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THE ROLE OF THE DOUBLE-SKIN FACADES SYSTEM TO ACHIEVE THERMAL COMFORT IN HOT AREAS

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ABSTRACT

The treatment with double-skin facades has recently been observed, and there is a conflict of opinion when choosing the depth of the air cavity between the two layers of skin of the facades, which ranges from 0.20 m: 2.00 m, resulting in interfaces that do not meet the needs of the users (thermal comfort, natural light, and air flow). The paper aims to determine the best suitable air cavity depth for buildings in hot areas, by following the experimental inductive method and analytical descriptive method. Process simulation on a scaled model in the laboratory is performed to determine the appropriate depth of the cavity that reduces air temperature of the internal spaces, and the proper air speed that achieves thermal comfort. It is concluded that there is an inverse relationship between the air speed and the depth of the air cavity.

KEYWORDS: Double-skin facade, Airflow, Hot areas, Thermal comfort.

1. INTRODUCTION

Thermal comfort is the main source of concern in Egypt's arid climate especially in summer [1, 2]. The poor design of buildings leads to pollution [3], which results in an unsuitable environment that is not suitable for the users [4]. The World Meteorological Organization, WMO stated that the four years 2015-2018 were the warmest years given the standard levels of greenhouse gas concentrations in the atmosphere [5]. Figure 1 shows the effect of the glass house and the warming of the Earth's surface [6], and is may be concluded from Fig. 2 that carbon dioxide contributes 9 to 26% of the global warming [7]. Other harmful gases contributing to global warming include CH_4, N_2O, PFCs, HFCs, SF_6 and NF_3 [8]. The greenhouse effect of the presence of these gases in the Earth's atmosphere is caused by four factors

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attributable to human behavior, the most important of which is the use of fossil fuels that represents 50% of these effects [9]. We can contribute to the mitigation of human impacts by rationalizing the consumption of energy needed to achieve comfort and take advantage of natural light in buildings, using processors with double skin-facade [10]. The success of the double skin-facade system strategies depends on the integration of the components of the system.

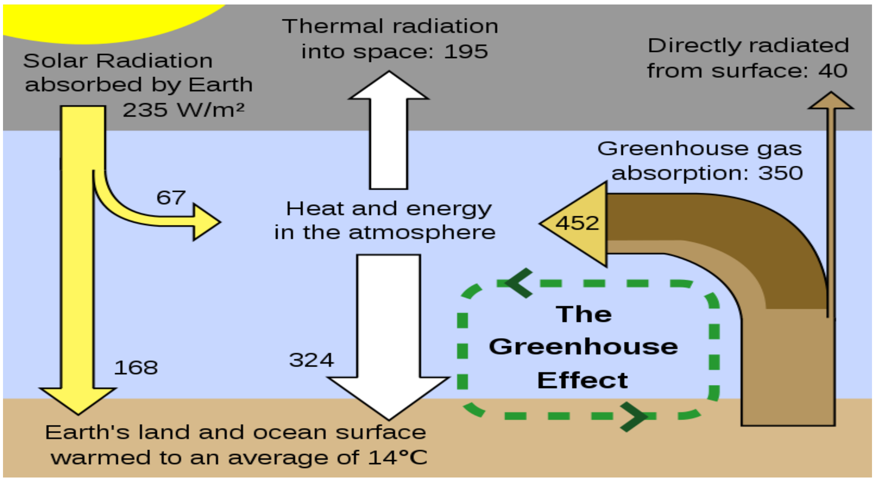

Fig. 1. Effect of the glass house, the warming of the Earth's surface [5].

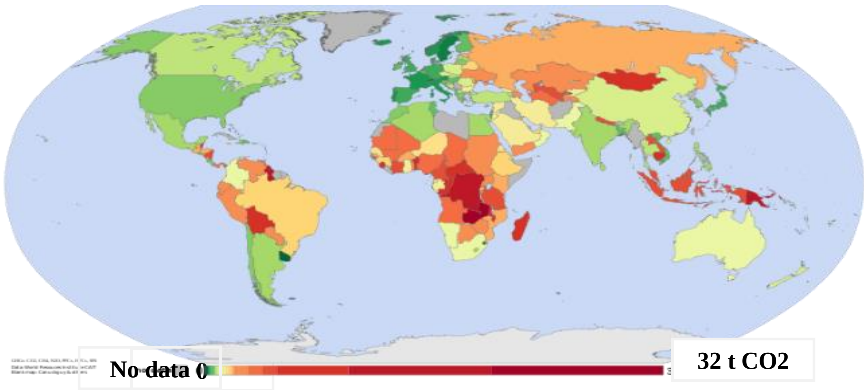

Fig. 2. Greenhouse gas intensity of national economies in 2000 [6].

2. SYSTEM COMPONENTS

The double-skin facades contribute to the realization of natural light, reduced heat transfer, natural ventilation, vacuum air purification and acoustic insulation by integrating system elements, skins, openings, shading devices, air cavity, and air flow [10]. The components of the system are detailed in Fig. 3.

3. LITERATURE REVIEW

Many studies and previous experiments aimed to discover the depth of the appropriate cavity in the hot arid areas. These will be summarized below.

3.1 Elisabeth Gratia, Andre De Herde

Greenhouse effect in double-skin façade was proposed. Experiments were conducted using a computer simulation program, in terms of coating materials, depth of cavity, and their effect on temperature in cavity and internal spaces. It was concluded that the air temperature of the internal spaces is reduced by using reflector glass that will reduce air temperature of the internal spaces and increases as the depth of the cavity decreases [11], and with movement of air as shown in Figs. 4-5. The experiments were on air cavities without calculating any effect of air movement.

3.2 André Albertoa, Nuno Ramosa, Ricardo

A parametric study of double-skin facades performance in mild climate countries was conducted. The effect of heat absorption inside the cavity with double-faced, in terms of cavity depth, in temperate zones, was studied and it was concluded that the best route to air movement is as described in Fig. 4. The airflow from the outside to the outside with multi-story double facades, causes a 30% reduction in the energy required for adaptation. By increasing the cavity depth, it is possible to reach the highest efficiency of cooling air within the cavity, where the deeper cavity directly increases airflow. The transition from a 0.25 to 1.0 m cavity depth reduces power consumption by about 9.5% as in Fig. 5 [12]. These experiments were performed using a computer simulation program.

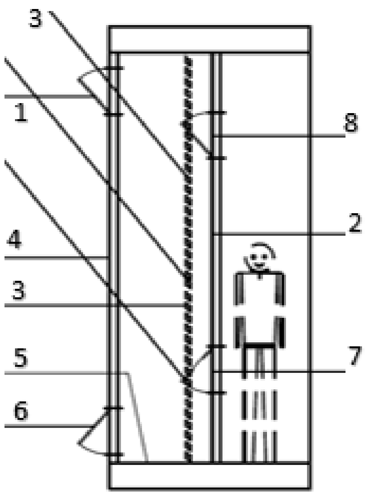

Fig. 3. Components of double skin- facades.

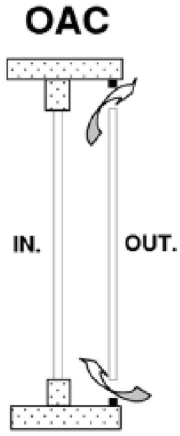

Fig. 4. One of the types of air movement [11].

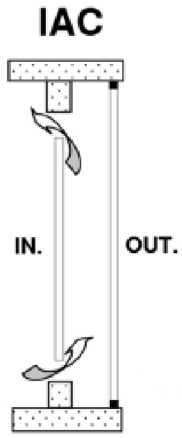

Fig. 5. Another type of air movement [11].

1-Hot air outlet, 2- Double glazing for inner skin, 3- Sun protection, 4- Single glazing for outer skin, 5- Galvanized iron mesh, 6- External air intakes, 7- Internal air intake, 8-Internal air outlet.

3.3 Dung Han Han and Others

An experimental study on thermal buoyancy-induced natural ventilation was carried out. A practical experiment examined the impact of the movement and density and speed of the air pressure differentials resulting from different temperatures through the flow of heat through an air intake box next to the floor, and the other near the ceiling as shown in Fig. 6. The results shows that the greater the difference between internal and external temperatures, the greater the amount of air flowing [13]. This experimental understanding of characteristics of air is a practical experience that does not depend on software. It depends on density difference. However, it did not address air inside a specific depth cavity.

4. VARIABLES AFFECTING THE SENSE OF THERMAL COMFORT

Thermal comfort is a mental state that contributes to human satisfaction with the surrounding environmental conditions [14]. It is a feeling of not being cold or hot, it is a condition that does not make you feel sensual harassment as a result of the disruption of the thermal environment [15]. It is a state of mind that assesses personal self-expression of satisfaction with the thermal environment through sense of direct temperature and humidity, and the effort needed to regulate internal body temperature [16]. Temperature, air speed and humidity, varying personal metabolic criteria, and clothing insulation are essential variables that affect the sense of thermal comfort [16].

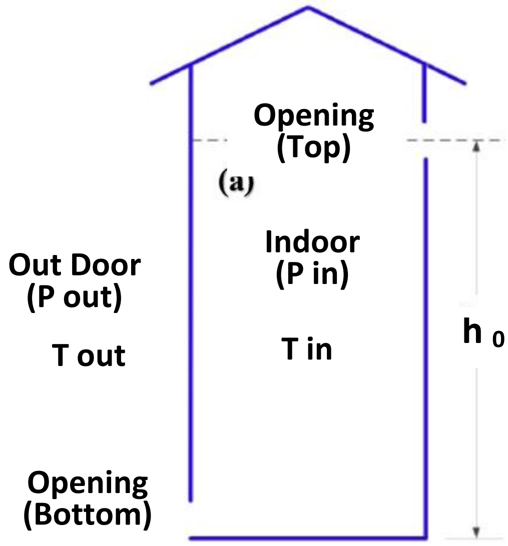

Fig. 6. The form of the experiment model and openings [13].

4.1 Air Temperatures

The human body performs the internal thermal regulation of the body. The skin temperature of the human being exceeding 45°C or less than 18°C causes suffering. Resting skin temperature is associated with stable activities between 33-34 °C, and decreases with increased activity, and in contrast the internal body temperature rises with activity. The center for regulating brain temperature is about 36.8°C at rest. It increases to about 37.4°C when walking and to 37.9°C when running [16].

4.2 Effect of Air Speed on Thermal Comfort Range

The benefits that can be gained by increasing air velocity depend on clothing, activity, and the difference between human skin surface temperature T_r and air temperature T_a [17]. Figure 7 illustrates that the thermal comfort zone is directly affected by the air velocity in increased range of temperatures and moisture ratios above normal [18]. Francis Beaufort designed a scale consisting of a series of numbers from zero to 17, to indicate wind speeds. Beaufort defined the concept of these numbers. According to this definition, wind speed from 1.5 - 3.3 m/s is acceptable. This is numbered (2) and is called Light breeze [19].

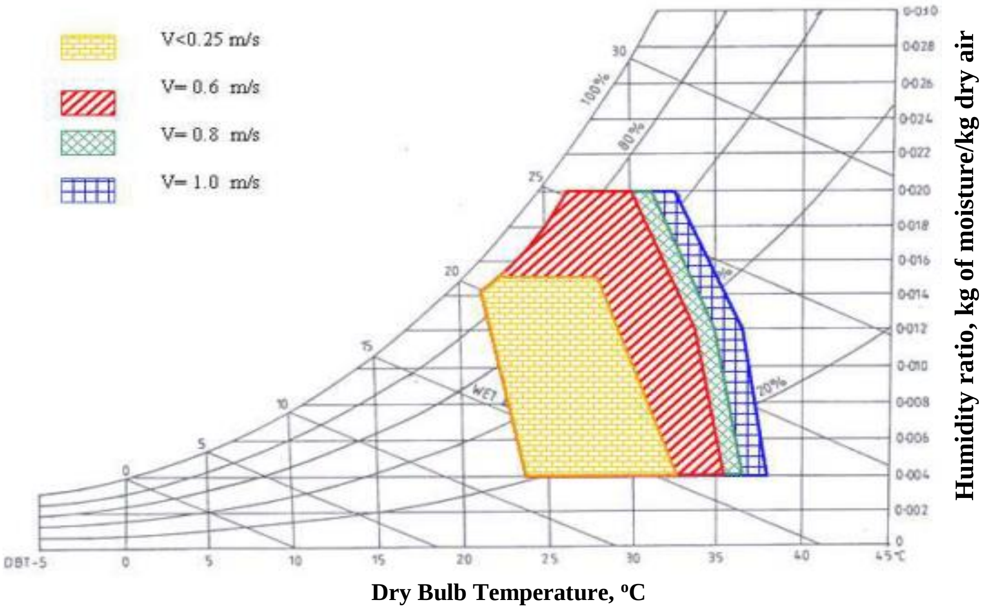

Fig. 7. The effect of increase in air speed on the thermal comfort zone [18].

5. STEPS OF PRACTICAL EXPERIMENTS

5.1 Objectives of the Experiment

The objectives of the experiment are to determine and measure the efficiency of the best air cavity with a double-skin facade system in terms of reduced air temperature in the interior spaces and increased air speed inside the interior spaces.

5.2 Preparation of the Model

With a scale of 1:33.333, the model was constructed with an area 4m×4m, three floors, each with a height of 3 m. A second envelope was added to one of the facades, so that the depth of the air cavity can be changed. Figures 8-9 show the model with the wind tunnel, and Figs. 10-11 show the vertical sections and plan.

Fig. 8. Compilation of the model.

Fig. 9. The model in the wind tunnel in the lab.

5.3 Devices Used

The heat wire is connected to the inner surface of the outer air cavity skin, then the two ends of the heat wire are connected to the temperature control device. The air and surfaces temperature monitoring points “thermo cables” are also installed in the model, which are connected to the data logger device. Air velocity is measured through a digital device “Veloci Calc”. Figures 12-13 present the devices used.

5.4 The Idea of Experiments

Experiments show that the inner surface of the outer skin of the cavity is exposed to temperatures that simulate the intensity of solar radiation. The experiment is based on studying the effect of the difference between the air temperature in the interior spaces and the air cavity, on the temperature and speed of the air flowing in the interior spaces while changing the depth of the cavity in each case at 0.20 m, 0.40 m, 0.80 m, 1.20 m, and 1.60 m.

5.5 Conducting Experiments

The model was placed in the wind tunnel and the inner surface of the outer skin of the cavity was heated, to activate the chimney feature and to increase the speed of air withdrawal from the model. Temperatures of the air, surfaces cavity, and air temperature of the internal spaces are measured. The air speed at the internal spaces and at the outlet of the air cavity are also measured. Tables 1-2 show the preliminary results prior to analysis of natural ventilation experiments resulting from temperature difference, the chimney effect.

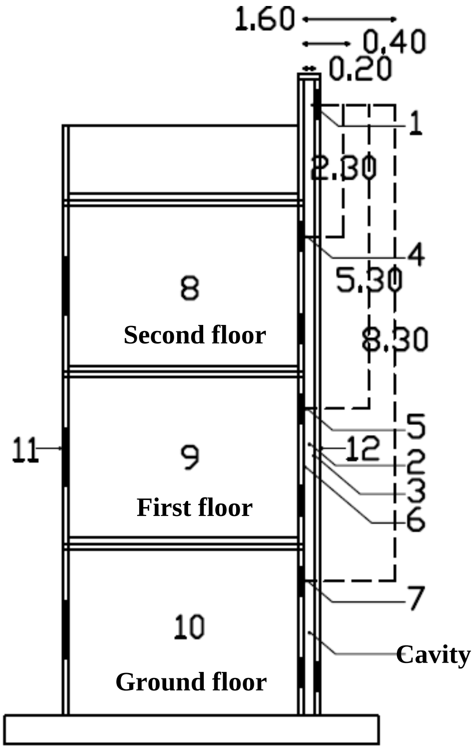

Fig. 10. Measurement points section of model.

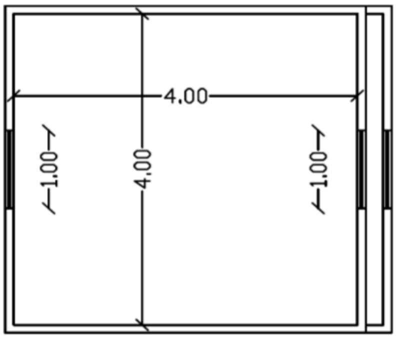

Fig. 11. Plan of the model.

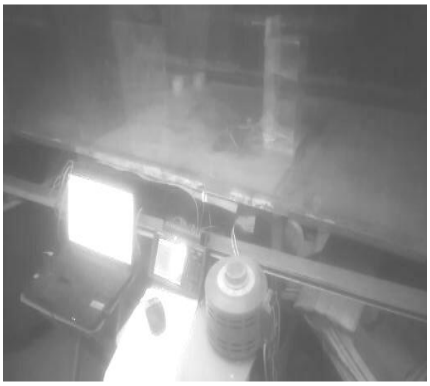

Fig. 12. The model and the devices.

Fig. 13. The digital device (Veloci Calc) to wind speed.

5.5.1 Analysis and extrapolation of Tables 1-2

It is observed from Table 1 that the maximum air temperature is at the air outlet in the top of the air cavity. It was also observed that the maximum increase in the temperature of the air of the internal spaces within the cavity was at the final floor, and the flow of air gets lower at that level.

Table 1. The experiment initial readings of the air temperatures, “chimney effect”.

(D) Depth of air cavity (in meters), (T1) air temperature at outlet of air cavity (°C), (T4, T5, and T7) air temperature at outlet of the second floor, first floor, and Ground floor levels, (T8, T 9, T10) Air temperature at the middle of spaces of the second floor, first floor, and Ground floor levels, (T11) air temperature at the front of the middle inlet of first floor, (EXP) Average temperature exposure of the inner surface of the outer skin of the cavity (°C).

D	T1	T4	T5	T7	T8	T9	T10	T11	EX P
M	°C	°C	°C	°C	°C	°C	°C	°C	°C
0.2	35.40	33.58	30.07	28.68	23.56	23.08	22.98	22.96	30.13
	58.10	50.74	41.78	35.82	26.14	23.66	23.55	23.41	41.23
	82.73	76.13	53.18	43.06	28.33	24.98	24.61	24.35	55.64
0.4	34.77	33.02	29.66	28.57	24.42	24.14	23.95	23.88	30.13
	57.14	48.86	40.25	34.94	27.19	24.78	24.64	24.44	41.23
	81.08	73.41	50.78	41.32	29.18	25.90	25.38	25.10	55.64
0.8	33.35	31.61	29.64	28.46	23.85	23.69	23.43	23.35	30.13
	53.58	43.70	38.11	33.11	25.58	23.67	23.48	23.27	41.23
	76.08	66.30	48.52	38.55	28.30	25.36	24.79	24.44	55.64
1.2	32.78	31.03	29.22	28.49	23.49	23.38	23.13	23.03	30.13
	53.33	41.20	38.09	33.14	23.35	23.68	23.47	23.21	41.23
	72.82	61.37	47.28	39.07	27.32	24.75	24.18	23.77	55.64
1.6	32.72	30.87	29.93	29.38	24.14	24.10	23.85	23.72	30.13
	53.14	39.56	37.68	32.77	26.63	25.04	24.78	24.45	41.23
	72.71	56.19	48.33	38.04	28.83	26.58	25.99	25.43	55.64

5.5.2 Heat transfer and depth of the cavity

Table 3 resulted from the analysis of Tables 1-2. It shows the direct relationship between the rate of marginal increase of the air temperature and speed of the air at ground floors with the different depths of the air cavity, that is the temperature difference ΔT (6.75 °C) between the air from inlet at front of the window of second floor level, and inner surface of the outer skin of cavity.

Table. 2. Experiment initial readings of air velocities, “chimney effect”.

(D) Depth of air cavity (in meters), (VA1) the speed of the air at outlet cavity Antenna (m/s), (VA) Air speed at air outlet of the second floor, first floor, and Ground floor levels, (EXP) Average temperature exposure of the inner surface of the outer skin of the cavity (°C).

D	V A 1	V A 8	V A 9	V A 10	EX P
M	m/s	m/s	m/s	m/s	°C
0.2	0.17	0.01	0.05	0.06	30.13
	0.31	0.02	0.07	0.11	41.23
	0.43	0.03	0.10	0.15	55.64
0.4	0.14	0.01	0.04	0.05	30.13
	0.29	0.02	0.06	0.10	41.23
	0.40	0.03	0.09	0.14	55.64
0.8	0.11	0.01	0.03	0.04	30.13
	0.23	0.03	0.05	0.08	41.23
	0.37	0.03	0.08	0.13	55.64
1.2	0.09	0.01	0.03	0.03	30.13
	0.20	0.03	0.05	0.07	41.23
	0.34	0.04	0.07	0.12	55.64
1.6	0.09	0.02	0.02	0.03	30.13
	0.20	0.04	0.05	0.07	41.23
	0.31	0.04	0.06	0.11	55.64

Table. 3. Effect of the depth of the air cavity in the ground floor at ΔT (6.75 °C).

D	H	H/D	T11	T10	(T10a)	(R)=100* ((T10a-T11a)/T11))	(V)
m	m	m	(°C)	(°C)	(30.13-23.39) = 6.75 (°C)	%	m/s
0.20	8.30	41.5	22.96	22.98	23.41	0.11	0.06
0.40	8.30	20.8	23.88	23.95	23.45	0.28	0.05
0.80	8.30	10.4	23.35	23.43	23.47	0.36	0.04
1.20	8.30	6.92	23.03	23.13	23.50	0.47	0.03
1.60	8.30	5.19	23.72	23.85	23.52	0.56	0.03
∑ (°C)			116.93				
Average (T11a) (°C) = 116.93/5			23.39				

(H) Height between the middle of the air outlet of the spaces level to the middle outlet of the air at the top of cavity, (T10a) The average spaces air temperature after unifying the air entering of the spaces = value (T10) for each cavity *(T11a) / the average value of (T11) for each cavity, (R) the ratio = 100 * ((T10a-T11)/ (T11a)), (V) = air velocity of spaces level at the air window inlet.

Similar to Table 3, we can reach a conclusion the results of which are shown in Table 4 and Fig. 14, which illustrate directly the relationship between the depth of the cavity and the increase in air temperature in the spaces in ground and first level, at ΔT (6.75 °C).

Table. 4. The air temperature at the different floor levels at ΔT (6.75 °C).

D	(R)=100* ((T8a, T9a, T10a-T11a)/T11)) %		
m	R (T8a) %	R (T9a) %	R (T10a) %
0.20	2.61	0.51	0.11
0.40	2.23	1.08	0.28
0.80	2.14	1.46	0.36
1.20	2.03	1.56	0.47
1.60	1.97	1.62	0.56

It was also observed from Table 4 and Fig. 14, that the maximum increase in the temperature of the air of the internal spaces was at the final floor, and the air speed was much lower at that level. This is because the outlet is not far off the final level, and the air speed can be increased by increasing the height of chimney outlet. It was also observed that air speed was quite high at the lower levels specially at the ground level and this was due to the chimney top was quite high. This leads to a conclusion that as the length of the chimney above the outlet opening increases the speed of air also increases due to the stack effect. This directly led to the decrease in internal air temperature of the spaces due to the higher dragging of air. It is also noticed that at ΔT (6.75°C) the direct relationship between the depth of cavity and increase in the temperature of the air at ground and first floor level, and the inverse relationship between the depth of cavity, and the air speed at the second floor level.

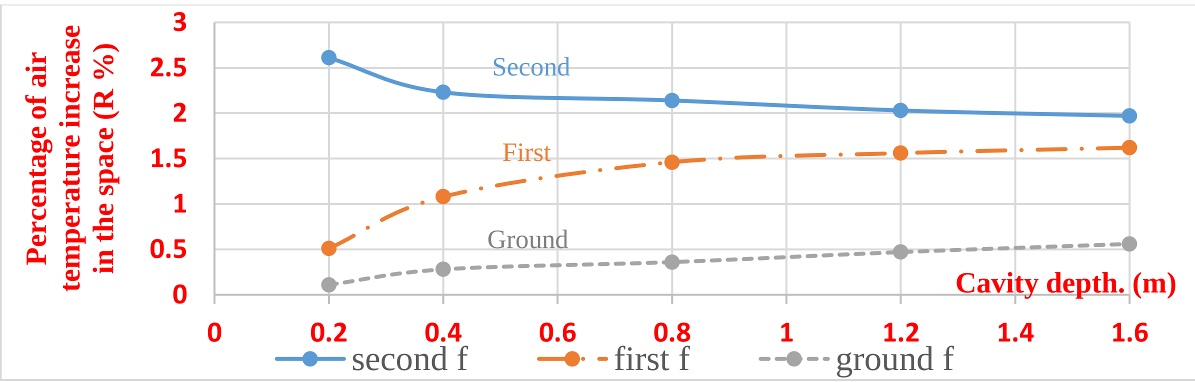

Fig. 14. The air temperature at the different floor levels (ΔT 6.75 °C).

5.5.3 The relationship between air temperature, air velocity, and cavity depths

Tables 5-7, and Figs. 15-17 show the effect of the air cavity depth on the increase of air velocity within the cavity leading to higher air velocity within the internal spaces, and this resulted from the chimney property “stack effect”. The increase of air velocity within the cavity led directly to a marginal increase in the internal air temperature percentage to the dry bulb temperature of (0.11, 0.61, 1.06% and 0.51, 1.07, 2.57%) at ΔT’s (6.75, 17.48 and 31.02 °C) within the ground and first floors respectively, but the ground floor was much lesser in temperature increase as shown Figs. 15-16. The temperature of the second floor was much higher by “2.61, 11.68 and 16.32%” as shown in Fig. 17. This was due to the height of the chimney from the different floor levels, and the depth of the cavity chosen was (0.20 m).

Table 5 and Fig. 15 clarify the direct relationship between the depth of cavity, and the marginal increase in the air temperature at ground floor level, and this was due to the increase of air speed at that level, at different ΔT’s (6.75, 17.48 and 31.02 °C). Where (ΔT) represents the difference between the normal air temperature in front of the shaded facade and the surface temperature of the facade exposed to solar radiation, and (R) represents the marginal increase of the internal air temperature percentage to the dry bulb temperature for the first and second floor areas.

Table. 5. Air temperature at the ground floor at ΔT’s (6.75, 17.48 and 31.02°C).

D	H	H/D	Air velocity and percentage of increase in air temperature in the ground floor at different exposure temperatures (ΔT’s)					
			at ΔT (6.75 °C)		at ΔT (17.48 °C)		at ΔT (31.02 °C)	
m	M	m	V (m/s)	R (%)	V (m/s)	R (%)	V (m/s)	R (%)
0.20	8.30	41.50	0.06	0.11	0.11	0.61	0.15	1.06
0.40	8.30	20.75	0.05	0.28	0.10	0.82	0.14	1.13
0.80	8.30	10.38	0.04	0.36	0.08	0.90	0.13	1.43
1.20	8.30	6.92	0.03	0.47	0.07	1.11	0.12	1.75
1.60	8.30	5.19	0.02	0.56	0.07	1.36	0.11	2.20

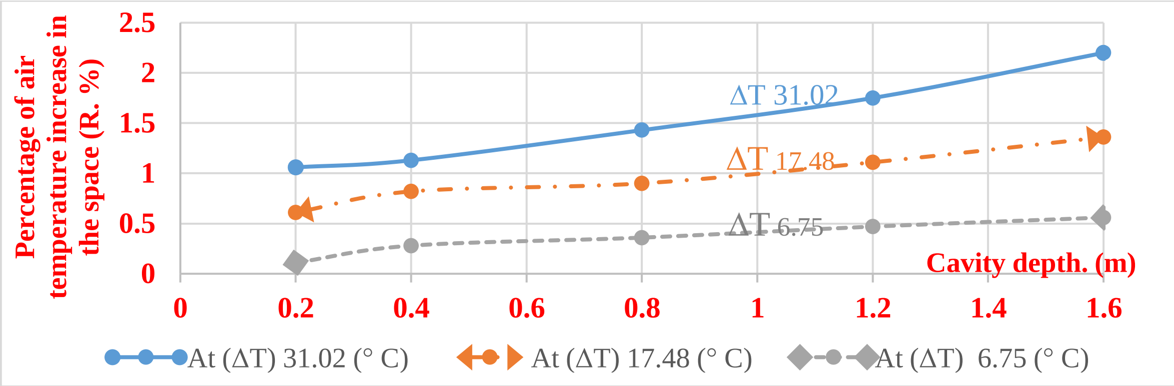

Fig. 15. Air temperature at the ground floor space at ΔT's (6.75, 17.48 and 31.02 °C).

Table 6 and Fig. 16 also clarify the direct relationship between the depth of cavity, and marginal increase in the temperature of the air at first floor level, which was less than the ground floor level. This again was due to the increase of the air speed at that level, at different ΔT's (6.75, 17.48 and 31.02°C).

Table. 6. Air temperature at the first floor level at ΔT's (6.75, 17.48 and 31.02 °C).

D	H	H/D	Air velocity and percentage of increase in air temperature in the first floor at different exposure temperatures (ΔT's)					
			at ΔT (6.75 °C)		at ΔT (17.48 °C)		at ΔT (31.02 °C)	
M	m	m	V (m/s)	R (%)	V (m/s)	R (%)	V (m/s)	R (%)
0.20	5.30	26.5	0.05	0.51	0.07	1.07	0.10	2.57
0.40	5.30	13.25	0.04	1.08	0.06	1.36	0.09	3.19
0.80	5.30	6.63	0.03	1.46	0.05	1.73	0.08	3.75
1.20	5.30	4.42	0.03	1.56	0.05	2.05	0.07	4.14
1.60	5.30	3.31	0.02	1.62	0.05	2.42	0.06	4.49

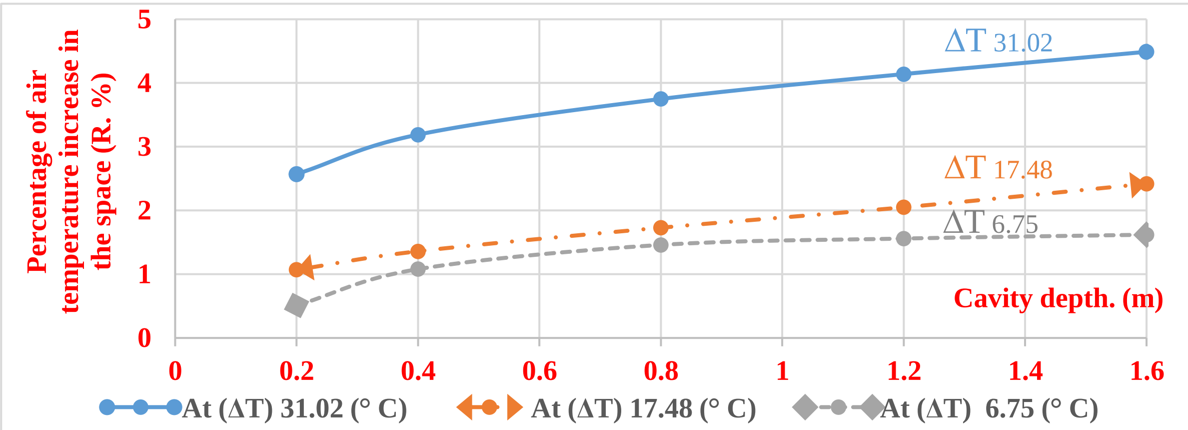

Fig. 16. Air temperature at the first floor level at ΔT's (6.75, 17.48 and 31.02°C).

Table 7 and Fig. 17 also show the inverse relationship between the depth of cavity, and increase in the air temperature at second floor level, and this was due to the decrease of the air speed at the second floor level, at different ΔT's (6.75, 17.48 and 31.02°C).

Table. 7. Air temperature at the second floor at ΔT's (6.75, 17.48 and 31.02 °C).

D	H	H/D	Air velocity and percentage of increase in air temperature in the second floor at different exposure temperatures (ΔT's)					
			at ΔT (6.75 °C)		at ΔT (17.48 °C)		at ΔT (31.02 °C)	
m	m	m	V (m/s)	R (%)	V (m/s)	R (%)	V (m/s)	R (%)
0.20	2.30	11.50	0.01	2.61	0.02	11.68	0.03	16.32
0.40	2.30	5.75	0.01	2.23	0.02	11.25	0.03	16.24
0.80	2.30	2.88	0.01	2.14	0.03	9.92	0.03	15.79
1.20	2.30	1.92	0.01	2.03	0.03	9.23	0.04	14.49
1.60	2.30	1.44	0.02	1.79	0.04	8.90	0.04	13.37

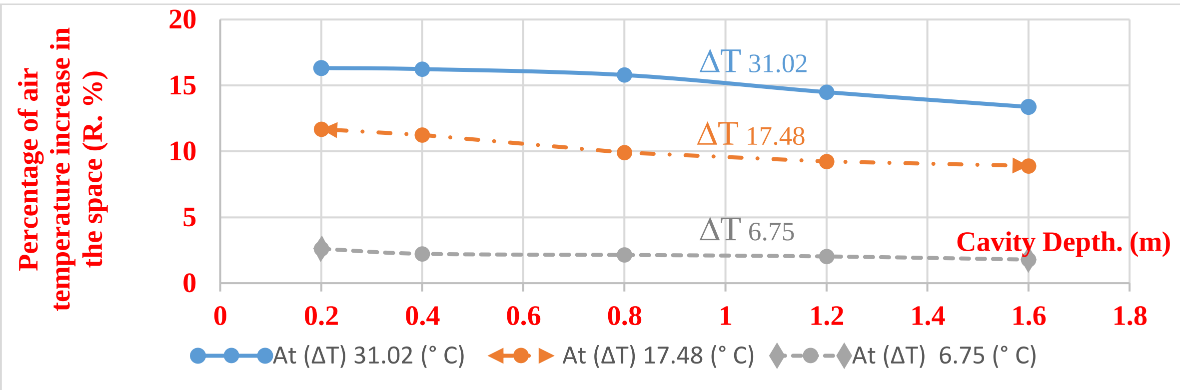

Fig. 17. Air temperature at the second floor level at ΔT's (6.75, 17.48 and 31.02°C).

6. DISCUSSION

The effect of air cavity depth on increasing air velocity was very clear and resulted from the chimney property "stack effect", as the cavity depth gets narrower and height of chimney gets higher the air intake speed directly increases, and led to reducing the air temperature at the ground and first floor levels. At the same time the air speed was decreasing and the air temperature increasing in the second floor, and this was due to the height of the chimney as the distance between the flow level and chimney outlet increases the air velocity increases and air temperature decreases and vice versa. Accordingly, the speed of air can be increased by increasing the height of the chimney outlet.

7. CONCLUSIONS

It was obvious that the lesser the cavity depth, the greater the air velocity within the cavity that led to a reduction of air temperature within the internal space, especially at the ground and first floor levels, while at the second floor space it was vice versa. This was due to the height of the chimney, the closer you get to the chimney outlet the lesser the drag of air that led directly to the increase in temperature. It was also observed that the best cavity depth that led to the higher velocities of air within the cavity was 0.20 m at ground and first floor levels. That led to a decrease in the internal air temperature of the spaces and it was vice versa at the second floor level. This was due to the distance between the second floor and the chimney outlet. This was overcome by increasing the chimney height up to 5.30 m above the middle height of the final floor outlet "window", in order to maximize the drag of air.

DECLARATION OF CONFLICT OF INTERESTS

The authors have declared no conflict of interests.

REFERENCES

1. Sameh, H., Elzafrany, A., and Attia, D. N., "Analysis of Thermal Comfort Enhancement Using Vernacular Architecture in Siwa Oasis, Egypt", Journal of Engineering and Applied Science, Vol. 66, No. 6, pp. 679-701, 2019.
2. Rovero, L., Tonietti, U., Fratini, F., and Rescic, S., "The Salat Architecture in Siwa Oasis-Egypt X11-XX Centuries", Construction and Building Materials, Vol. 23, No. 7, pp. 2492-2503, 2009.
3. Masaruf, M., and Muhammad, S., "Analyzing The performance of Passive Cooling System In Building- Designing Natural Solution To Summer Cooling Loads and Architectural Interventions", American Journal of Engineering Research, Vol. 6, No. 10, pp. 272-280, 2017.
4. Yuan, Y., Yang, X., Yu, X., Xiao, Y., Bo, X., and Wang, Y., "Bionic Building Energy Efficiency and Bionic Green Architecture", Renewable and Sustainable Energy Reviews, Vol. 74(C), pp. 771-787, 2017.
5. https://en.wikipedia.org/wiki/Greenhouse_effect (Accessed 07/07/2020).
6. https://www.google.com/search?q=Glass+House+Effect&client=firefox-b- (Accessed 28/01/2019).
7. https://ar.wikipedia.org/wiki/%D8%A7%D9%84%D8%A7%D8%AD%D8%A

A%D8%A8%D8%A7%D8%B3_%D8%A7%D9%84%D8%AD%D8%B1%D8%A7%D8%B1%D9%8A (Accessed 7/07/2020).
8. https://ghgprotocol.org/sites/default/files/standards_supporting/Required%20gases%20and%20GWP%20values_0.pdf (Accessed 7/07/2020).
9. Richardson, J., "Planning and Installing Bioenergy Systems", 1st Edition, John Wiley & Sons, Ltd, pp. 16-20, 2005.
10. Alison, G., and Walter, T., "The Green Studio Handbook, Environmental Strategies for Schematic Design", 1st Edition, Routledge, pp. 42-43, 2007.
11. Elisabeth, G., "Greenhouse Effect in Double-Skin Façade", Energy and Building Journal, Vol. 39, No. 2, pp. 199-211, 2007.
12. Andre, A., Ramos, N., and Almeida, R., "Parametric Study of Double-Skin Facades Performance in Mild Climate Countries", Journal of Building Engineering, Vol. 12, pp. 87-96, 2017.
13. Han, D., Kim, S., Choi, J., Kim, Y., Chung, H., Jeong, H., Watjanataepin, N., Ruangpattanawiwat, C., and Choi, S., "Experimental Study on Thermal Buoyancy-Induced Natural Ventilation", Energy and Buildings Journal, Vol. 177, pp. 1-11, 2018.
14. Watson, D., and Labs, K., "Climatic Design: Energy-Efficient Building Principles and Practices", McGraw-Hill, p. 26, 1983.
15. Thomas, A., Markus, E., and Morris, N., "Buildings Climate and Energy", Pitman Pub, p. 47, 1980.
16. ASHRAE Handbook Fundamentals, "Thermal Comfort", Chapter. 9, Edition. S1, pp. 9.1- 9.16- 9.17. 2017.
17. ANSI/ASHRAE Standard 55-2004, "Thermal Environmental Conditions For Human Occupancy", ANSI/ASHRAE, pp. 5-8, 2004.
18. https://www.google.com/imgres?imgurl=https%3A%2F%2Fwww.researchgatene %2 F profile% 2FShak (Accessed 14/8/2019).
19. https://www.marefa.org/%D9%85%D9%82%D9%8A%D8%A7%D8%B3%D8%A8%D9%88%D9%81%D9%88%D8%B1%D8%AA (Accessed 14/8/2019).

دور نظم الواجهات المزدوجة لتحقيق الراحة الحرارية في المناطق الحارة

يهدف البحث إلى الوصول لأفضل عمق للتجويف الهوائي المناسب للمباني في المناطق الحارة بإتباع المنهج الاستقرائي التجريبي والمنهج الوصفي التحليلي، من خلال المحاكاة على نموذج بالمعمل لتحديد العمق المناسب الذي يعمل على خفض درجة حرارة الهواء بالفراغات الداخلية ويساعد على زيادة سرعة الهواء لتحقيق الراحة الحرارية. كما يهدف البحث إلى الوصول لأفضل عمق للتجويف الهوائي المناسب للمباني في المناطق الحارة، وذلك بإتباع المنهج الاستقرائي التجريبي، والمنهج الوصفي التحليلي، من خلال عملية محاكاة على نموذج بالمعمل، لتحديد العمق المناسب الذي يعمل على خفض درجة حرارة الهواء بالفراغات الداخلية، ويساعد على زيادة سرعة الهواء لتحقيق الراحة الحرارية.