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Comparison of Occupant Thermal Comfort with and without Passive Design for a Naturally Ventilated Educational Building: a case study in Cairo, Egypt

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Occupant thermal comfort in educational buildings is important for students as it support the educational process itself. The passive design of naturally ventilated buildings plays a crucial role in achieving occupant thermal comfort but the passive design itself might be of higher cost to convince the owner even with proofs from the pre and while design simulation outputs. In this paper, the as built of a 1000 students' educational building is simulated using Design Builder and compared with the same thermal zones of the as built but with passive cooling applications. Two wind catchers, shading devices, low e-glass windows, double skin façade, and double roof were applied as amelioration strategies. The status of student comfort was improved in terms of both Predicted Mean Vote and air temperature, compared with the base case of the building. It is concluded that shading the roofs and southern facade of the building envelope were the most efficient scenarios for the passively modified version of the building.

Keywords: passive cooling, educational buildings, occupant thermal comfort, design builder, shading, PMV.

1. Introduction

Human thermal comfort is an important sustainability, wellbeing and productivity measure for buildings



indoor spaces, [1]. Speaking about thermal comfort as a sustainability measure is crucially correlated to the energy consumption of mechanically cooled building. It is used as an indicator for the HVAC systems set points so that the cooling loads can be estimated efficiently, and the whole system can be designed [2]. On the other hand, indoor thermal comfort represents how occupants feel indoors which mean that their productivity can be estimated and maximized for better outcomes of the employer. Therefore, the assessment of thermal comfort status became a hot topic since the Fanger Predicted Mean Vote (PMV) have been adopted [3]. Since then, a lot of thermal comfort research has been undertaken which revealed many new and improvements for existing indices such as the Standard Equivalent Temperature (SET) and others [4-8]. In this concern, natural ventilation in buildings as a passive design strategy is characterized with wind flow stimulators like wind catchers or courts or so, in addition to applying shading as main heat gain prevention strategy, [9]. Moreover, the shade generation by fences, green roofs [10], double roofs and double skin facades are getting much interest in the recent years attributed to its efficiency in minimizing the heat gain and improving indoor thermal comfort in the excessive heat conditions of naturally ventilated buildings but subject to the optimization between the need to solar prevention and the need to daylighting even in the outdoor spaces, [11]. Further, improving and/or providing acceptable occupant thermal comfort levels is not only subject to the building envelope passive applications but extends to the outdoor environment that has to be coupled with indoor one not only for the sake of energy efficiency as discussed by Fahmy et al., [12,13], but also for the sake of occupant thermal comfort. However, assessment of post occupancy or existing buildings in terms of sustainability measures is gaining more platform [14-16]. From this standing point, the post occupancy of a naturally ventilated but not comfortable educational building in Cairo, Egypt using building performance simulation will be assessed in comparison to different scenarios of passive treatments in order to improve indoor thermal comfort.

2. Methodology

The methodology is divided into two main subsections: 1) case study and passive improvement strategies; and 2) design builder calibration and simulation. The first subsection describes the case study and the passive improvement strategies that were implemented in the simulations, whereas the second one describes the calibration and the setting of the design builder tool through the various simulations. The dynamic simulation tool DesignBuilder V4.2, [17], was used to estimate the occupant thermal comfort PMV levels as it incorporates an easy and simple CAD interface for the EnergyPlus core calculations. Site data is based on WMO meteorological measurements of station no.623660 at Cairo international airport, which is classified by Energy Plus conversion tool [8] statistically as mixed dry/semi-arid whereas the extreme hot week typically lies between June 26th and July 2nd with a maximum dry bulb temperature of 44.0 °C. the weather data file that has been used is modified one by METEONORM [18] to adjust the exact data for the site which is far of about 5km from the above mentioned WMO station.

2.1. Base case and passive improvement strategies for thermal comfort

The case study building is a higher education building in Cairo, Egypt, which comprises of five above grade floors, ground floor and four typical floors, with a foot print area of 1950 m² as shown in Figure 1. The building comprises lecture halls, classrooms, and computer labs, as well as, W.C.s in each floor. The building is oriented 30 degrees in direction of the north east. Ten simulations were conducted; one simulation for the base case and other nine simulations for modified scenarios of the same building in order to improve passively the thermal comfort inside the building and decrease the air temperature in the summer months. There are seven correlated strategies are modified in each simulation to achieve the maximum achievable passive thermal improvement, which are: 1) walls; 2) openings; 3) window airflow control; 4) louvers; 5) double roofing; 6) wind catcher; and double skin façade.

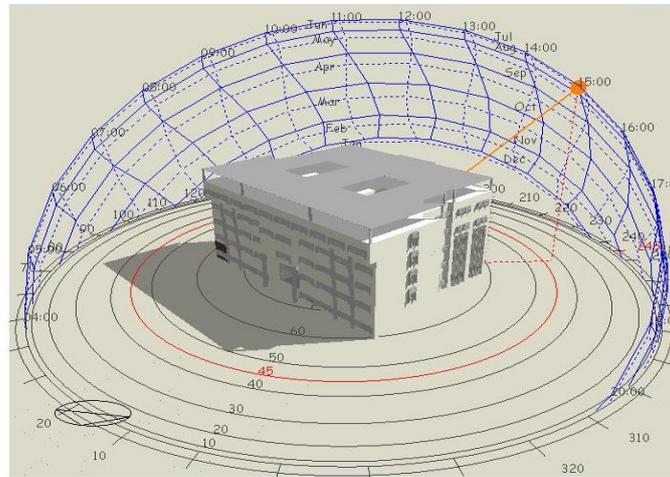


Figure 1: Design builder case study model

Table 1. Passive improvement domains for simulation scenarios

Simulation Scenarios	Walls	openings	Window air flow control	Louvers	Double ceil	Wind catcher	Double skin Façade
Base case	Single wall 250 mm brick	Single clear glass	No window air flow control	No louvers	No double roofing	No wind catchers	No double skin façade
Scenario (S1)	Double layer wall 250 mm brick- foam insulation- 125mm brick	Double glazing Low-E 6mm glass- argon filled gap	No window air flow control	0.5 overhang louvers	Double roofing with holes over inner courts	No wind catchers	No double skin façade
Scenario(S2)	Double layer wall 250 mm brick- air gap-125mm brick	Double glazing Low-E 6mm glass- argon filled gap	No window air flow control	0.5 overhang louvers	Double roofing with holes over inner courts	No wind catchers	No double skin façade
Scenario(S3)	Single wall 250 mm brick	Double glazing Low-E 6mm glass- argon filled gap	No window air flow control	0.5 overhang louvers	Double roofing with holes over inner courts	No wind catchers	No double skin façade
Scenario(S4)	Single wall 250 mm brick	Double glazing Low-E 6mm glass- argon filled gap	No window air flow control	0.5 overhang louvers	Double roofing with holes over inner courts	No wind catchers	No double skin façade
Scenario(S5)	Single wall 250 mm brick	Single glazing	No window air flow control	0.5 overhang louvers	Double roofing with holes over inner courts	No wind catchers	No double skin façade
Scenario(S6)	Single wall 250 mm brick	Single glazing	No window air flow control	0.5 overhang louvers	Double roofing with holes over inner courts	No wind catchers	double skin Inclined fins at south façade
Scenario(S7)	Single wall 250 mm brick	Double glazing Reflective 6mm glass- air filled gap	No window air flow control	0.5 overhang louvers	Double roofing with holes over inner courts	No wind catchers	double skin Inclined fins at south façade
Scenario(S8)	Single wall 250 mm brick	Double glazing Reflective 6mm glass- air filled gap	Existence of air flow control	0.5 overhang louvers	Double roofing with holes over inner courts	No wind catchers	double skin Inclined fins at south façade

Simulation Scenarios	Walls	openings	Window air flow control	Louvers	Double ceil	Wind catcher	Double skin Façade
Scenario(S9)	Double layer wall 250 mm brick-foam insulation-125mm brick	Double glazing Low-E 6mm glass- argon filled gap	No window air flow control	0.5 overhang louvers	Double roofing (inclined panels)	8 wind catchers	double skin Inclined fins at south facade

2.2. Design builder calibration and simulation

Design Builder software was used for simulations of the base case and the nine scenarios. There are two main tabs in the software interface have the same setting through all the simulations: activity tab and HVAC tab. In the activity tab the schedule of the occupancy was chosen to be educational classrooms with time schedule from 8 am: 2 pm and from 5 pm: 10 pm. In the environmental control, the cooling set back temperature is set to be 20 degree Celsius. For the indoor minimum temperature control in the ventilation set point temperatures, the minimum temperature definition was set to be by schedule and the minimum temperature schedule was set to be 20 degree Celsius through six seven days of week except Friday is of for all the twelve months. Moreover, the office equipment and computers are checked on. In the HVAC tab, the template was selected to be natural ventilation with no heating nor cooling. The mechanical ventilation is checked on. Besides, the natural ventilation was activated with the same operation schedule as the occupancy in the activity tab. Further, in the seventh and the eighth simulation, the air flow controlled was activated to force keeping some selected windows opened and the source of air was outdoor, and the destination was the indoor.

3. Results

Figures 2 and 3, and tables 2 and 3 show the graphical and numerical representation of the resulted simulation outputs for both averaged PMV and air temperature (T_a) for the whole thermal zones of the examined building.

As illustrated in figure 2 and 3, the monthly distribution of PMV for all scenarios (column 2-9) compared to the base case results of column 1 show that generally summer alleviation was limited which can be owed to the original compact design of the building. In addition, despite some scenarios have made a slight alleviation in summer, all scenarios increased the PMV values in winter. However, only the wind flow stimulation through the long corridor side windows was effective when compared to using of wind catchers in S9 that hasn't been effective at all as shown in both tables 2 and 3. In summer months of June and July, the most improvement for PMV happened S7 and S8 (double roofing and double skin at southern façade with reflective glass) that reached a reduction of 0.1 and 0.15 respectively and corresponding to about 0.8°C reduction of T_a for both June and July months.

All building envelope design scenarios that has either double wall with cavity or double wall with insulation didn't reveal any improvements to the indoor conditions which can be attributed to same thermal effect of the insulation that it makes. It insulates and lags the conductive heat transfer from outside to inside and the same applies from inside to outside which means capturing the heat inside building and prevention of heat release.

In winter, the most effective scenarios were S5 and S6 which provided a slight heating with an increase of about 0.6 PMV in both January and February values corresponding to about 1.6°C and 1.9°C.

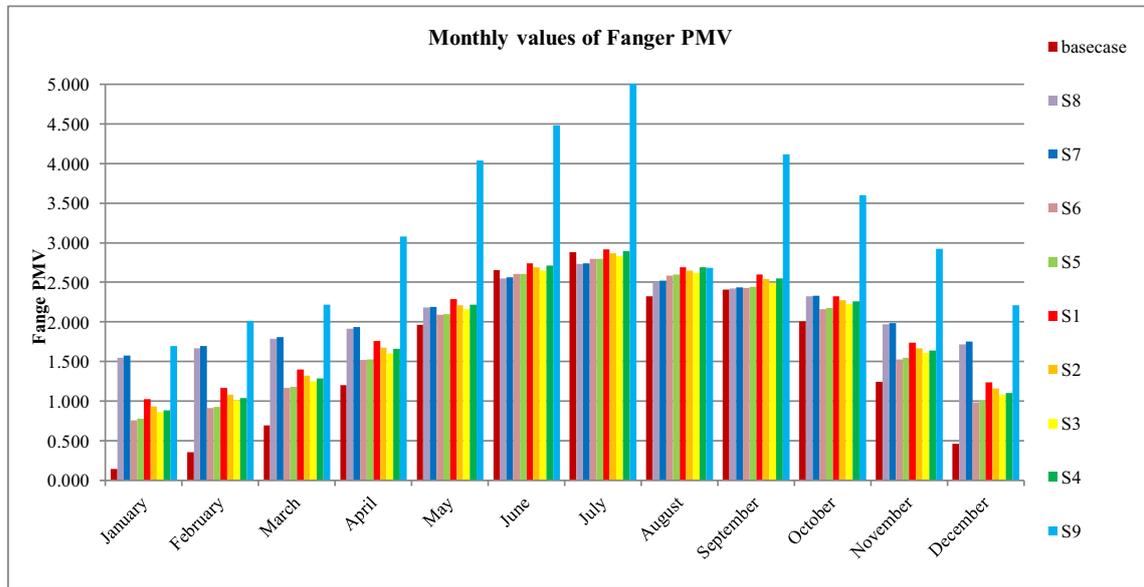


Figure 2: Fanger PMV monthly simulation results distribution for the base case and nine scenarios

Table 2: Fanger PMV monthly simulation numerical results for the base case and nine scenarios

Date/Scenarios	Basecase	S1	S2	S3	S4	S5	S6	S7	S8	S9
January	0.144	1.024	0.937	0.862	0.885	0.780	0.760	1.579	1.548	1.696
February	0.353	1.167	1.083	1.011	1.037	0.930	0.916	1.696	1.667	2.011
March	0.695	1.397	1.320	1.254	1.288	1.180	1.169	1.810	1.789	2.219
April	1.200	1.762	1.676	1.604	1.658	1.525	1.518	1.932	1.914	3.081
May	1.963	2.285	2.214	2.158	2.216	2.098	2.094	2.193	2.180	4.038
June	2.655	2.742	2.689	2.647	2.713	2.607	2.604	2.563	2.551	4.482
July	2.882	2.915	2.869	2.832	2.897	2.797	2.794	2.742	2.731	5.019
August	2.324	2.689	2.650	2.620	2.692	2.595	2.587	2.521	2.510	2.683
September	2.406	2.595	2.539	2.493	2.550	2.443	2.431	2.436	2.423	4.113
October	2.005	2.326	2.273	2.228	2.262	2.179	2.165	2.332	2.321	3.598
November	1.245	1.735	1.669	1.612	1.636	1.548	1.530	1.985	1.968	2.920
December	0.463	1.239	1.157	1.084	1.105	1.005	0.987	1.749	1.720	2.210

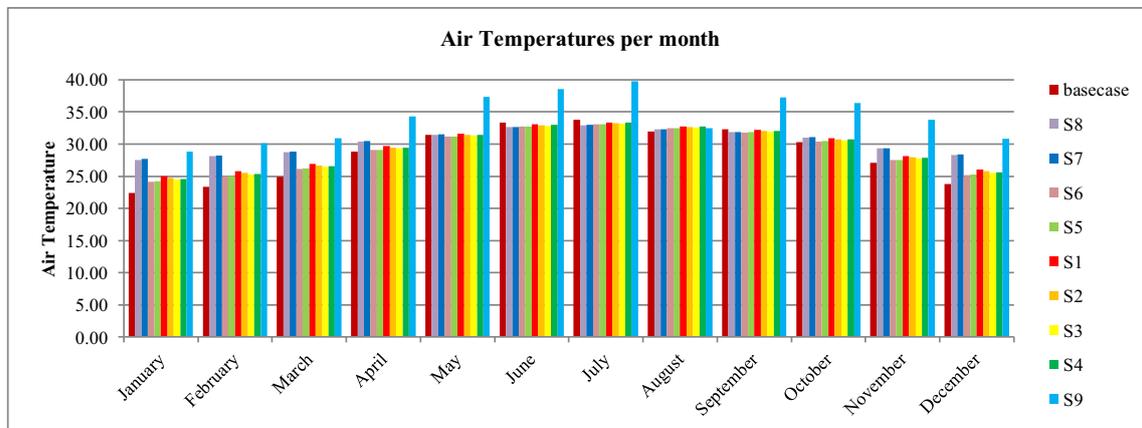


Figure 3: Air temperature monthly simulation results distribution for the base case and nine scenarios

Table 3: Air temperature monthly simulation numerical results for the base case and nine scenarios

Date/Scenarios	Basecase	S1	S2	S3	S4	S5	S6	S7	S8	S9
January	22.37	25.04	24.75	24.50	24.57	24.21	24.15	27.66	27.54	28.79
February	23.39	25.80	25.52	25.28	25.37	25.01	24.96	28.26	28.14	30.09
March	24.88	26.93	26.67	26.46	26.57	26.20	26.17	28.82	28.73	30.88
April	28.81	29.67	29.48	29.31	29.43	29.11	29.10	30.44	30.39	34.33
May	31.39	31.60	31.44	31.32	31.44	31.17	31.16	31.50	31.47	37.32
June	33.38	33.04	32.92	32.83	32.97	32.73	32.72	32.67	32.65	38.56
July	33.77	33.35	33.25	33.17	33.31	33.08	33.07	32.97	32.95	39.81
August	31.92	32.70	32.61	32.54	32.71	32.48	32.46	32.32	32.30	32.51
September	32.29	32.18	32.05	31.96	32.08	31.83	31.81	31.88	31.85	37.21
October	30.33	30.91	30.74	30.60	30.71	30.43	30.39	31.07	31.03	36.36
November	27.12	28.16	27.95	27.76	27.84	27.55	27.49	29.38	29.32	33.74
December	23.77	26.04	25.77	25.53	25.60	25.25	25.20	28.42	28.30	30.80

4. Conclusion

This research aimed to make a spot light on evaluating the application of different passive scenarios for an educational building in Cairo, Egypt after it has been already constructed to improve the post occupancy thermal comfort. The different scenarios showed in table 1 applied all available interventions of thermal insulation, ventilation and shading such as wind catchers, louvers, double skin facades, double roofing, double glass windows, etc. There was evident results for the effectiveness of the shading strategy (with reflective glass) in S7 and S8 compared to other strategies especially in the hot summer months of June and July. Thermal insulation using either double wall and cavity or double and filling insulating material didn't conclude any improvement but in fact made the results worse for the examined building as it depends on natural ventilation and needed to release the heat gained during day which hasn't been available because of the insulation. It was clear that the already existence of such a compact educational building and trying to modify its as built is much harder than constructing a pre and while designed passive cooling building which might has necessitated a different educational building zoning form to allow wind flow for a maximized ventilative cooling in addition to the shading.

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