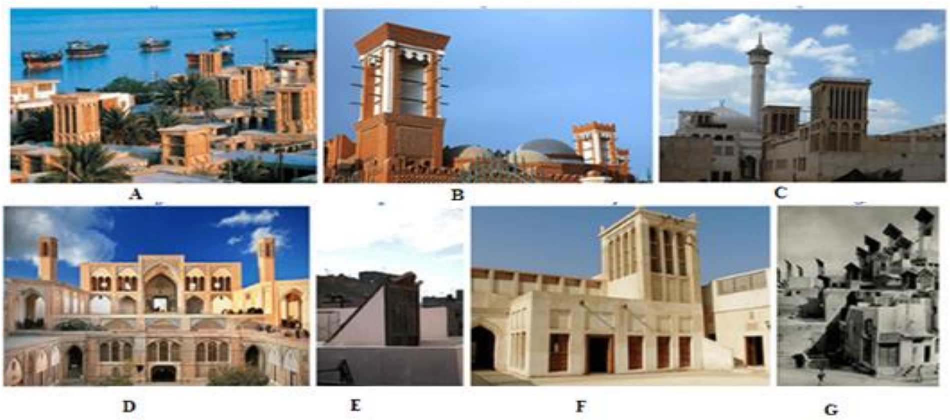


Figure 3. *Different traditional wind catchers in the Middle East: (A) Badger in the hot and humid climate of Iran; (B) decorative Barjeel in Qatar; (C) Barjeel in the Bastakiya Quarter of Dubai; (D) Badger in the hot and dry climate of Iran; (E) Malqaf in Egypt; (F) Barjeel in Bahrain; (G) Mungh in Pakistan [6].*

2. THE FUNCTION OF THE WINDCATCHER

The primary function of the windcatcher is to provide buildings with natural ventilation by implementing both natural wind-driven ventilation and the chimney effect. Therefore, there are two basic functions of the windcatcher, the first is to bring fresh air into the building and the second is to extract hot and polluted air outside the building. Therefore, it works as a ventilation and suction system at the same time. There is a movement from positive pressure to negative pressure, which causes natural ventilation. This process creates a positive pressure zone at the windcatcher due to the density of the air in the direction of the wind, in the opposite direction of the windcatcher there will be a negative pressure zone (fig. 4) [5].

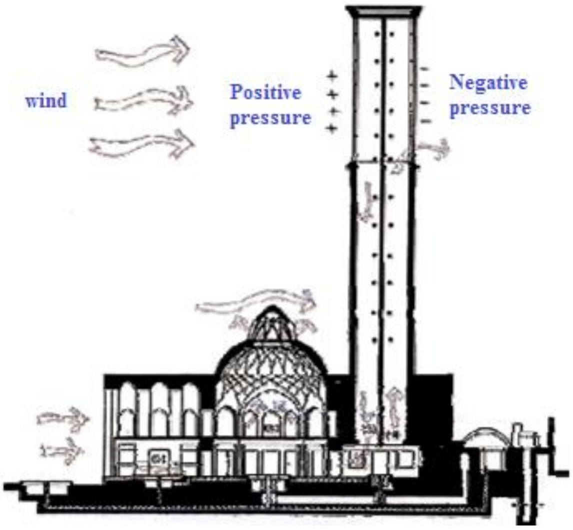


Figure 4. *Wind effect on the windcatcher*

3. THE WIND CATCHER TYPES IN TERMS OF EXTERNAL SHAPE

Generally, there are two main groups for windcatcher; unidirectional and multidirectional windcatcher. The unidirectional also called one-sided windcatcher and the multidirectional are classified under three types: two, three, and four-sided windcatcher, which usually have a square plan, hexahedral, and octahedral windcatcher.

3.1. One-Sided Wind Catcher

This type of windcatcher was used in many countries of the Middle East where the permanent winds are in one direction, but if the winds have different directions; this type of windcatcher will not work properly, whereas this types of windcatcher usually have openings in the north or north-west direction, with a sloping roof and one or two vents (fig.5). The wind enters the building from the opening in the windcatcher and passes via the living space, and going out from the exhaust vents, windows, and doors [6].

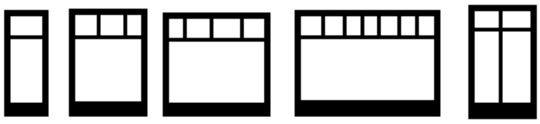


Figure 5. *a typical plan of a one-directional windcatcher*

3.2. The Two Directional Windcatchers

This type of windcatcher has been divided into two parts by using a partition made of bricks. They are oftentimes called by direction, such as the south-north windcatcher. Roaf's survey indicates that 17% of these types are made in traditional houses (fig.6A, 6B),[6].

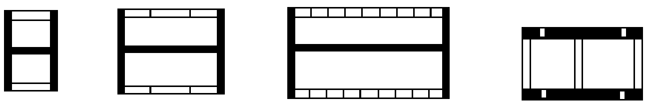


Figure 6. *(A) a typical plan of two-directional wind Catchers*

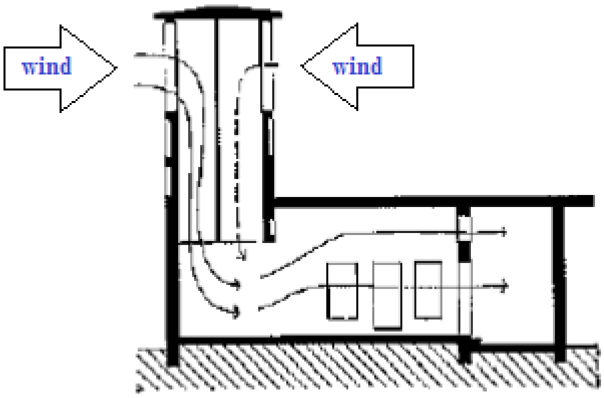


Figure 6. *(B) two-directional wind catcher section*

3.3. The Four Directional Windcatchers

Studies generally indicate that all of the windcatchers in the hot humid region are four directional types, and more than half of these types of windcatchers in the hot and dry region that has been used in Iran, (fig7(A),(B)). The most common windcatchers have four main vertical shafts split by partition[7].

Figure 7. *(A). Four directional Wind Catcher in Iran*

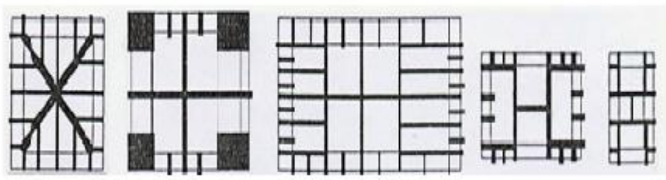


Figure 7. *(B) a typical plan of four directional windcatcher*

3.4. The Eight Directional Windcatchers

Only twenty multi-directional examples Out of seven hundred and thirteen windcatchers have been reported. The greatest badger on top of Khan's Pavilion at Bagh-e-Dowlatabad (fig. 9), has an octagonal plan. While they are the most popular on-water cistern (fig 8) [8].

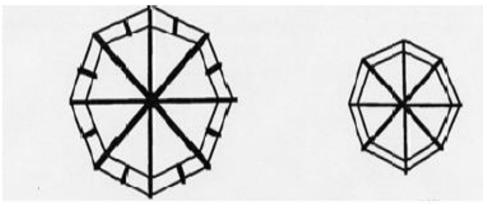


Figure 8. *a typical plan of eight directional windcatchers*

Figure 9. *baghe-dolatabad win catcher*

4. GENERAL DIMENSIONS OF WIND CATCHERS IN HOT DRY REGIONS

The square, rectangular and octagonal forms of the geometrical plan of the windcatchers have been reported. In the four-directional windcatchers in Yazd, the square shape is the type that is generally used. Windcatchers that have rectangular shapes consist of one, and two directions and those with an octagonal plan have eight directions. There are different size and dimension for the windcatcher started from 0.40m x 0.80m to 5x5 m. The ratio between widths and length in the plan is 1:2 of which is reported. The partitions generally start between 1.5-2.5 m above the ground floor level, and there is a wide variety of forms used in windcatcher partitions, but the most popular was in the shape of H, diagonal, and I. As wide as the external wall, secondary partitions remain about 20-25 cm. More than 60% of the windcatchers are less than 3meters above the roof level, while 15% more than 5 meters have been reported [6].

5. METHODOLOGY

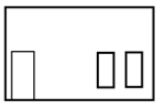
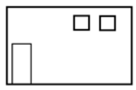
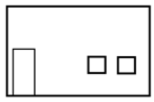
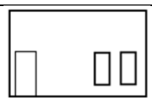
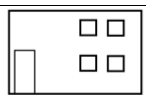
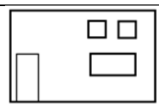
Roaf [12] has conducted an analytical study of wind catchers morphology and statistical analysis on its different criteria, such as the size of the openings, the number of vents, and the cross-section composition, in addition to the different heights of the windcatcher. Studies indicated that 53% of the windcatchers have a height between eight and eleven meters, and 70% of windcatchers have a barrier or partitions with a height between two and four meters [9]. Based on these studied and recommended criteria, the scope to work on was determined to test the influence of these criteria on thermal comfort when designing a windcatcher in Khartoum-Sudan. It is possible to obtain different kinds of results to calculate parameters whenever a measurement is needed by a physical or a virtual model. Via the building simulation method, the impact of building orientation, sunshine, wind behavior, etc. can be measured[10]. The task of defining variables such as DBT (Dry Bulb Temperature), WBT (Wet Bulb Temperature), humidity levels inside the spaces, and so on, is simplified by different simulation tools, such as 'Design Builders' and 'Ecotect Analysis Software'. During the analysis process, the parameters, the equations for various probabilities can be adjusted, thereby conclude the best choice for execution into the particular construction configuration of the respective location[11]. In this study, 47 simulations have been performed using the design-builder program. In each simulation, the effect of the different criteria affecting the designs of the windcatchers have been tested, and determine how they affect the internal air temperature of the living room, taking into consideration that area is the most commonly used during the day. The criteria that affect the design of the windcatcher are:

1. The dimension of the windcatcher, 2. The height of the windcatcher, 3. The opening direction in the windcatcher, 4. The Number of the vent in the windcatcher, 5.The partition in the windcatcher, 6.The dimensions of the room in the target area, 7. The Living room Windows Location, 8. The Living room Windows Design. To identify the criteria that may reduce the air temperature inside the living room in Khartoum climate, three variables were been tested for each one of the eight criteria that affecting on the design of the windcatcher, this has been performed by fixing the seven criteria and testing three variables in the eighth criteria. Changing between the criteria each time can determine which of these eight criteria is the most influential when designing a windcatcher and leads to reduce the air temperature inside the living room. Three different times during the day were selected to take temperature readings, 4 am: where

external temperatures are lowest, 2 pm: where external temperatures are highest, 10 pm: where outside temperatures start decreasing significantly. The best values and results from these three criteria were selected and combined in a new design and simulated again. In the last simulation, the Water spray is added for testing the effect of evaporation cooling on the windcatcher.

5.1. The Variables of the Simulated Elements in the Windcatcher

Table 5.1. *Variables of the simulated criteria in the Windcatcher*

criteria	Variables of Simulated criteria		
The dimension of the windcatcher (DW)	1.5m*1.5m	2m*2m	3m*3m
The height of the windcatcher (H)	6m	8m	10m
The opening direction in the windcatcher (OD)	One-way windcatcher,	two-way windcatcher	four-way windcatcher
The Number of the vent in the windcatcher (NV)	1	3	5
The partition in the windcatcher (P)	 Type (a)	 Type (b)	 Type (c)
The dimension of the rooms in the target area (RD)	4m*6m	5m*6m	6m*6m
The Living room Windows location (WL)	 Type (a)	 Type (b)	 Type (c)
The Living room Windows Design (WD)	 Type (a)	 Type (b)	 Type (c)

5.2. Experimental Study:

To discover the most suitable windcatcher in Khartoum, which is located within the hot dry region, a windcatcher has been added to the traditional building with the following characters:

The traditional building has a dimension of 13*13.5 meters and with a height of 3 meters, consist of a living room, two bedrooms, men reception, a kitchen, and a bathroom, (fig 10-11).

<u>Material Usage of the Traditional Building and Windcatcher simulation:</u>

<u>For the wall:</u> 300mm of mud bricks which have a thermal conductivity of about 0.7500(W/m.k).

<u>For the roof:</u> 150mm of concert slap +.0100 bitumen emulsion for insulation

<u>For the Ground floor:</u> 150 mm concrete slap (Dens) + emulsion for insulation + ceramic tiles

<u>For the Windows:</u> Double glazing 1.5m*.5m reflective, with shading over each window, and wood window frame.

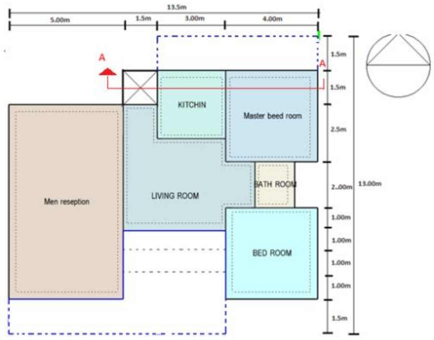


Figure 10. plan for the simulated building

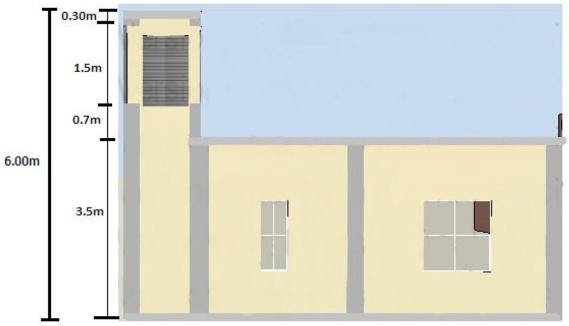


Figure 11. section of the simulated building

5.3. Simulation Table

To identify the best model with the best criteria variables simulation table has been done.

Table 5.2. *The simulation table shows the variables in the criteria that have been examined with the different models.*

BSN	DW	H	OD	NV	P	RD	WL	WD
BS1	DW(1.5m*1.5m)	**H(6m)**	OD(S)	NV(1)	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS2	DW(1.5m*1.5m)	**H(8m)**	OD(S)	NV(1)	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS3	DW(1.5m*1.5m)	**H(10m)**	OD(S)	NV(1)	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS4	DW(1.5m*1.5m)	H(6m)	**OD(S-N)**	NV(1)	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS5	DW(1.5m*1.5m)	H(8m)	**OD(S-N-E-W)**	NV(1)	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS6	DW(1.5m*1.5m)	H(6m)	OD(S)	**NV(3)**	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS7	DW(1.5m*1.5m)	H(6m)	OD(S)	**NV(5)**	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS8	DW(1.5m*1.5m)	H(6m)	OD(S)	NV(1)	**P(B)**	RD(4m*6m)	WL(a)	WD(a)
BS9	DW(1.5m*1.5m)	H(6m)	OD(S)	NV(1)	**P(C)**	RD(4m*6m)	WL(a)	WD(a)
BS10	DW(1.5m*1.5m)	H(6m)	OD(S)	NV(1)	P(A)	**RD(5m*6m)**	WL(a)	WD(a)
BS11	DW(1.5m*1.5m)	H(6m)	OD(S)	NV(1)	P(A)	**RD(6m*6m)**	WL(a)	WD(a)
BS12	DW(1.5m*1.5m)	H(6m)	OD(S)	NV(1)	P(A)	RD(4m*6m)	**WL(b)**	WD(a)
BS13	DW(1.5m*1.5m)	H(6m)	OD(S)	NV(1)	P(A)	RD(4m*6m)	**WL(c)**	WD(a)
BS14	DW(1.5m*1.5m)	H(6m)	OD(S)	NV(1)	P(A)	RD(4m*6m)	WL(a)	**WD(b)**
BS15	DW(1.5m*1.5m)	H(6m)	OD(S)	NV(1)	P(A)	RD(4m*6m)	WL(a)	**WD(c)**
BS16	DW(2m*2m)	**H(6m)**	OD(S)	NV(1)	P(A)	RD(4m*6m)	WL(a)	WD(a)

BS17	DW(2m*2m)	**H(8m)**	OD(S)	NV(1)	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS18	DW(2m*2m)	**H(10m)**	OD(S)	NV(1)	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS19	DW(2m*2m)	H(6m)	**OD(S-N)**	NV(1)	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS20	DW(2m*2m)	H(6m)	**OD(S-N-E-W)**	NV(1)	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS21	DW(2m*2m)	H(6m)	OD(S)	**NV(3)**	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS22	DW(2m*2m)	H(6m)	OD(S)	**NV(5)**	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS23	DW(2m*2m)	H(6m)	OD(S)	NV(1)	**P(B)**	RD(4m*6m)	WL(a)	WD(a)
BS24	DW(2m*2m)	H(6m)	OD(S)	NV(1)	**P(C)**	RD(4m*6m)	WL(a)	WD(a)
BS25	DW(2m*2m)	H(6m)	OD(S)	NV(1)	P(A)	**RD(5m*6m)**	WL(a)	WD(a)
BS26	DW(2m*2m)	H(6m)	OD(S)	NV(1)	P(A)	**RD(6m*6m)**	WL(a)	WD(a)
BS27	DW(2m*2m)	H(6m)	OD(S)	NV(1)	P(A)	RD(4m*6m)	**WL(b)**	WD(a)
BS28	DW(2m*2m)	H(6m)	OD(S)	NV(1)	P(A)	RD(4m*6m)	**WL(c)**	WD(a)
BS29	DW(2m*2m)	H(6m)	OD(S)	NV(1)	P(A)	RD(4m*6m)	WL(a)	**WD(b)**
BS30	DW(2m*2m)	H(6m)	OD(S)	NV(1)	P(A)	RD(4m*6m)	WL(a)	**WD(c)**
BSS31	DW(3m*3m)	**H(6m)**	OD(S)	NV(1)	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS32	DW(3m*3m)	**H(8m)**	OD(S)	NV(1)	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS33	DW(3m*3m)	**H(10m)**	OD(S)	NV(1)	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS34	DW(3m*3m)	H(6m)	**OD(S-N)**	NV(1)	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS35	DW(3m*3m)	H(6m)	**OD(S-N-E-W)**	NV(1)	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS36	DW(3m*3m)	H(6m)	OD(S)	**NV(3)**	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS37	DW(3m*3m)	H(6m)	OD(S)	**NV(5)**	P(A)	RD(4m*6m)	WL(a)	WD(a)
BS38	DW(3m*3m)	H(6m)	OD(S)	NV(1)	**P(B)**	RD(4m*6m)	WL(a)	WD(a)

BS39	DW(3m*3m)	H(6m)	OD(S)	NV(1)	**P(C)**	RD(4m*6m)	WL(a)	WD(a)
BS40	DW(3m*3m)	H(6m)	OD(S)	NV(1)	P(A)	**RD(5m*6m)**	WL(a)	WD(a)
BS41	DW(3m*3m)	H(6m)	OD(S)	NV(1)	P(A)	**RD(6m*6m)**	WL(a)	WD(a)
BS42	DW(2m*2m)	H(6m)	OD(S)	NV(1)	P(A)	RD(4m*6m)	**WL(b)**	WD(a)
BS43	DW(2m*2m)	H(6m)	OD(S)	NV(1)	P(A)	RD(4m*6m)	**WL(c)**	WD(a)
BS44	DW(2m*2m)	H(6m)	OD(S)	NV(1)	P(A)	RD(4m*6m)	WL(a)	**WD(b)**
BS45	DW(2m*2m)	H(6m)	OD(S)	NV(1)	P(A)	RD(4m*6m)	WL(a)	**WD(c)**
SBS(1)	DW(1.5m*1.5m)	H(6m)	OD(S-N-E-W)	NV(1)	P(A)	RD(6m*6m)	WL(b)	WD(b)
SBS(2) +water spray	DW(1.5m*1.5m)	H(6m)	OD(S-N-E-W	NV(1)	P(A)	RD(6m*6m)	WL(b)	WD(b)

6. RESULTS AND DISCUSSIONS

The results obtained in these tests show that after testing the eight criteria by using 47 simulations three criteria have been observed as the most influential on the designs of the windcatchers, the changes in these criteria could lead to reducing the internal temperatures of the living room. These criteria are:

6.1. Height of the Windcatcher

The Altitudes that have been tested are 6m, 8m, and 10m. When the building height is 3m, and the height of the windcatcher was changed, the air temperature in the living room at 2 pm was being increased with the increase of the height. The air temperature was increased from 33.14 celsius in (BS1) to 34.62 celsius in (BS3), Which means the air temperature of the living room has been increased 1.5 Celsius at a height of 10 meters (fig12).

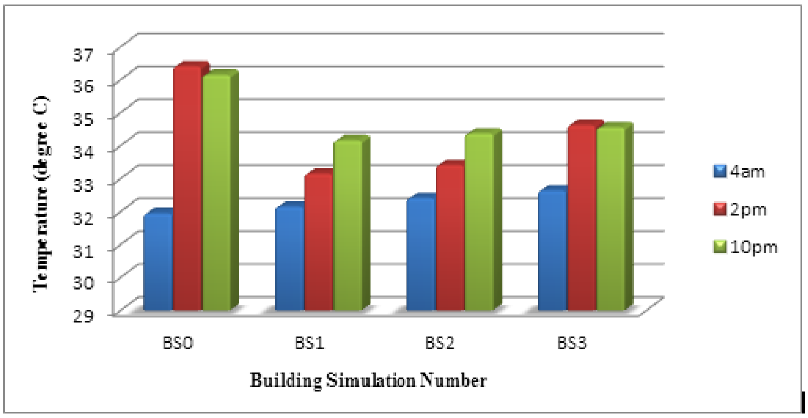


Figure 12. *changing in the height of the wind*

6.2. The Opening Direction in the Windcatcher

The openings directions that were been tested are, north, south, and north-south-east-west. After the direction of the windcatcher openings were been changed from only north or south to north –south –east –west (four-way directions), the air temperature has been decreased from 33.12 celsius (BS4) to 33 celsius (BS5), hence the best thermal performance has been achieved when using the four-way windcatcher in the living room(fig 13).

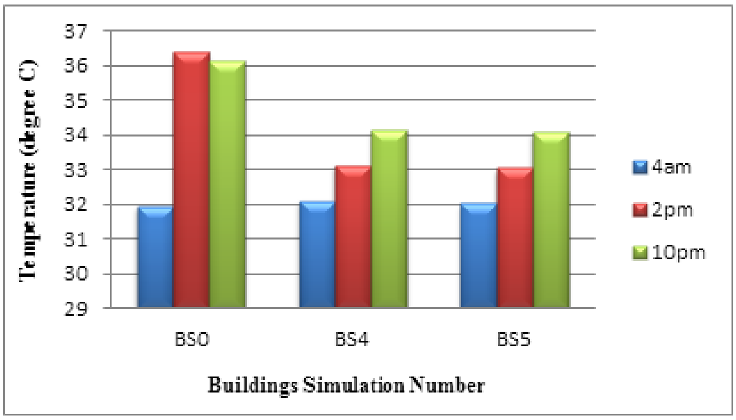


Figure 13. *changing in the opening direction of the windcatcher*

6.3. The Living Room Dimensions

The living room dimensions that were been tested are: (4m*6m), (5m*6m), (6m*6m). Changing the room dimensions from larger to smaller has been lead to better thermal performance during the day and night periods. The air temperature has been decreased about 0.5 celsius at night, and 0.2 celsius during the day in (BS11). Hence the dimension of (6m*6m) had a better thermal performance than the room with the dimension of (5m*6m), and the dimension of (5m*6m) is better than (4m*6m)), (fig 14).

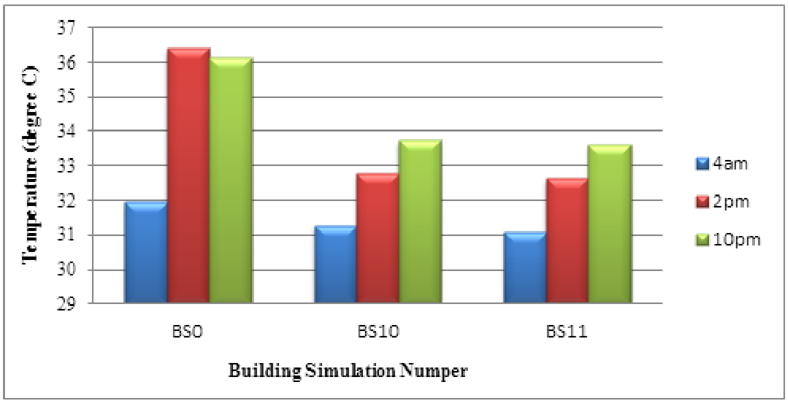


Figure 14. *changing in the living room dimensions of the windcatcher*

6.4. The Water Spray

The best values and results from these three elements have been selected and combined in a new design and simulated again. In the last simulation, water spray has been added for testing the effect of evaporation cooling on the windcatcher (fig 15). The results show that the use of the water spray has lead to a decrease in the temperature of the living room by 32.25% which is 4.19°C (fig 16).

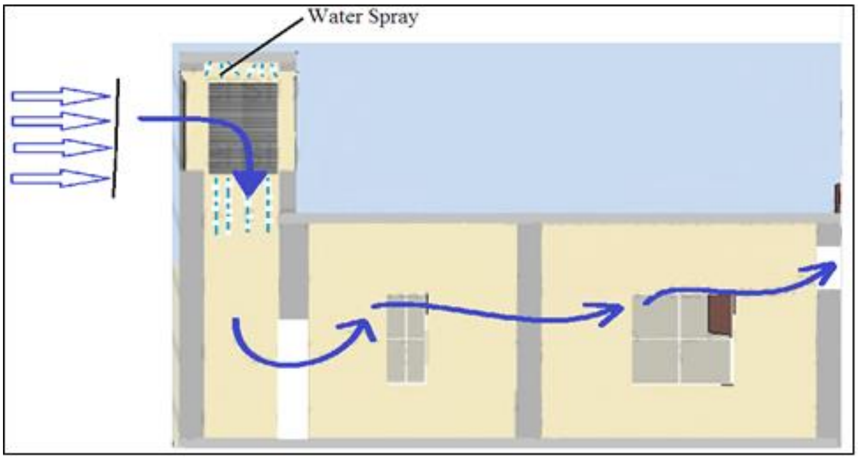


Figure 15. *water spray in the windcatcher*

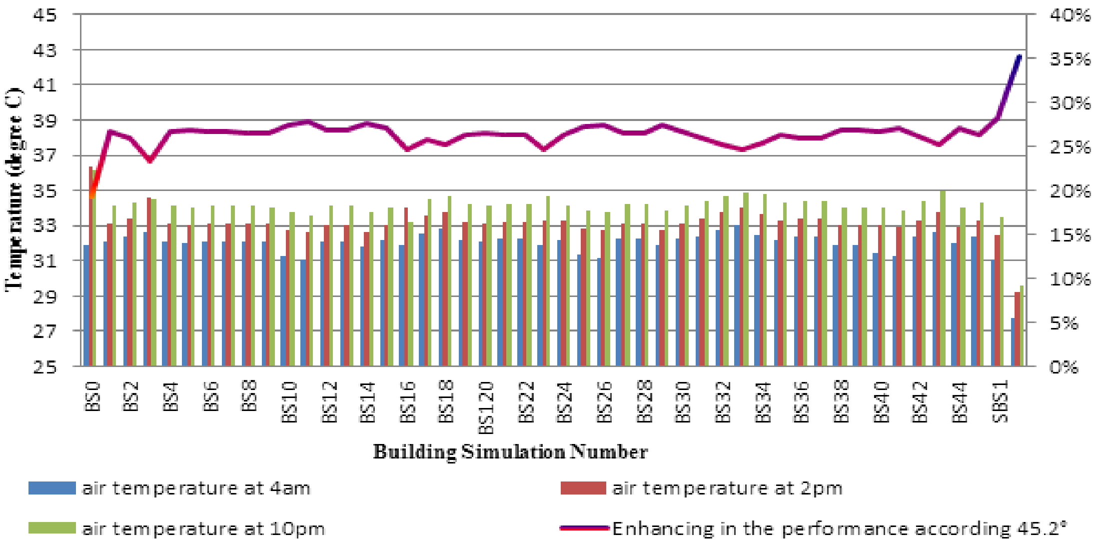


Figure 16. *the deference's in thermal performance during the day*

6.5. Comparing Between the Designs (with and without windcatcher)

Building without Windcatcher

In figure (17) It can observe that, the effect of the hot wind coming from outside in the living room and the movement of the hot air, where it starts to spread out across the living room gradually from the windows and getting out after gaining heat from the living room.

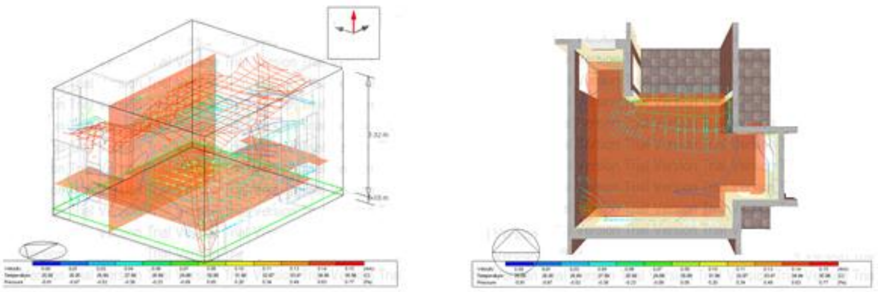


Figure 17. CFD analysis for the building without windcatcher

Building with Windcatcher

In figure (18) it can be seen the effect of the windcatcher on the living room and the movement of cold air that comes from the outside and gets colder when mixed with water coming from the water spray inside the windcatcher. it starts to spread out across the living room gradually from the air inlet in the windcatcher until reaches the windows and getting out after gaining heat from the living room.

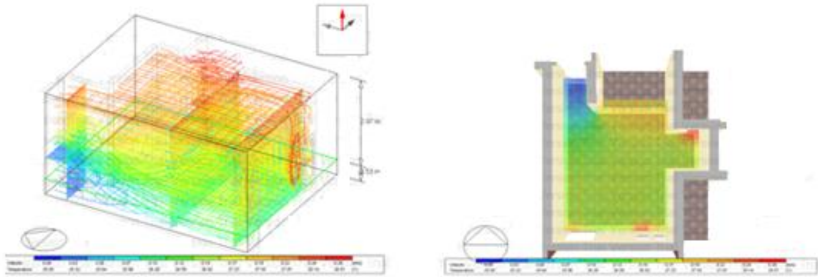


Figure 18.CFD analysis for the building with windcatcher

Ventilation

By looking at the heat balance charts between the buildings with windcatcher and the building without windcatcher, It can be observed that the size of the internal natural ventilation in the living room increases at noontime and decreases in the building without windcatcher. In the total fresh air charts, It can observe the air movement inside the living room in the building with a windcatcher is better than the air movement inside the living room in the building without a windcatcher, figure(19).

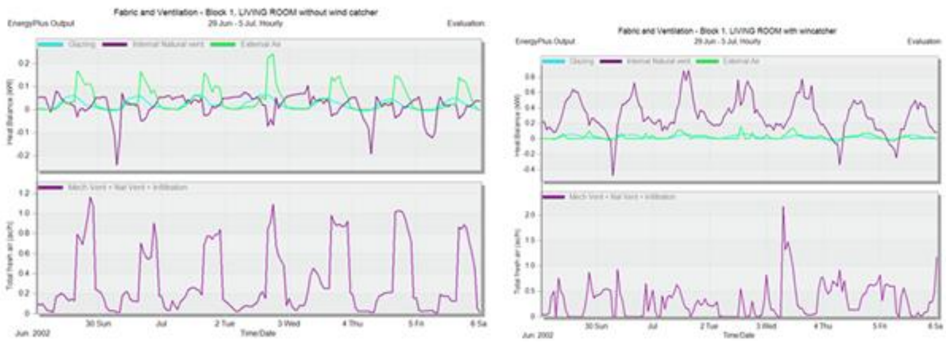


Figure 19. *chart of Ventilation*

7. CONCLUSIONS

The influences of design criteria; dimension of the windcatcher, opening direction in the windcatcher, the number of vent in the windcatcher, partition in the windcatcher, the dimension of the living room, living room Windows location, living room Windows Design, on the windcatcher performance have been investigated. The results obtained that after testing the eight criteria by using 47 simulations three criteria have been observed as the most influential on the designs of the windcatchers like as the height of the windcatcher, the opening direction in the windcatcher, the living room dimensions in Khartoum at 2 pm. Changing the height of the windcatcher from 10m, to 6m when building height is 3m increased the performance of the air temperature by 27.03% in the living room. Changing the opening direction in the windcatcher to a four-way direction increased the performance of the air temperature by 27.5%, and changing the living room dimensions in the windcatcher from (4m*6m) to (6m*6m) increased the performance of the air temperature by 29.93%. The combination of these different variables in a windcatcher increased the performance of the air temperature by 30%. The adding of the water spray to the windcatcher increased the relative humidity and decreased the air temperature of the living room, and the thermal performance of the building has been increased by 35.37% which means the air temperatures decreased by about 15.99°C according to outside air temperature, hence the outside air temperature is 45.2°C, the inside air temperature was 29.21°C. Therefore, the windcatcher with the suggested criteria and water spray provides more pleasant conditions and thermal comfort in the hot dry climate of Khartoum

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