Thermal Retrofitting of Primary School Buildings in Egypt Optimizing Energy Efficiency and Thermal Comfort

Maha Fawzy Aly Anber

Assistant Professor of Architecture, the Higher Institute of Engineering, Shorouk Academy, Mahafawzyaly88@gmail.com

Abstract:

As buildings are responsible for almost 30% of the total energy consumption worldwide, it makes it a necessary thing to study them and provide solutions to optimize their energy consumption, provide more thermal comfort for their users and mitigate their negative environmental impacts. Governmental school buildings in Egypt follow the same prototypes since the 1992 earthquake, these buildings represent a broad sector of buildings. These building prototypes are implemented in all Egypt governorates regardless of their climatic conditions and location which results in the lack of achieving the required thermal comfort for the students. This research paper aims at determining the most effective optimization strategies for school buildings in Egypt to enhance the occupants' thermal comfort. The chosen school building prototype is the `most widely used in Cairo, Egypt as it represents around 34% of the seven prototypes of the constructed school buildings according to the General Authority for Educational Buildings (GAEB). By applying these retrofit strategies to the chosen prototype, the thermal retrofitting of existing school buildings in Egypt will create thermally optimized indoor environments for classrooms which will contribute to improving the educational environment in Egypt. Moreover, it will provide enhanced thermal comfort conditions to its users which will reflect on their academic development. The main contribution of this research is that the simulation studies highlighted the importance of integrating low-cost retrofitting strategies to balance the indoor temperature and increase the students' thermal comfort. By applying simple low-cost retrofitting strategies such as roof shading and window shading, the discomfort hours in classrooms were reduced by 20%.

Keywords:

Thermal retrofit, educational buildings, school buildings, Designbuilder software

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1- Introduction:

Around 30% of primary energy consumption is consumed by the building sector. Building energy retrofits make a significant contribution to decreasing the energy use and carbon emissions[(1)]. While residential sector consumes 42% of the total energy consumption in Egypt, commercial and educational buildings consume 30%[(2)]. Educational buildings are considered a significant sector not only for its high energy consumption, but for the importance of achieving comfort for its users, as students spend more than 36.5% of their time in classrooms[(3)]. Educational buildings are considered valuable assets that contribute to the educational process while operating all year long in different climate conditions and weather situations[(4)]. Studies proved that there is a strong correlation between air quality and thermal indoor environment of classrooms and the students' performance, well-being, and concentration[(5)]. These studies clarify the importance of achieving thermal comfort in educational buildings as a significant factor that shapes the future of nations.

Education is believed to be a human right for everyone. The United Nations Educational, Scientific and Cultural Organization (UNESCO) states that their vision is to change peoples' lives by education as it is the main incentive towards development and towards achieving sustainable development goals (SDGs) [(6)]. To provide appropriate education, the learning environment should be productive and comfortable for the students as they spend long hours in classrooms and in indoor environments generally[(7)].

Considering the energy consumption of school buildings and spreading the culture of enhancing the thermal comfort of buildings among this building sector will promote these ideas in other building sectors as well. In hot arid climate, thermal

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(3) Rahman, Ali & Ali, Prof. Dr. -Rady, Ahmed & Abdel-Abdel Eng, Ahmed Hamza H. & Ookawara, Shinichi (2014) “An Analysis of Thermal Comfort and Energy Consumption within Public Primary Schools in Egypt”.

(4) Alshibani, A. Prediction of the Energy Consumption of School Buildings. *Appl. Sci., 2020*. https://doi.org/10.3390/app10175885

(5) ear R.J., Akimoto T., Arens E.A., Brager G., Candido De D C., Cheong K.W.D., Li B., Nishihara N., Sekhar S.C., Tanabe S., Toftum J., Zhang H., Zhu Y., (2013) “Progress in thermal comfort research over the last twenty years” Indoor Air, 23: 442–461.

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(7) Haddad, Shamila & King, Steve & Osmond, Paul. (2012). Enhancing thermal comfort in school buildings. 10th International Conference on Healthy Buildings 2012. 2.

comfort in educational buildings is essential for building users[1]. Students in classrooms are greatly affected by thermal conditions in physical and social aspects[2]. Building the same school prototypes by the General Authority for Educational Buildings (GAEB) in Egypt in all climatic zones of Egypt regardless to the variation of the climatic conditions leads to creating spaces that lack the thermal and visual comfort. As stated by Abdelsalam (2020), providing roof insulation to school buildings in United Arab Emirates (UAE), hot arid climate, similar to Egypt's climate resulted in 21.5% annual electricity consumption[3]. While in Lombardy Italy, temperate zone, retrofitting the building envelope of school building achieved 22% annual energy consumption[4]. According to Sameh Monna et al, uninsulated roofs caused heat gain in summer and students reported that they felt uncomfortable during their school days in summer[5].

The research problem is the indoor environmental quality of school classrooms. Students and teachers spend almost 50% of their daytime within school buildings. During daytime, the main occupancy time of school buildings, external environmental conditions are so challenging and require providing architectural solutions to provide the optimum parameters for occupants. Since school buildings rely on natural lighting and ventilation, discomfort among occupants is a critical issue. The main objective of this research paper is to provide and enhance thermal comfort for occupants of school buildings in Egypt. An analytical study of the thermal comfort of classrooms and the discomfort hours will be conducted in relation to multiple retrofitting strategies to determine the most effective strategies for achieving thermal comfort.

2- Research Methodology:

This research paper applies a computer-based study to assess the thermal comfort in primary school buildings in Cairo, Egypt as shown in Figure 1.

The research methodology consists of the assessment of the case study base case model, the modeling of the base case model, thermal comfort analysis of the base case model and a simulation study of several alternatives to determine the most effective retrofit strategy to provide the optimum conditions of thermal comfort in school buildings.

The computer-based study starts with the modeling of the base case with the input of the building construction, occupancy, geometry, orientation, activity, and materials. Then the simulation of retrofit measures to determine the energy saving and thermal comfort enhancement after the retrofit.

A comparative study is conducted to determine the most effective retrofit strategies in enhancing the thermal comfort of students in classrooms.

The expected results are the most effective retrofit strategies in decreasing the discomfort hours in the indoor environment of classrooms. The results will help authorities to incorporate these strategies in future school buildings of the same prototype and similar school buildings designs to provide more thermally comfort indoor environment for classrooms.

The literature review explains educational buildings in Egypt and issues concerning the thermal comfort in these buildings which negatively affect the students' performance and concentration levels. The second part of the literature review is concerned with thermal comfort in buildings and the potential thermal retrofitting strategies. The climatic conditions of the case study building location is analyzed to reach the suitable thermal retrofitting strategies for hot arid climates.

3- Thermal Comfort:

According to The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Thermal comfort is the mind state expressing that person's satisfaction with the surrounding thermal environment[6].

The risk of overheating in buildings in Egypt is considered a severe state where it might affect occupants concerning thermal discomfort, decreased productivity, and illness[7]. The impact of climate change and its facts and figures shows that the temperature inside buildings in Egypt are most likely to increase[8]. This fact gives a high priority for investigating thermal comfort in Egypt generally and specially in buildings that are not air-conditioned like school buildings.

(1) Rahman, Ahmed Hamza H. -Ahmed A. Saleem, Ali K. Abel Ali, Shinichi Ookawara, (2014) "An Analysis of Thermal Comfort and Energy Consumption within Public Primary Schools in Egypt" The Asian Conference on Sustainability, Energy and the Environment.

(2) C. Munonye, Y. Ji (2019) " Investigating the comfort temperature for school children in a warm and humid climate of Imo State Nigeria" African Journal of Environmental Research 2.

(3) Aldawoud, Abdelsalam & Hosny, Fatma Elzahraa. (2020). Energy Retrofitting of School Buildings in UAE. Energy Engineering. Vol.117, No.6, 2020. 381-395,. 10.32604/EE.2020.011863.

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(5) Sameh Monna et al, (2019) "Improving thermal environment for school buildings in Palestine, the role of passive design" Journal of Physics: Conference Series. Doi:10.1088/1742-6596/1343/1/012190

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Thermal comfort in hot arid climates is considered an important topic to be addressed as it reflects on the energy consumption and internal temperature of indoor spaces. School buildings deal with children in an age that shapes their characters and personalities yet an age that makes them more exposed to the environmental factors than grown-ups(1). Providing appropriate indoor environment for children is a necessity to grant them the optimum learning experience and the best outcome. An investigation study of thermal comfort conditions that was conducted on school building in Egypt showed that the air temperature inside classrooms was raised by an average of 6ºC which causes discomfort for students[2]. Using passive solar architecture to adjust the building envelope to achieve more thermal comfort in indoor spaces is considered a significant contribution with low-cost ad no negative environmental impacts. It was found that 82% of hours in classrooms in public primary schools in Egypt are not in comfort zone. (7)

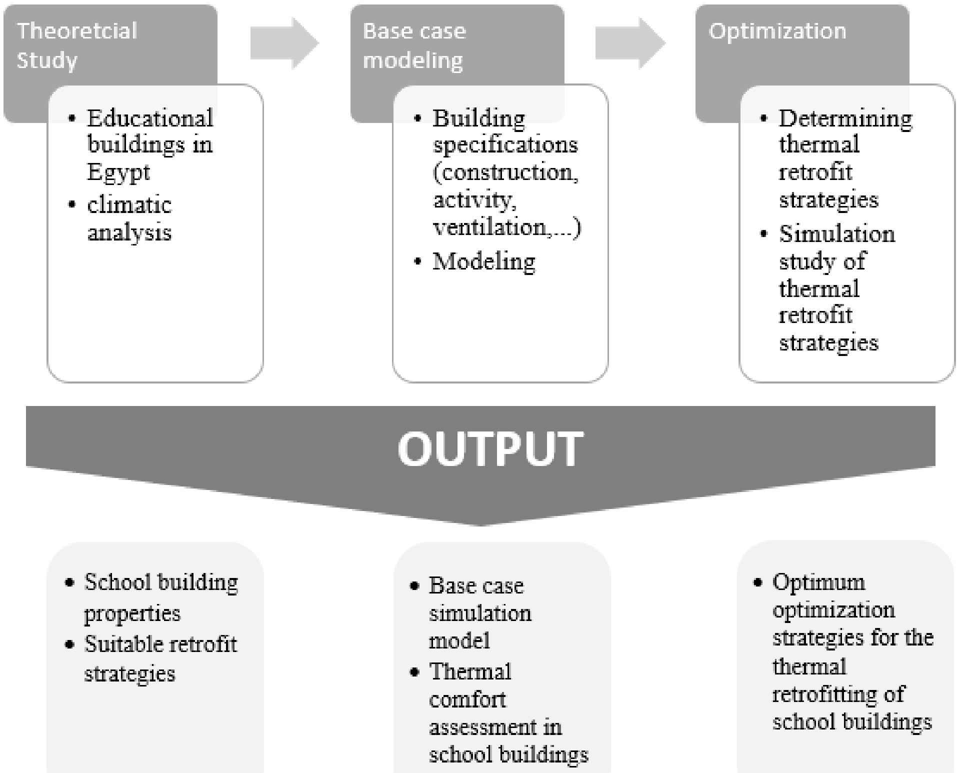

Fig. 1: Research analysis strategy
Source: Researcher

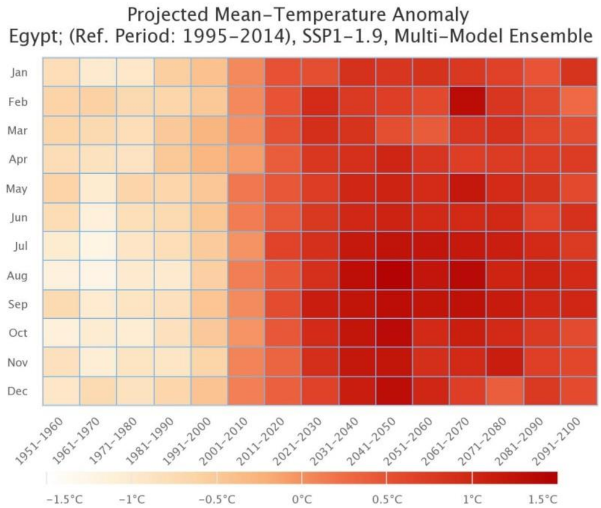

Fig. 2: Projected mean- temperature Anomaly Egypt (1995-2014) multi model ensemble

, W. A. Suk K. Murray, M. D. A akian (2003) Environmental hazards to childrens health in the modern world Mutat. Res., vol. 544)1(no. 2–3, pp. 235–242, PUBMED ELSEVIER. DOI: 10.1016/j.mrrev.2003.06.007

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As shown in Figure 2, the climate projections of Egypt show that temperatures are getting higher in summertime. This research paper aims at directing future research concerns and designs towards considering the future climate(18).

4- Educational Buildings in Egypt:

According to the Ministry of Education and Technical Education, the number of public schools in Egypt raised from 52,022 to 56,569 schools through the academic years 2015-2016 to 2019-2020(19).

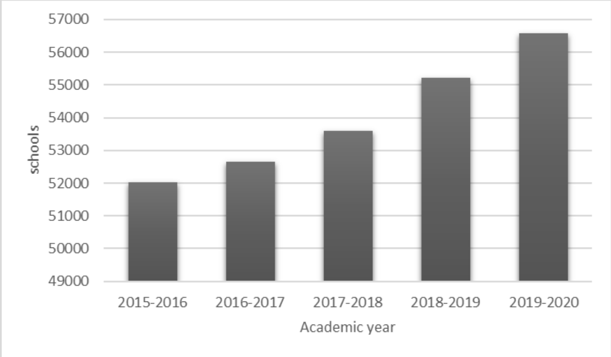

Fig. 3: Number of Schools in Egypt

After 1992 earthquake in Egypt, the government started building substantial number of school buildings in specific prototypes instead of the school buildings that were lost in the disaster at reduced cost an increased implementation speed. Figure 3 shows the great growth in the number of school buildings in Egypt in the last few years showing the significance of retrofitting these buildings to enhance thermal comfort. The school buildings prototypes by the government lack the architectural aesthetics, lack greenery, lack the thermal comfort of users in the classrooms and have visual discomfort (glare) (20).

According to the Building Bulletin BB101, the maximum number of hours with class temperature above 28°C should not exceed 120 hours. Whilst the internal temperature of the classrooms while occupied should not exceed 32°C(21).

As shown in Figure 4, the total hours in discomfort are obvious in daytime and specially in buildings that are occupied mainly during daytime like school buildings. The months with overheating stress are April, May, June, July, August, September, and October.

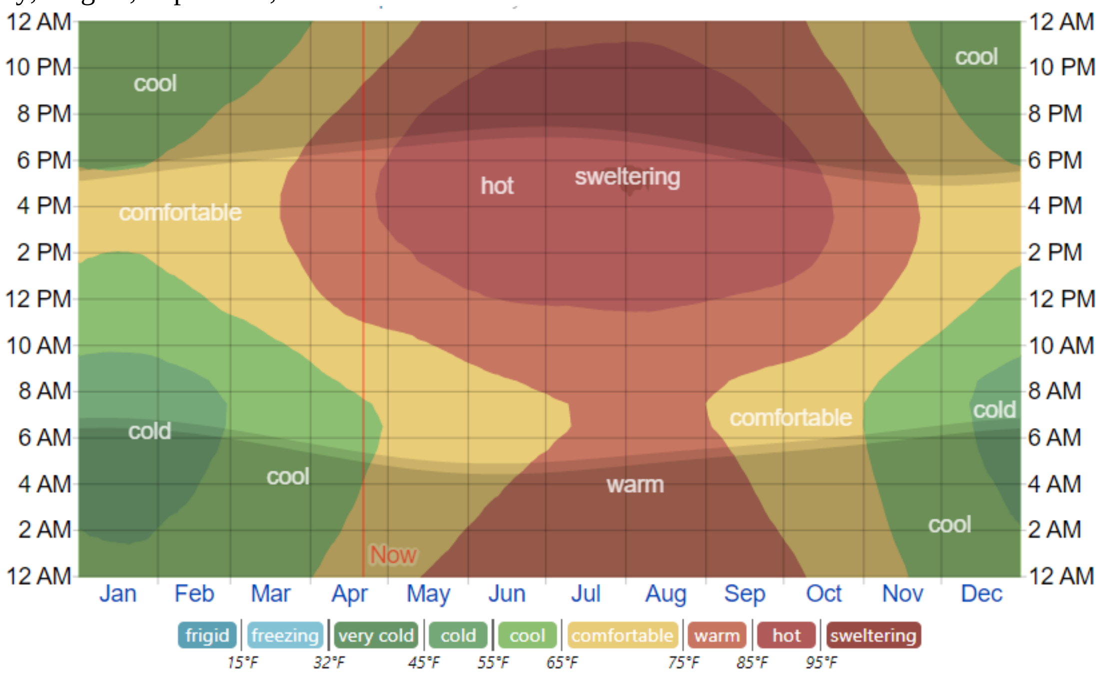

Fig. 4: The average hourly temperature in Cairo showing overheating hours

[18] Climate change knowledge portal for development practitioners and policy makers- World Bank Group

[19] Ministry of Education and Technical Education.

[20] Gado, T & Mohamed, Mady & Unwin, S. (2005). The environmental performance of classrooms: a case study from El-Minya governorate, Egypt. The Second Scottish Conference for Postgraduate Researchers of the Built & Environment (PRoBE 2005)- Glasgow Caledonian University, UK. Volume: 1.

[21] Building Bulletin (BB) 101- Ventilation for school buildings.

5- Thermal Retrfoitting of Buildings:

According to Claire et. al, the thermal performance of buildings controls the quantity of energy that is used for the heating and cooling of buildings that in return affects energy efficiency(22). Thermal retrofitting of buildings is considered an efficient method that leads to economic and environmental advantages, it works on enhancing the building exterior envelope's thermal features that reduces the heating and cooling loads, carbon dioxide emissions and enhances thermal comfort of users(23). Thermal retrofitting is concerned with controlling the thermal performance of building. It is stated that its essential to consider using passive cooling strategies along with retrofitting the external envelope of the building to maintain the indoor thermal comfort(24). According to ABCB 2016, building envelope is the structural components that separate the interior of the building from the exterior of the building, it consists of external openings, doors and windows, external walls, roof, and ground as shown in Figure 5(25). Building envelopes are the main reason for discomfort in indoor spaces, according to Zhao Rui et. al, the main cause of the heat transfer from external walls is the windows(26). Adjusting openings has great potential in controlling heat transfer to buildings. According to Osman 2011, directing the airflow and controlling its speed is determined by the type of opening which can enhance the natural ventilation inside the spaces(27). Not only does openings play an important role in controlling heat gain, but also external walls. According to Wanas 2013, applying wall insulation in hot climates such as Cairo, the case study location, will mitigate the heat transfer from the outdoor to the interior of the building(28).

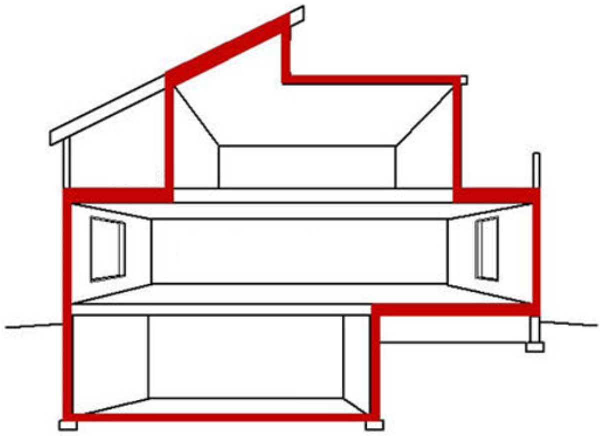

Fig. 5: Building envelope diagram

5-1 Choice of Retrofit Strategies:

The choice of applying passive retrofit strategies to school buildings is based on the high cost of active systems that will not be suitable for this building type specifically in Egypt(29). According to Attia 2010, using active solar retrofit strategies require the passive solar architecture measures to be implemented first(30). According to the International Energy Agency, educational buildings suggested retrofit strategies are improving the thermal properties of the external building envelope, adjusting heating, cooling and ventilation systems, solar control, and lighting system(31).

6- Applied Study:

6-1 Building Prototype Case Study Description:

The case study location is selected as Cairo, Egypt's capital, and the biggest city with high population growth rate. It also has the biggest number of schools among other Egyptian governorates. The case study school building prototype is chosen according to GAEB, this school prototype represents almost 34% of school buildings in Cairo among the seven school prototypes. The building is a skeleton building of concrete structure. Its length is 28 meters and height are three floors (ground floor and four typical floors). Classrooms are located in the typical floors; each floor has four classrooms. Each classroom is 8 meters* 5 meters(32). Thermal properties of building materials of the base case school building are shown in table number 6.

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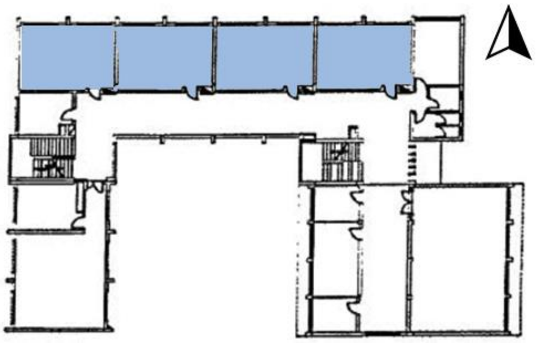

Fig. 6: Typical floor plan of school building prototype- classrooms highlighted

Table 1: Thermal properties of building materials of the base case school building

Component	Density	Specific Heat Capacity	Conductivity
Cement mortar	1650 Kg/m^3	920 J/kg.K	0.72 W/m.K
Reinforced concrete	2300 Kg/m^3	840 J/kg.K	1.9 W/m.K
Sand	2240 Kg/m^3	840 J/kg.K	0.8 W/m.K
Cement tiles (roof)	2100 Kg/m^3	800 J/kg.K	1.4 W/m.K
Bitumen sheets	1090 Kg/m^3	1000 J/kg.K	0.06 W/m.K
Hollow clay bricks	1790 Kg/m^3	260 J/kg.K	0.6 W/m.K
Low density polystyrene foam	38 Kg/m^3	1130 J/kg.K	0.033 W/m.K
Cement plaster	1860 Kg/m^3	840 J/kg.K	0.72 W/m.K

6-2 DesignBuilder Base Case Model Settings:

The modeling of the case study building on Design Builder software for simulation had input from real data. The clothing values of the users is set to 0.7 clo., which consists of a long-sleeved shirt or a T-shirt, trousers, a pair of socks and a pair of shoes for boys, and for girls is a dress with long trousers, a pair of socks and a pair of shoes. The activity level is set to sedentary; 70 W/m2. As for the artificial lighting, each classroom had four lighting fixtures, each lighting fixture contains three 1200 mm fluorescent T-8 lamp[33]. The ventilation strategy is set to natural ventilation where windows are operable from 8 am to 5 pm. The infiltration rate is set to 0.5 ac/h. The thermal properties of the building materials of the base case are as shown in Table 1.

The urban context of the case study is set to a typical urban context of Cairo that is surrounded by paved asphalt streets. According to the urban sites for educational buildings and urban planning laws, the setting of the base case overlooks a six meters width main street (minimum), the setbacks of the school building should be at least three meters. The school should have more than one entrance.

According to the General Authority of Educational Buildings (GAEB), and the statistics of the average capacity of school buildings in Cairo, the occupancy level is set to 0.98 per/m2 [**Error! Bookmark not defined.**].

6-3 Retrofitting Strategies:

The study tested multiple retrofitting strategies which are roof insulation, roof shade, wall insulation, double glazing, providing fully operable windows, window shading and low E-coating glass. The properties of retrofit strategies are; roof insulation (EPS) expanded polystyrene sheets with U-value 0.27 W/m²K. roof shade is a horizontal shade that is installed parallel to the roof with height 2.5 m to be usable and is created using tent fabric with U-value 5 W/m²K. Wall insulation with U-Value 1.6 W/m2k. Providing fully operable windows that direct the airflow inside spaces. The size of the operable area of the window is set to be 100% operable area. The window shading is 50 % shading coefficient (SC). Low emissivity coated glazing (Low-E) is used with U-value 4 W/m2k.

6-4 Energy Simulation Process:

The study proposes an annual simulation of the school building where the zones that will be simulated are classrooms on the first and second floor. According to the climate analysis, the simulation months will be months with overheating and where the students attend for the school year which are April, May, June, September, and October. July and August will be excluded as they are summer vacation time.

The building will be simulated in the ordinal and cardinal directions, North, North-east, East, South-east, South, South-west, West, North-west.

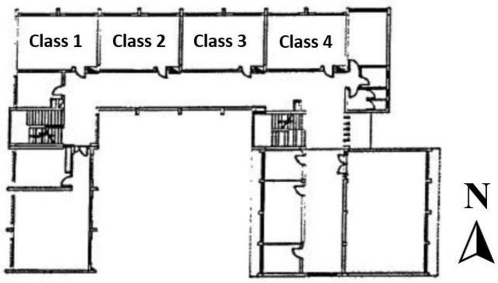

Fig. 7: Simulated classes- first floor

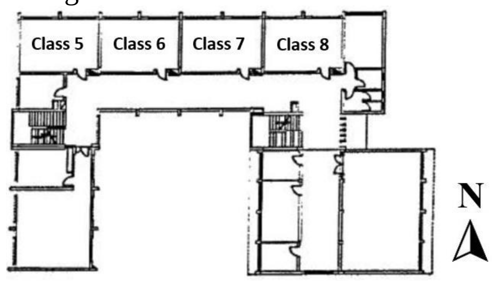

Fig. 8: Simulated classes- second floor

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Table 2: Discomfort hours percentage- North orientation

Class	Discomfort hours percentage
Class 1	14.5 %
Class 2	11.2 %
Class 3	12 %
Class 4	12.8 %
Class 5	24.1 %
Class 6	19.2 %
Class 7	18.5 %
Class 8	17.1 %

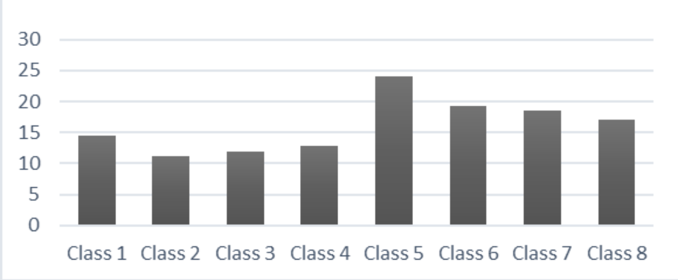

Fig. 9: Discomfort hours percentage- North orientation

Table 3: Average indoor temperature in June (North orientation)

Class	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Mean temperature	30.4°C	31°C	32.5°C	32.8°C	33.8°C	33.4°C	33.6°C	33.5°C

Table 4: Discomfort hour’s percentage- North- east orientation

Class	Discomfort hours percentage
Class 1	13.6 %
Class 2	13.3 %
Class 3	13.5 %
Class 4	14.1 %
Class 5	22 %
Class 6	23.4 %
Class 7	23.5 %
Class 8	22.6 %

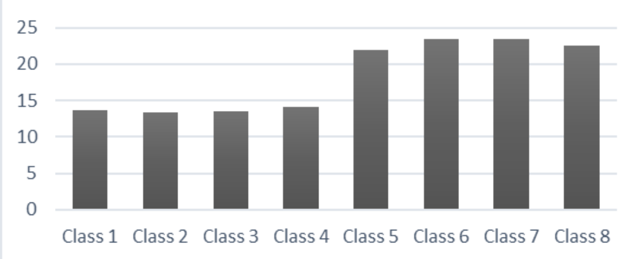

Fig. 10: Discomfort hours percentage- North- east orientation

Table 5: Average indoor temperature in June (North- east orientation)

Class	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Mean temperature	30.7°C	31.3°C	32.8°C	32.9°C	33.2°C	33.3°C	33.4°C	33.6°C

Table 6: Discomfort hours percentage- East orientation

Class	Discomfort hours percentage
Class 1	15.2 %
Class 2	17.1 %
Class 3	17.3 %
Class 4	17.5 %
Class 5	25.4 %
Class 6	27.6 %
Class 7	27.8 %
Class 8	26.8 %

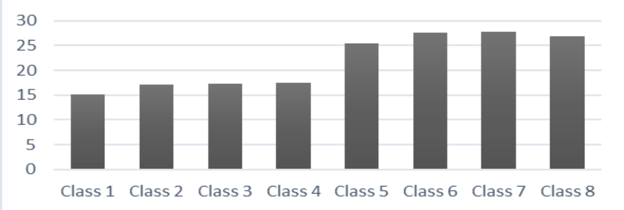

Fig. 11: Discomfort hours percentage- East orientation

Table 7: Average indoor temperature in June (East orientation)

Class	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Mean temperature	30.9°C	31.4°C	31.5°C	32.7°C	33°C	33.5°C	33.6°C	33.7°C

Table 8: Discomfort hours percentage- South- east orientation

Class	Discomfort hours percentage
Class 1	15.9 %
Class 2	16.7 %
Class 3	16.6 %
Class 4	19.3 %
Class 5	26.4 %
Class 6	27.3 %
Class 7	27.4 %
Class 8	28 %

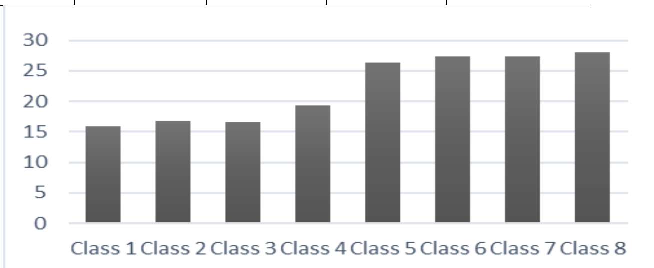

Fig. 12: Discomfort hours percentage- South- east orientation

Table 9: Average indoor temperature in June (South- east orientation)

Class	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Mean temperature	30.7°C	31°C	31.1°C	32.4°C	33.1°C	33.2°C	33.4°C	33.5°C

Table 10: Discomfort hours percentage- South orientation

Class	Discomfort hours percentage
Class 1	19.6 %
Class 2	18.5 %
Class 3	18.8 %
Class 4	20.5 %
Class 5	28.4 %
Class 6	27 %
Class 7	27.1 %
Class 8	30.2 %

Fig. 13: Discomfort hours percentage- South orientation

Table 11: Average indoor temperature in June (South orientation)

Class	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Mean temperature	30.4°C	30.2°C	30.6°C	32.1°C	32.6°C	33°C	33.1°C	33.7°C

Table 12: Discomfort hours percentage- South-west orientation

Class	Discomfort hours percentage
Class 1	29.2 %
Class 2	28.7 %
Class 3	28.9 %
Class 4	29 %
Class 5	38.7 %
Class 6	38.6 %
Class 7	38.9 %
Class 8	37.9 %

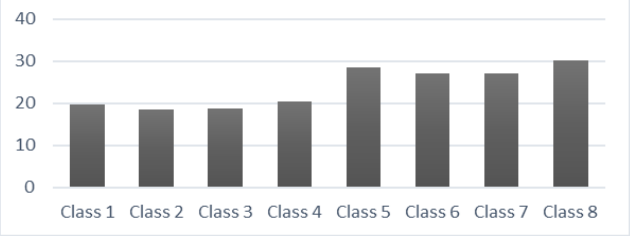

Fig. 14: Discomfort hours percentage- South west orientation

Table 13: Average indoor temperature in June (South- west orientation)

Class	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Mean temperature	31.4°C	31°C	31.2°C	31.5°C	33.4°C	33.3°C	33.2°C	34.8°C

Table 14: Discomfort hours percentage- west orientation

Class	Discomfort hours percentage
Class 1	31.4 %
Class 2	29.6 %
Class 3	29.8 %
Class 4	28.1 %
Class 5	38.4 %
Class 6	38.5 %
Class 7	38.7 %
Class 8	36.2 %

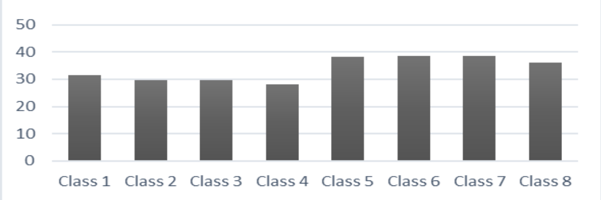

Fig. 15: Discomfort hours percentage- west orientation

Table 15: Average indoor temperature in June (west orientation)

Class	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Mean temperature	32°C	31.9°C	32°C	31.1°C	34.3°C	33.8°C	33.5°C	35°C

Table 16: Discomfort hours percentage- North-west orientation

Class	Discomfort hours percentage
Class 1	22.1 %
Class 2	18.7 %
Class 3	19 %
Class 4	19.2 %
Class 5	31.6 %
Class 6	29.5 %
Class 7	29.8 %
Class 8	25.8 %

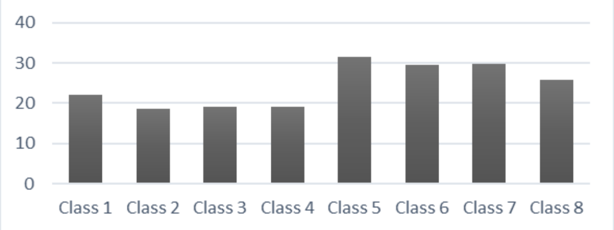

Fig. 16: Discomfort hours percentage- North west orientation

Table 17: Average indoor temperature in June (North- west orientation)

Class	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Mean temperature	31°C	30.2°C	30.9°C	31.1°C	34.2°C	33.7°C	33.5°C	34.6°C

6-5 Thermal Performance Analysis

The lowest average indoor temperature in classes is when the building is oriented to the North direction. The average indoor temperature in classes is when the building is oriented to the west and south west orietations. When the building was oriented to the north, the maximum recorded indoor temperature was 33.8 °C while the maximum recorded indoor temperature when the building was oriented towards the west was 35°C.

Discomfort hours in classrooms record the highest in the west orientation and south west orientation at a percentage of approximately 38.7% which accounts for 459.7 hours representing almost 58 whole school days of discomfort. While discomfort hours in classrooms record the lowest in the north orientation. This difference of thermal discomfort occurs due to the indirect solar radiation on the façade where the classrooms are located while having diffused lighting all year long, with a good ventilation due to being in the prevailing wind direction. The solar gains from windows at the north orientation is about 215 Kwh, while the south west orientation has solar gains of approximately 877 kwh. As shown in table 18, the maximum sensible heat gain source is solar gains from external windows with a percentage of 52% while the second most source is the roof with a percentage of 18%.

Table 18: percentages of sensible heat gain in classrooms in June

Sensible heat gain source	percentage
Roof	18%
Solar gains from external windows	52%
lighting	3%
Occupants	27%

7- RESULTS

Thermal Retrofitting of School Building Prototype

Thermal retrofitting strategies that are applied to the BaseCase are: roof insulation, roof shade, wall insulation, double glazing, fully operable windows, window shading 50% SC and low E-coating glazing as shown in Figure 17.

The results of the simulation process for the retrofit strategies are compared against the BaseCase concerning the discomfort hours as shown in Figures 18,19,20,21,22,23,24,25 and Tables 19,20,21,22,23,24.

Roof
- roof insulation
- roof shade

Walls
- wall insulation

Openings
- double glazing
- fully operable windows
- window shading 50% SC
- low E-coating glass

Fig. 17: Applied retrofit strategies

1- Roof Insulation:

Table 19: Discomfort hours percentage- roof insulation

	Base Case	Roof Insulation
Class 1	14.5	14.1
Class 2	11.2	10.9
Class 3	12	11.8
Class 4	12.8	12.4
Class 5	24.1	23.5
Class 6	19.2	18.4
Class 7	18.5	17.7
Class 8	17.1	16.5

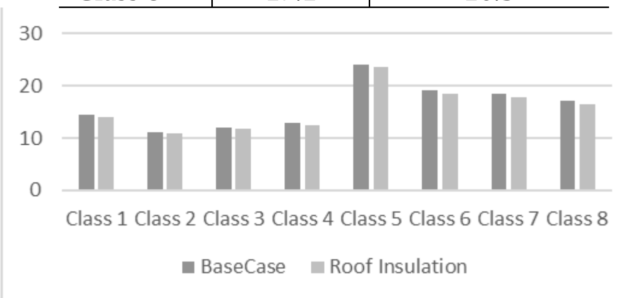

Fig. 18: Discomfort hours percentage- roof insulation

Adding roof insulation includes polystyrene to increase the U-value of the roof slab. It achieved a decrease of discomfort hours as shown in table 19 and figure 18.

2- Roof Shade:

Table 20: Discomfort hours percentage- roof shading

	Base Case	Roof Shading
Class 1	14.5	13.3
Class 2	11.2	9.8
Class 3	12	10.7
Class 4	12.8	11.3
Class 5	24.1	22.3
Class 6	19.2	17.3
Class 7	18.5	16.4
Class 8	17.1	14.8

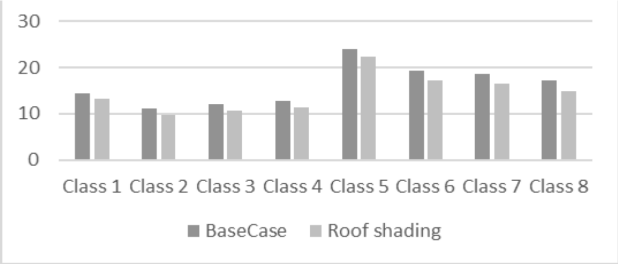

Fig. 19: Discomfort hours percentage- roof shading

Roof shade installed parallel to the roof to minimize the direct solar radiation on the roof. The roof shade achieved great decrease in the discomfort hours as shown in table 20 and figure 19.

3- Wall Insulation:

Table 21: Discomfort hours percentage- wall insulation

	Base Case	Wall Insulation
Class 1	14.5	15
Class 2	11.2	11.9
Class 3	12	12.6
Class 4	12.8	13.3
Class 5	24.1	27.5
Class 6	19.2	23.4
Class 7	18.5	23.5
Class 8	17.1	23.8

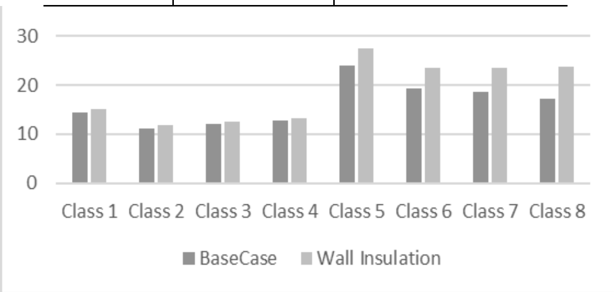

Fig. 20: Discomfort hours percentage- wall insulation

As shown in table 21 and figure 20, Installing wall insulation was suggested but it led to more discomfort as in this case, the Window to Wall Ration (WWR) of 36% with no shading devices caused a rise in the indoor temperature as the heat flux to move in the outward direction through glazing and walls. This simulation proved the wall insulation to be inefficient in this case.

4- Double Glazing:

Table 22: Discomfort hours percentage- double glazing

	Base Case	Double Glazing
Class 1	14.5	14.9
Class 2	11.2	11.7
Class 3	12	12.5
Class 4	12.8	13.2
Class 5	24.1	24.5
Class 6	19.2	19.5
Class 7	18.5	18.7
Class 8	17.1	17.3

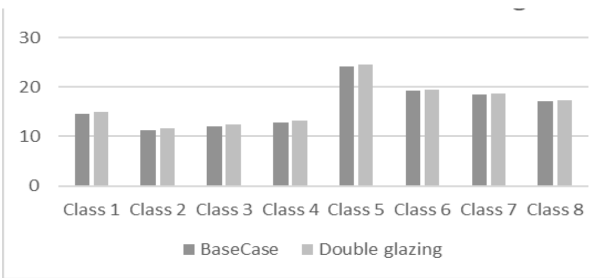

Fig. 21: Discomfort hours percentage- double glazing

Installing double glazing windows to decrease the solar heat gain achieved an increase in the discomfort hours inside classrooms as shown in table 22 and figure 21.

5- Fully Operable Windows:

Table 23: Discomfort hours percentage- fully operable windows

	Base Case	fully operable windows
Class 1	11.2	10.8
Class 2	12	11.5
Class 3	12.8	12.2
Class 4	24.1	23.3
Class 5	19.2	18.3
Class 6	18.5	17.7
Class 7	17.1	16
Class 8	11.2	10.8

Fig.22: Discomfort hours percentage- fully operable windows

As opening types determine the airflow and control its speed, applying fully operable windows enhance the ventilation inside the classrooms which decreased the discomfort hours as shown in table 23 and figure 22.

6- Window Shading 50% SC:

Table 24: Discomfort hours percentage- window shading

	Base Case	Window shading
Class 1	14.5	13.3
Class 2	11.2	10.1
Class 3	12	11
Class 4	12.8	11.8
Class 5	24.1	23.7
Class 6	19.2	18.9
Class 7	18.5	18.2
Class 8	17.1	17

Fig.23: Discomfort hours percentage- window shading

Applying window was effective as 30% of the heat gain in classrooms happens because of the direct solar radiation on the exposed roof of the building. Dealing with the window shading requires considering the daylight as well as the heat transfer as shown in table 24 and figure 23.

7- Low- E Coating Glass:

Table 25: Discomfort hours percentage- Low- E coating

	Base Case	Low- E Coating
Class 1	14.5	13.6
Class 2	11.2	10.4
Class 3	12	11.2
Class 4	12.8	11.8
Class 5	24.1	24.03
Class 6	19.2	19.12
Class 7	18.5	18.41
Class 8	17.1	17.04

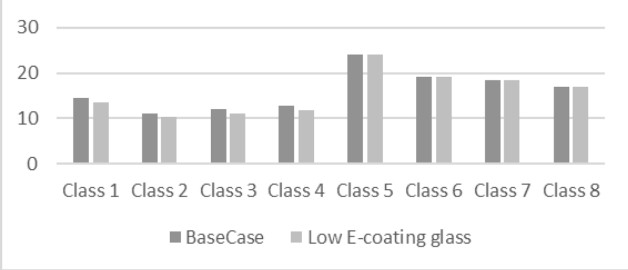

Fig.24 : Discomfort hours percentage- Low-E Coating

Low-E coated glass used in the retrofitting of the building achieved slight decrease in the discomfort hours as shown in table 25 ad figure 24.

As seen from the previous charts and Tables 19,20,21,22,23,24,25 and Figures 18,19,20,21,22,23,24 representing the discomfort hours of the BaseCase and after appling the thermal retrofitting strategies, the strategy with less discomfort hours is the roof shading over all other strategies. The roof shading strategy has more significant effect than the roof insulation as it provides blocking to the direct solar radiation as well as letting the heat transfer through the roof slab from the indoor of the classroom to the outdoor of the classroom. Installing operable windows eliminated discomfort hours by around 6 hours. Among strategies that were used for the openings, using the shading with 50% shading coefficient proved being effective in providing more comfort hours.

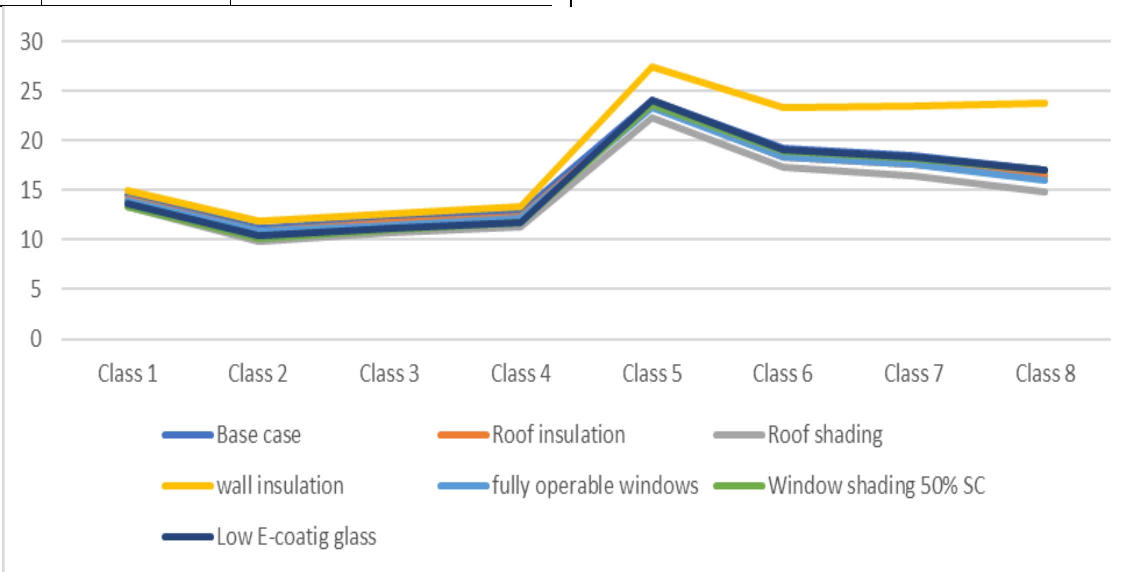

Fig. 25: Discomfort hours for BaseCase and after applying Thermal Retrofit Strategies

7-2 Integration of the Optimum Retrofitting Strategies

The following Table 26 and Figure 26 show the decrease in discomfort hours after applying the most effective thermal retrofitting strategies which are: roof shading, installing fully operable windows and installing shading with 50% SC.

As shown in Table 26 and Figure 26, integrating the most effective thermal retrofitting strategies resulted in enhancing the thermal indoor environment of the classes. This optimization resulted in reducing the discomfort hours by 20% than the discomfort hours of the basecase school building.

Table 26: Discomfort hours percentage- Integration

	Base Case	Integration
Class 1	14.5	13
Class 2	11.2	9.6
Class 3	12	10.6
Class 4	12.8	11.3
Class 5	24.1	19.9
Class 6	19.2	14.5
Class 7	18.5	13.7
Class 8	17.1	12

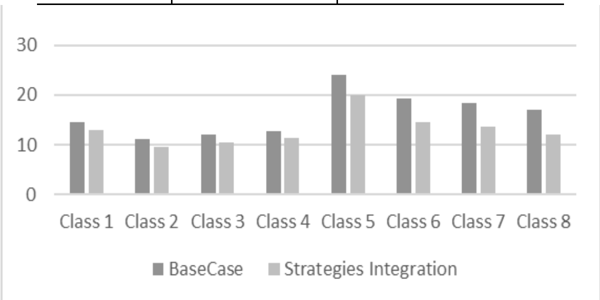

Fig.26 : Discomfort hours percentage- Integration

8- DISCUSSION:

The research findings agree with relevant studies in similar climatic conditions yet in school buildings, the daylight analysis indicates that the levels of natural lighting exceeds the required illumination level in classrooms. Roof shading is the measure of priority to be applied to north oriented school prototype while applying exterior window shading with 50% SC is the measure of priority for south oriented school prototypes. For east oriented school prototypes, it is also recommended to add window shading with 50% SC. For the integration of retrofitting strategies, solar shading is proved to be the most effective for application in the four main orientations by decreasing the amount of discomfort hours.

9- CONCLUSIONS:

The best school orientation of the classrooms is the North orientation in means of thermal comfort and not only visual comfort and daylight considerations. Applying roof shading for the school building is the optimum retrofitting strategy to be applied to school buildings as it results in the greatest decrease in discomfort hours for the occupants. In the case of integrating the thermal retrofit measures, it is better to combine using roof shading, installing fully operable windows and installing shading device with 50% SC. Installing fully operable windows allows for better airflow in the classrooms which increases the thermal comfort and increases the exposure of the thermal mass to the airflow. The results of this research paper will allow decision makers to make decisions that aims at enhancing the indoor environment of school buildings and as well consider these strategies in designing future school buildings. The results of this research can be generalized to school buildings in Egypt that have the same climatic conditions and aiming at providing an enhanced indoor environment for occupants where they feel more thermal and visual comfort.

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