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INVESTIGATING THE INTEGRATION OF AIR-BASED THERMO-ACTIVE BUILDING STRUCTURE (A-TABS) INTO SCHOOL BUILDINGS IN EGYPT

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ABSTRACT

Passive use of thermal mass in buildings has been widely studied and proved its efficiency in increasing thermal comfort and decreasing cooling load. Whereas active utilization of building's thermal mass can enhance the indoor thermal performance and decrease the cooling loads with low energy consumption. This study investigates the integration of active thermal mass strategies into educational buildings. As a case study, a classroom in a governmental school has been referenced and modeled throughout this paper. In this paper, the main focus is drained to numerical simulation which investigates the thermal performance of the classroom case study when its structure is integrated to the proposed Air-based Thermo Active Building Structure (A-TABS) System. Herewith, a set of different simulation scenarios with different simulation parameters are conducted. In this case, every A-TABS system scenario is modeled separately in order to investigate its performance separately and easily compare the results. Results indicate that, by integrating the A-TABS system into the classroom model and under typical summer day conditions; it is observed that the indoor air temperature can be decreased by a range from 0.8°K to 3.2°K. Additionally, the thermal comfort is also monitored to be increased with less energy consumptions and less running costs compared to conventional air conditionings.

Keywords: thermal mass, predictive mean vote model, thermal comfort, discomfort hours, thermo-active building.

1. Introduction

Thermal mass principles can be used in buildings to reduce the need for and the dependence on mechanical heating and cooling systems whilst maintaining environmental comfort [1, 2 and 6]. Unlike passive thermal mass, the walls, slabs or ceiling of a space is made active through the incorporation of pipes or hollow cores. Active thermal mass strategies control the heat storage and release from thermal mass by flowing air or fluid inside it [1 and 10]. Air-based Thermo-Active Building Structure (A-TABS) storage systems operate by drawing ventilation air through the thermal mass at low velocity to maximize the heat transfer with the air.

The basic idea of A-TABS is to make use of thermal properties of concrete to dissipate heat by circulating air through cores inside it. As air from fans travels into the cores, the warm air becomes cooler by giving up some of the heat to the surrounding thermal mass [4]. In this active system, building structure, such as walls and slabs, are considered as a path for supplying air to the classroom increasing the coupling between thermal mass and supply air in order to absorb some of the excess heat from the air that is delivered through it. Fans are placed in the concrete core to supply air into the hollow core slab, other fans are placed at the end of the concrete cores to extract the air from the slab and supply it to the room [3].

For the design of new Egyptian buildings to include active thermal mass strategies, experience from international projects and design guidelines can be used by engineers. Moreover, dynamic thermal modeling is required to accurately investigate the system thermal performance when integrated to the classroom model through virtual test environment. Simulation results provide information about the possibilities of introducing new strategies for building thermal mass activation in Egypt and especially in Cairo.

The A-TABS system is considered an application for the active hollow core precast concrete panels. According to many researches, standard precast concrete slab width is up to 1.2m wide with a span up to 18m and its thickness varies according to the span. Each precast slab has four (or more) hollow cores. The ends of the cores are capped, where each of these cores is connected by bends to form a serpentine air path. Ventilating air is supplied to each slab through centered holes drilled in the bottom of the slab via a main supply duct. Air is then extracted from the room by fans into the ventilation main duct, which distributes the air again to the hollow core concrete slab to be cooled and then to the room. Once the air passes through the cores, it exchanges heat with the concrete. The bottom side of the slab is exposed to the occupied space below, which is also adding thermal mass to the room [11]. The air flow source, in this case, could be fresh air that is fed from outside or re-circulated air from the room.

According to literature, A-TABS slab systems can enable a cooling capacity up to 40W/m^2 and its performance during the heating season is also excellent, utilizing the hollow core slabs for heating and cooling an attractive year-round design option [12]. Jian Yang et al. (2015) established a heat transfer model of active hollow block wall by using numerical simulation method. According to their result, the energy efficiency and indoor thermal comfort of hollow block wall are much better than that of the common wall [17]. Moreover, the thermal performance of hollow block ventilated wall becomes better with the increase of the cavity size. Samo Venko, et al. (2012) studied the cooling potential of thermo activated wall in an office building [18]. The heat that is transferred on a vertical cooled wall is enhanced by a longitudinal jet of supplied fresh air from diffusers mounted parallel on the top of the wall. Their results show a significant decrease of the cooling load and a decrease in energy consumption for cooling the office with a better adaptive thermal comfort.

Whereas, many studies investigate the thermal performance of integrating A-TABS into building construction through experimental tests; in this context, Wahid S. Mohammad et al. (2014) performed an experimental study for the temperature distribution in a space conditioned with A-TABS during summer season in Iraq [12]. Their results so far confirm the advantages of the use of A-TABS system for ventilation and cooling/heating purposes in arid and hot climate for its ease, simple, good performance and energy saving potential. Additionally, their results also show that a good heat reduction could be achieved when the air inlet velocity is equal to 1m/s with different external load, internal load and core temperature. P. Sormunen (2007) developed several concepts to integrate active thermal mass slabs and air-conditioning systems to meet the requirements of energy efficiency and good indoor conditions [21]. His simulation models were validated against measurements. The basic strategy for thermal mass utilization during cooling season is cooling down the slab during unoccupied time by night ventilation to decrease the day time cooling need in the room. His results showed 4% to 10% savings in the heating energy, 46% to 47% savings in the cooling energy and 12% to 23% savings in the fan consumed power compared to traditional systems with passive use of thermal mass.

Throughout literature, it is clear that there is a need for investigating the suitability of integrating active thermal mass strategies in Egyptian climate. In addition, according to the author knowledge, there is not any research so far which investigates such a system into educational buildings. Furthermore, there is not any research that monitors the after construction running costs. Based on the results in [19], which investigate through numerical simulations the annual thermal performance of a classroom in governmental school building in Egypt, the discomfort hours in the classroom have reached 45% of annual academic hours. This paper investigates through software modeling and numerical simulations the thermal performance of the same classroom case study when its structure is integrated into active thermal mass strategies, especially Air-based thermo active building structure (A-TABS) in Egypt. In order to briefly summarize the structure and analysis of this paper, it is important to highlight the problem definition of this paper and its main objectives:

- **Problem definition:** with the rapid increase in energy prices, the field of integrating new energy efficient methods for stabilizing the indoor spaces in educational facilities, especially school buildings, has been much less studied than in other buildings such as offices and commercial buildings.
- **Main objective:** The main objective of this paper is investigating the integration of "Air-Based Thermo-Active Building Structure" system into educational buildings as an approach to stabilize the indoor temperature, eliminate the dependence on conventional air-conditioning systems and reduce the space cooling loads with low energy consumption.

This paper is organized in four sections, Section 1 concerns the introduction and literature reviews. Section 2 discusses the dynamic numerical simulation and software modeling tool that is used for the investigations. It presents its features and potentials in modeling a classroom case study with integrating the Air-Based Thermo-Active Building Structure model through it. Moreover, it presents the simulation scope, methods, parameters and scenarios. Section 3 analyzes the annual results according to the simulation process discussed in the previous section. It evaluates the annual thermal performance of the A-TABS as a cooling system compared to the Base Case (BC) performance by evaluating the mean indoor air temperature, predictive mean vote model, number of discomfort hours, annual energy consumption and average monthly running costs in summer for all scenarios trying to achieve the most efficient performance scenario among other scenarios. Finally, Section 4 is the conclusion of this work and recommendations for integrating the A-TABS system into future Egyptian buildings.

2. Methodology

2.1. Computer modeling and simulation

The authors have selected for their investigation the dynamic numerical simulation tool Energy plus (E+) version 8.2.0.024 with an interface to the software modeling tool Design Builder (DB). E+ has widely been selected by huge number of scientific communities to be used as a tool for thermal and energy performance simulations, as it has been considered more suitable to make a realistic simulation models. Moreover, Design Builder provides advanced modeling and a tool in an easy-to-use interface. Energy plus has been validated under the comparative Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs BESTEST/ASHARE STD [9]. In addition, it has been validated by Energy Efficiency and Renewable Energy (EERE) program, U.S. Department of Energy (DOE). Moreover, Wael Sheta et al. (2010) have validated the Design Builder modeling tool, with the energy plus simulation tool, in Egypt, especially in Cairo region climate [9]. They concluded that DB modeling tool with E+ is a satisfactory and reliable simulation package for investigating the sustainability and thermal performance analysis.

2.1.1. Climatic features and weather data file of greater Cairo region

The case study investigated in this paper is a public primary school building located in the east of Cairo governorate, Egypt. Köppen classification Cairo climate as a hot semi-arid climate, with hot to extremely hot dry summer, and mild to warm wet winter [14]. According to the reports published by the EMA (Egyptian Meteorological Authority) based on other reports from the Climate Research Unit (CRU), university of East Anglia in UK, monitoring the climatic data in the period from 1996 to 2004, recorded 40.0-45.0°C as a maximum temperature range in summer, 20.0-25.0°C as a maximum temperature range in winter, 20.0-25.0°C as a minimum temperature range in summer, and 5.0- 10.0°C as a minimum temperature range in winter.

E+ Weather data file represents the typical long-term weather patterns of the intended region. The weather data file used for this study is (EGY_ALQAHIRAH_CAIRO INTL_ AIRPORT_ETMY.epw); [14]. This file particularly is an Energy Plus weather file with the summary statistics report.

2.1.2. Base case modeling

In this paper a school building is considered as a basic case study for all U-shape single loaded prototype public primary school buildings in Cairo, Egypt, as shown in Fig. 1. The selected classroom (classroom under test) is a cuboidal space with a spatial dimension of 8.00m × 4.80m × 2.90m (length × width × height). The classroom is located in the 2nd floor of a four-story building. It has one external façade (oriented towards the south) which has two windows with a 2.80m length and a 1.30m height. This classroom is selected to investigate its thermal performance when A-TABS systems are integrated into its structure. The base case classroom construction details are mainly based on construction dataset provided with Energy Plus simulation tool are presented in Table1.

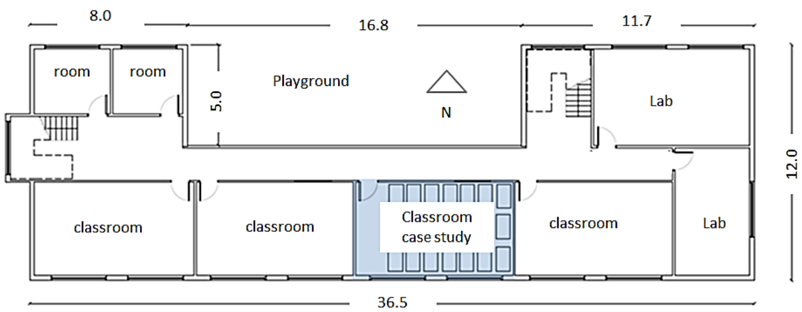


Fig. 1. typical floor plan of typical governmental primary school and selected reference case classroom

Table 1.
Construction details description based on construction dataset provided with Energy Plus simulation tool

Element	Materials	Width (cm)	Materials properties			Thermal transmittance U-value (W/m^2-K)	Specific heat capacity (kj/m^2-k)
			Conductivity W/m^2-k	Specific heat capacity j/kg-k	Density Kg/m^2		
External Walls	Cement mortar and plaster	2.0	0.35	840	950	1.502	147.98
	Red brick	12.0	1.0	800	1950		
	Air gap	5.0					
	Red Brick	12.0	1.0	840	1950		
	Cement mortar and plaster	2.0	0.35	840	950		
Interior partitions	Cement mortar and plaster	2.0	0.35	840	950	2.08	175.96
	Precast concrete	10.0	1.3	840	2100		
	Cement mortar and plaster	2.0	0.35	840	950		
Slab	Marble tiles	2.00	3.5	1000	2800	1.646	208.62
	Cement mortar	2.00	0.72	920	1650		
	Sand	~6.00	2.00	1045	1950		
	Precast concrete	7.0	1.3	840	2100		
	Air gape	5.0					
	Precast concrete	7.0	1.3	840	2100		
Internal doors	Painted Wooden	4.00	-	-	-	3.00	
Windows glazing	Single glazing	0.6	-	-	-	5.77	
	Aluminum framing	6.00	-	-	-		

2.1.3. Air-based thermo-active building structure (A-TABS) system modeling

A-TABS system is integrated into building structure (slabs/walls) and modeled in E+ in a "detailed HVAC model" [16] as a path for supplying air to the classroom. Ventilation air from the inside space is supplies to the active slab/wall through "air loop supply plenum" which acts as a main duct that distributes the air to the hollow core concrete slab. Air is then extractes from the active slab/wall through air loop extract plenum and hence to the room. The air flowing system model for the integrated air loops, intake and outtake into active zones, is implemented in Energy Plus simulation tool as detected in block diagram Fig. 2.

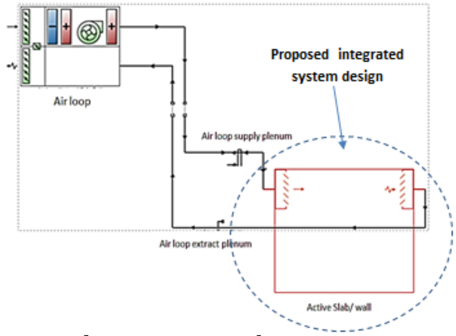


Fig. 2. A typical air loop system layout integrated to active structure: air intake and outtake into zones naming active walls or active slabs (source: E+ detailed HVAC model) [16]

2.1.3.1. Modeling hollow core slab

With a reference to the hollow core slabs manufacture [15], the width of each slab is 1.2m so that in total four slabs are used to compose the floor (width 4.8m) with a length of 8.00m (the classroom length). Hence, the air paths through the four ducts of each slab for 8.00m long. Typically, the two central cores are used for air distribution. The ends of the cores are capped and the cores are connected by bends to form a serpentine air path, as drawn in Fig. 3.

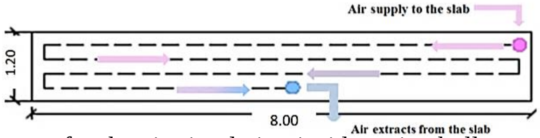


Fig. 3. Schematic diagram for the air circulation inside active hollow core slab (proposed system diagram is designed by the author)

Each slab is cored by means of four cylindrical ducts with circular section, each with a diameter of 0.17m, as shown in Fig. 4. According to Ren, M. J. (1998) discussing the difficulty of modeling the hollow core slab, the following calculations were made to achieve an equivalent model [5]:

- Cross sectional area of concrete = $(120\times25) - (4 \times \pi \times 8.5^2) = 2092.54$ cm²
- By splitting the concrete slab between two plates, there is 1046.27 cm² of concrete in contact with the room above the hollow core slab and 1046.27 cm² is in contact with the room below the hollow core slab (the classroom case study).
- The area of the 1st plate is 1046.27cm² and the depth is 1046.27cm²/120cm= 8.718, so that the 1st concrete plate dimension is 120cm × 8.718 cm (length × depth).
- The area of the second plate is 1046.27cm² and the depth is 1046.27cm²/120cm= 8.718cm, so that the 2nd concrete plate dimensions are 120cm × 8.718cm (length × depth).
- To keep the cross sectional area of the air path through the slab the same, the depth of the air void is determined by this: Area of the air void is $4 \times \pi \times 8.5^2 = 907.46$ cm², the depth of air void is 907.46cm²/ 120cm = 7.56 cm, so dimensions of the air void in between the concrete slab is 120cm × 7.56cm (length × depth).

In the proposed active slab design, each concrete plate is modeled separately. Since the temperature in the four cores is identical, i.e. it is assumed that there is not any heat transfer between cores. Hence, the four cores are modeled as single rectangular core with a dimension of 120cm × 7.6 cm. The equivalence measurements for the simplified model are shown in Fig. 5.

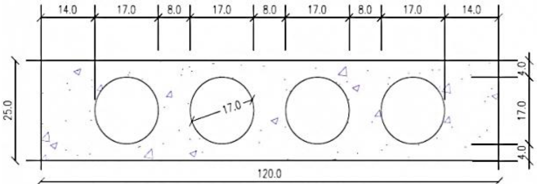


Fig. 4. the precast hollow core concrete slab section

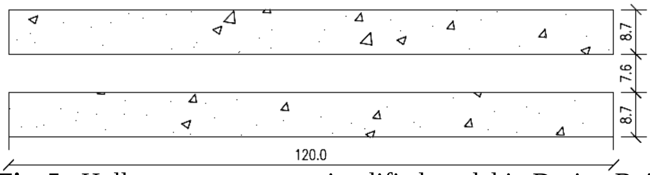


Fig. 5. Hollow core concrete simplified model in Design Builder

As the air passes through the cores, it exchanges heat with the concrete slab. Hence the air is extracted from the room to the slab through extracting vents. Then the air is supplied to the room from the slab panels through the supply vents at the middle of the slab, as shown in Fig. 6.

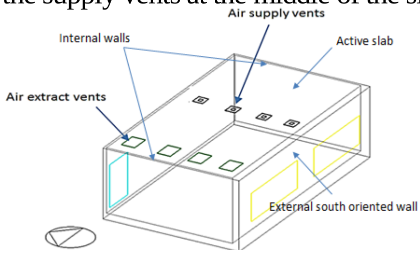


Fig. 6. Modelling the A-TABS system integrated into slab of base case classroom with the supply and extratct vents on the inner side of the system

2.1.3.2 Modeling hollow core walls

The width of each slab is 1.2m such that four wall panels compose the wall of width 4.8m and a height of 2.9m (classroom height from the floor to the ceiling). So, the air paths through the four ducts in each slab for 2.9m long. Typically, the two central cores are used for air distribution. The ends of the cores are capped and the cores are connected by bends to form a serpentine air path, as shown in Fig. 7.

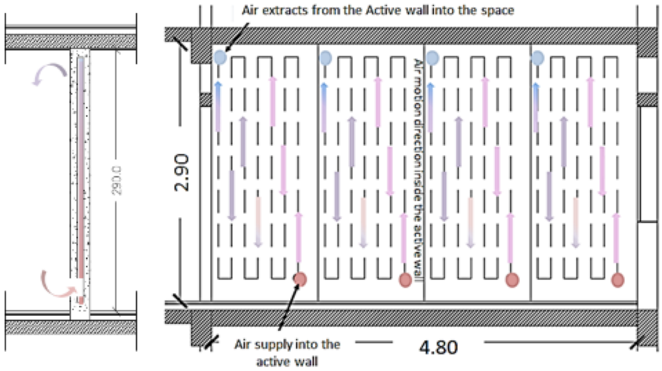


Fig. 7. Schematic diagram for the air circulation inside active hollow core wall (designed by the author)

Each wall is cored by means of eight cylindrical ducts with circular section with a diameter of 0.15m, as shown in Fig. 8. Similar to active hollow core slabs modeling, the active hollow core walls have follows the same calculations to achieve an equivalent model:

- Cross sectional area of concrete= $(120 \times 15) - (8 \times \pi \times 5^2) = 1172$ cm²
- By splitting the concrete wall between two plates there is 586cm² of concrete in contact with the room next to it and 586cm² is in contact with other room (the classroom case study), Fig. 8.
- The area if the first plate is 586 cm² and the depth is 586cm²/120cm= 4.9cm, so the 1st concrete plate dimensions are 120cm × 4.9cm (length × width).
- The area if the second plate is 586 cm² and the depth is 586cm²/120cm= 4.9cm, so 2nd concrete plate dimensions are 120cm × 4.9cm (length × depth).
- To keep the cross sectional area of the air path through the walls the same as the depth of the air void is determined by this: Area of the air void is $8 \times \pi \times 5^2 = 628$ cm², the depth of air void is 628cm²/ 120cm = 5.23cm, so dimensions of the air void in between is 120cm × 5.23cm (length × depth).

Each concrete plate is modeled separately, since the temperature values in the eight cores is identical it is valid to assume that there is no heat transfer between cores, so that the air cores can be modeled as a single rectangular core of dimensions: 120cm × 5.2cm (length × depth), see Fig. 9.

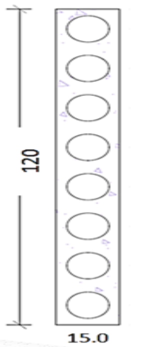


Fig. 8. Precast hollow core concrete wall section

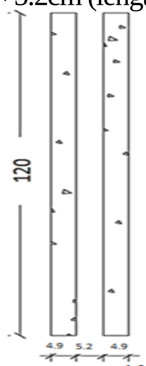


Fig. 9. Hollow core concrete simplified model in E+

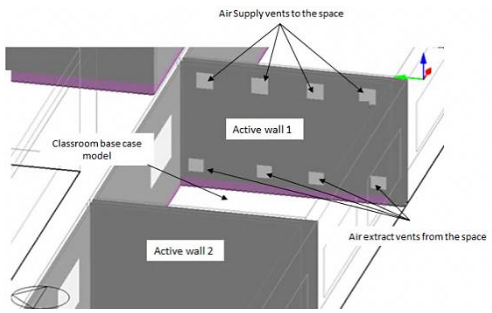


Fig. 10. Modelling the A-TABS system integrated into internal walls of base case classroom with the supply and extratct vents on the internal walls of the classroom

2.2. Simulation scope and method

The A-TABS system simulation scope is to recirculate the indoor air through the designed hollow core ducts into the slabs or walls in order to increase the contact between the air and the concrete thermal mass. Hence, it was mandatory to investigate the efficiency of this mechanism to decrease the temperature of the inlet air supply. The system is studied through the following considerations in Energy Plus simulation tool:

- The slab cores have been simplified as two parallel plates with air passing between them. The internal surface area, volume and cross sectional area of the concrete remains the same and the concrete slab heat transfer coefficient is calculated accordingly.
- **For active slab:** to model a 25cm thick concrete slab with air ducts in the middle, a "building zone" would be defined between stories, quite a lot similar to a standard plenum zone where the ceiling and floor of the plenum zone is set up using 8.7cm concrete constructions with a 7.6cm air duct in-between.
- **For active wall:** similarly to model a 15cm thick concrete wall with air ducts in the middle, a "building zone" would be defined between the two concrete plates, also, very similar to a standard plenum zone and the two concrete plates of the plenum zone is set up using 4.9cm concrete constructions with a 5.2cm air duct in-between
- The active slab/wall double plates were modeled by using a detailed Heat Ventilation Air-Conditioning “HVAC supply” active plenums in Design Builder modeling tool taking into account the heat transfer coefficient and thermo-physical properties.
- Set the Zone type of any active wall/slab plenum zones to “4-Plenum”. This makes the necessary changes in the tool as the plenum zones should have no internal gains, occupancy, lighting etc.,
- In the plenum section, select the “4-Ceiling diffuser” interior convection heat transfer coefficient, for plenum zones, in order to model the effect of air supply rate on the surface heat transfer.
- The outlet from the system supply plenum flows through the zone supply plenum to the zone terminal unit, taking the advantages of the plenum material thermal properties.
- The plenum connection allows air from the supply fans to be passed through the plenum zone before being delivered to the occupied spaces.
- The air is delivered and extracted from the classroom through placements of vents placed into the concrete plate contact to the room where fans are placed.

2.2.1. Input simulation parameters

Simulation parameters are divided into two sections: parameters concerning the geometrical and occupancy levels of the building and parameters concerning the geometrical, thermal characteristics and active considerations of the A-TABS system, as shown in Table 2 and Table 3 respectively.

Table 2.
Simulation fixed parameters concerning the geometrical and occupancy levels of the building in Design Builder modeling tool

Element	Description
Space dimensions	4.80m width x 8.00m length x 2.90m height
Orientation	South oriented
Occupancy pattern	• Sunday to Thursday day, is normal school days, between 8:30 am until 2:30 pm, with occupants rate 1.12person/m² • June and July are considered summer school months, between 9:00 am until 12:30 pm, with occupants rate 0.5person/m² • August is assumed to be vacation to all students and teachers
Lighting	18 fluorescent lamps with a standard intensity of 450 lux

Element	Description
Internal gain	• Penetrating solar heat radiation through openings • Solar heat penetrating through thermal mass • Occupancy: Convective fraction: 4 W/m2 (50%), Radiative fraction: 4 W/m² • and lighting Convective fraction: 8.64 W/m2 (72%), Radiative fraction: 3.36 W/m²
Metabolic rate	0.75
Holidays	2 days / week
Annual vacation	August month
Construction	As best case
Openings orientation	South orientation
Openings percentage	33%
Opening dimensions	Two windows south oriented each 2.80 length x 1.30 height
Internal blinds	non
External shading elements	non

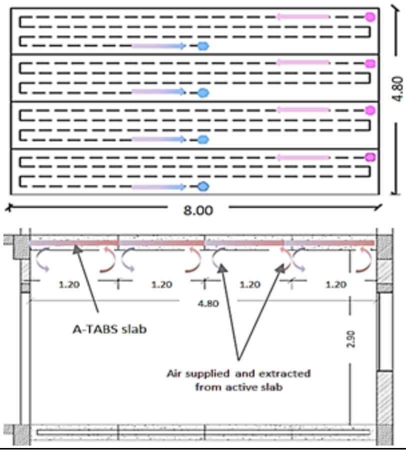
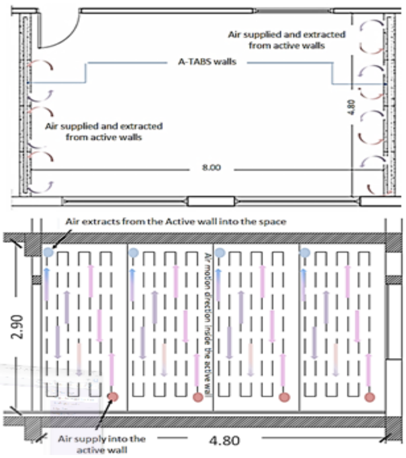
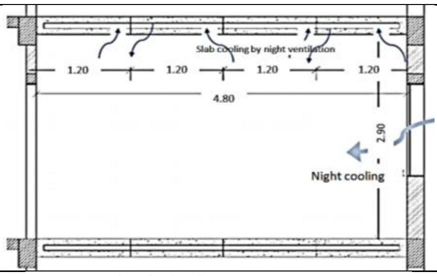
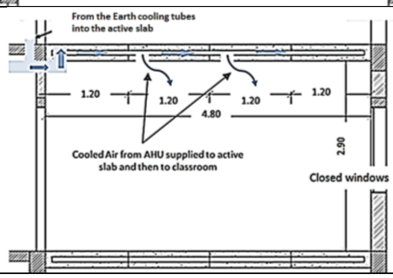
Table 3.
fixed parameters concerning the geometrical, thermal characteristics and active considerations of the A-TABS system

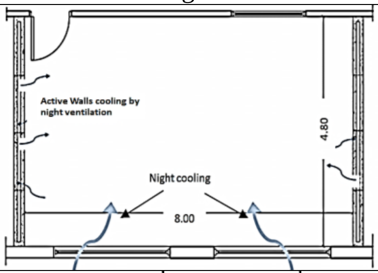
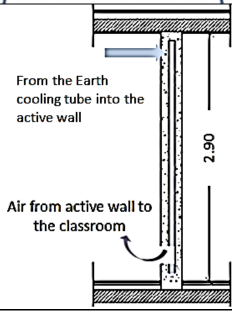
Parameter	Value
Concrete panel parameters	
Conductivity	1.4 W/mK
Specific heat	840 J/kgK
Density	2100 kg/m³
Absorptivity	0.6
Area of fabric in contact with the air	Area of slab=38.4m² Area of 2 walls= 2×13.92= 27.84m²
Placement of active slab/walls	Active Slab: Contact to ceiling Active Wall: 2 internal walls
Active parameters	
Air supply rate	0.045m3/s
Fan running times	8am until 2:30
Average Inlet air temperature	30°C

2.2.2. Simulation scenarios

In this simulation process the authors investigate the potential performance of Air-based Thermo Active Building Structure (A-TABS) through simulating different scenarios using the virtual test environment Energy Plus simulation tool for a full year investigations. The differences in scenarios depend on the air supply and exhaust sources. In which: for the SC1 and SC2, the space air is re-circulated and supplied to the active wall/slab and then to the space once more via supply and exhaust fans embedded in the active slab/wall. While in SC3 and SC5 the night cooling is introduced to the system in order to cool the active slab/walls at night. For SC4 and SC6, the earth cooling tubes are introduced in order to cool the air before it enters the active slab/walls [20]. Simulation schematic diagram of each scenario, designed by the author, are presented in Table 4.

Table 4.
A-TABS simulation scenarios

Scenario	Diagram
SC1 Integrating the A-TABS into classroom slab	
SC2 Integrating the A-TABS into internal walls	
SC3 Integrating the A-TABS-slab in addition with night cooling to cool the thermal mass	
SC4 Integrating the A-TABS-slab in addition with a underground earth cooling tubes, and hence into the slab	

Scenario	Diagram
SC5 Integrating the A-TABS-walls in addition with night cooling to cool the thermal mass	
SC6 Integrating the A-TABS-wall in addition with a underground earth cooling tubes, and hence into the wall	

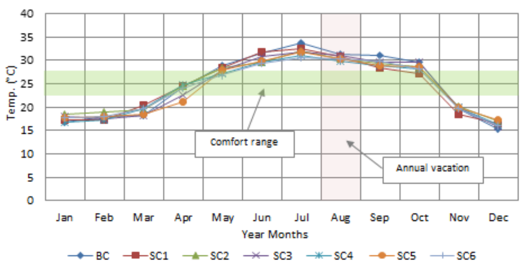
3. Results and discussion

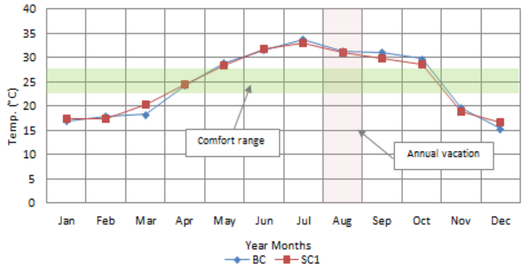
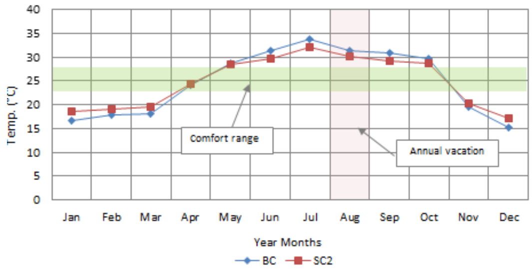
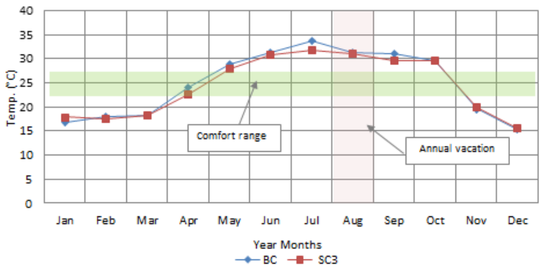
In order to evaluate the performance of the A-TABS cooling system, 6 different scenarios are simulated and analyzed, according to simulation process discussed at the pervious section. Results for a complete one year evaluations are presented and compared to the Base Case (BC) in the next section.

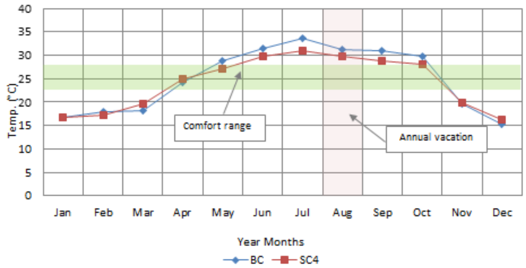
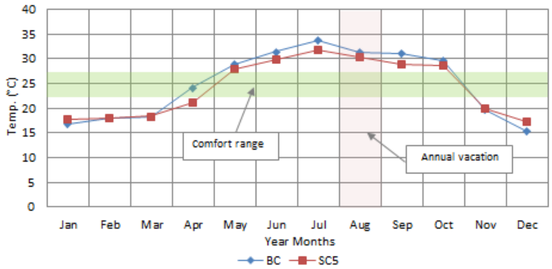
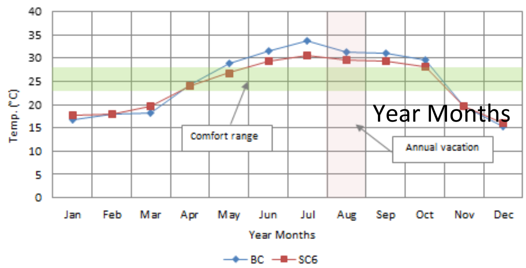
3.1. Annual mean air temperature

Annual mean indoor air temperature is simulated for every A-TABS scenario, results for all scenarios show that A-TABS is considered efficient heat storage systems that can stabilize the indoor air temperature. Results indicate that A-TABS system can decrease the mean indoor air temperature by a range from 0.8°K to 3.2°K in very hot summer months depending on the scenario efficiency and energy consumed. The Adaptive Comfort Standard (ACS) in this case is calculated to be in the range of 23.5-28°C [8]. Table 5 lists the results of the annual mean indoor air temperature in Energy Plus simulation tool.

Table 5.
Results of Annual mean indoor air temperature

Scenarios	Simulation result versus BC
All SCs	
	Analysis: All the scenarios are in the comfort range until May, thereafter, from June until the first half of september all scenarios are out of comfort range. However, some scenarios are near to the comfort range. All scenarios are under the comfort range from

<table>
<tr><th>Scenarios</th><th>Simulation result versus BC</th></tr>
<tr><td></td><td>January until March, as well as, November and December. The annual temperatures of evey scenario are presented in the next section compared individually to the BC.</td></tr>
<tr><td rowspan="2">SC1</td><td>
</td></tr>
<tr><td>Analysis: In SC1, the indoor air is circulated into the hollow core concrete slab panels and hence, supplied once more to the classroom space after being interacted with the concrete material thermal properties. Through regular school months, i.e., until May, the internal temperature is in comfort range and the A-TABS system presents minor role. In extreme summer months from June until the end of July, SC1 decreases the extreme high temperatures by about 0.8°K; however, it is also out of the comfort range. It is important to mention here that August is considered an annual vocational month and is not included in the occupied hours investigations in the simulation tool.</td></tr>
<tr><td rowspan="2">SC2</td><td>
</td></tr>
<tr><td>Analysis: In SC2, the indoor air is circulated through a hollow core concrete wall panels through the 2 internal partitions, and hence supplied once more to the classroom space after it is being interacted with the concrete material thermal properties. Through regular school months, i.e., until May, the internal temperature is in comfort range and the A-TABS system presents no role. In extreme summer months from June until the first half of October, it is clear from our results that SC2 decreases the extreme high temperatures by about 1.7°K and considered more efficient than SC1; however, it is also out of the comfort range.</td></tr>
<tr><td rowspan="2">SC3</td><td>
</td></tr>
<tr><td>Analysis: In SC3, the indoor air is circulated through a hollow core concrete slab panels and hence, supplied once more to the classroom space. Night ventilation (NV) is integrated to the system in order to discharge the concrete thermal mass to be able to charge once more in the next day. Through the school months, until May, the internal temperature is in the comfort range and</td></tr>
</table>

<table>
<tr><th>Scenarios</th><th>Simulation result versus BC</th></tr>
<tr><td></td><td>the A-TABS system presents a minor role. In extreme months, SC3 decreases the extreme high temperatures by about 2.0°K in July. In SC3, the concrete panels present more efficiency in June and July than the previous scenarios due to the discharging by night cooling. However, in August the air temperatures present a little decreasing in temperatures.</td></tr>
<tr><td rowspan="2">SC4</td><td>
</td></tr>
<tr><td>Analysis: in SC4, the outdoor air is circulated by pumps into the underground earth cooling tubes and then into the hollow core concrete slab panels and hence, supplied to the classroom space. In summer months, SC3 decreases the extreme high temperatures by about 2.7°K in July and 1.5°K in August. In SC4 The concrete panels present more effectiveness than the previous scenarios due to their integration to the underground earth tubes as a cooling source. However, it shows increase in energy consumption and running costs.</td></tr>
<tr><td rowspan="2">SC5</td><td>
</td></tr>
<tr><td>Analysis: In SC5, the indoor air is circulated into a hollow core concrete wall panels in the internal partitions and hence, supplied once more to the classroom space. Night ventilation is integrated to the system for discharging the concrete wall panels to be able to be charged once more the next day. Through school months, until May, the internal temperature was in the comfort range and the A-TABS system presents no role. In extreme summer months, i.e., from June until August, SC5 decreases the extreme high temperatures by about 2.0°K in July and 1.0°K in August. In SC5, the concrete panels present more efficiency in summer months than SC1, SC2 and SC3 due to its discharging by night cooling.</td></tr>
<tr><td>SC6</td><td>
</td></tr>
</table>

Scenarios	Simulation result versus BC
	Analysis: In SC6, the outdoor air is circulated by air pumps into the underground earth cooling tubes and then into the hollow core concrete wall panels and hence, supplied to the classroom space. In summer months, i.e., from April until October, the A-TABS SC3 decreases the extreme high temperatures by about 3.2°K in July and 2.0°K in August. In SC6, the concrete panels present more effective than in SC4; the mean air temperature is near the comfort zone.

3.2. Annual thermal comfort

Students' thermal comfort is one of the primary elements determining the quality of indoor environment in classrooms, as it affects students' productivity and health [7]. Whereas, occupancy rate, metabolic rate, and indoor air temperature are factors that affect directly the student thermal comfort rate. According to the reference case classroom in the governmental school in Egypt, the occupancy rate is 1.12 person/m²; this rate is more than the classrooms occupancy rates standards. Metabolic rate and clothing insulation were estimated according to ASHRAE standards 55[8], and being fixed in all scenarios to allow a fair comparison. This section examines the thermal comfort criteria of Fanger Predicted Mean Vote (PMV) [7], which is calculated according to ISO 7730, for all scenarios in the classroom comparing them with the BC. According to ASHRAE 55 standards, the acceptable thermal comfort range for a PMV lies between -1 and +1 [7].

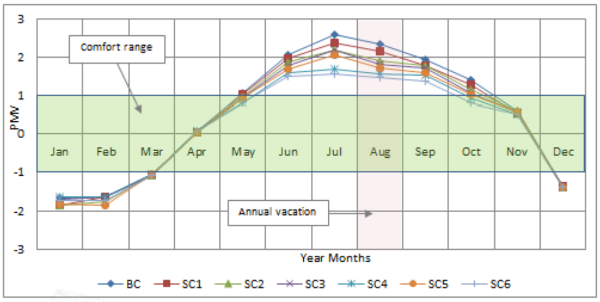


Fig. 11. Annual average thermal comfort indicator predictive mean vote (PMV) of all A-TABS scearios Vs. BC

Figure 11 indicates that the annual average PMV of all proposed scenarios are in the comfort range from March up till May and from October until November. All scenarios are out of comfort range from June until September (due to the extreme high temperature) and in January, February and December (due to the extreme low temperature). For the base case BC, in which there is no active system, the PMV records its highest range in July, it is about 2.59. For SC1, in which air flows in the concrete hollow core slab, is having the highest PMV range; it reached its maximum value in July to be about 2.38. August is proposed in energy plus as the annual academic vacation month, however, it is considered in the annual PMV calculations.

For SC2, in which air flows in the two concrete partitions, is considered more comfort than SC1; the PMV reached its maximum values in July to be 2.20. For SC3, in which the air flows in the concrete slab with the presence of night ventilation to discharge the concrete, expresses lower PMV range than SC1 as the night cooling decreases the slab temperature to reach its maximum value in July to be 2.18.

The PMV range of SC4 presents a range lower than all the previous scenarios, this is due to the reason that in this scenario the air is circulated into the underground earth cooling tubes then to the slab and hence, to the classroom, its maximum value reaches 1.68. For SC5, in which the air is forced into wall partitions with the presence of night cooling, its maximum value is less than what is recorded by SC2, it reaches 2.08. Finally, SC6, in which the air is circulated into underground earth cooling tubes and then into walls, has recorded the lowest PMV value. Additionally, it has the best PMV range compared to all other scenarios, as it reaches a maximum value of about 1.58. Therefore, the A-TABS can decrease the PMV model from 2.59 (in BC) to reach 1.58 (in SC6)

3.3. Annual discomfort hours

As a definition, the discomfort hours are the time when the combination of zone humidity ratio and operative temperature is not in the ASHRAE 55-2004 ***summer or winter*** region [8]. Fig. 12 presents the number of discomfort hours during the classroom occupied time.

The annual discomfort hours results, presented in Fig. 12, show that SC1 decreases the discomfort hours by about 451.68 hours (i.e. 16.3%). SC2 is enhanced and decreases the discomfort hours by about 561.05 hours (20.3%). For SC3, the number of discomfort hours is very close to SC2, compared to BC, where it reduces the discomfort hours by about 596.5 hours (21.6%). SC4 is better than all the previous scenarios as the air is cooled before entering the slab. It reduces the number of discomfort hours by about 889.93 hours (32.1%) which is considered a great achievement. SC5 is having more discomfort hours than SC4; it decreases the discomfort hours by about 774.04 hours (28%) compared to the BC. The best scenario is considered to be SC6 as it has the lowest discomfort hours among all other scenarios. It reduces the discomfort hours of BC by about 1010.72 hours (36.5%), though; it has the highest energy consumption among all other scenarios.

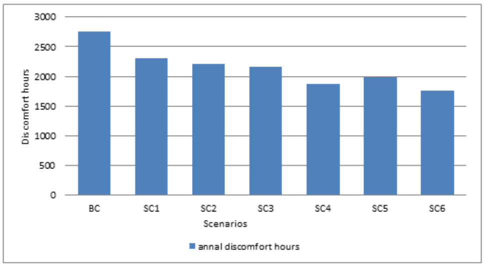


Fig. 12. results of annual discomfort hours for all scenarios Vs. BC

3.4. Annual energy consumption

Annual energy consumption is defined as the energy consumed for the active cooling or heating system during a year. All A-TABS system different scenarios consume energy for the supplies and exhaust fans or for pumping the air into the ground cooling tubes. Fig. 13 presents the annual energy consumption of every scenario compared to the base case.

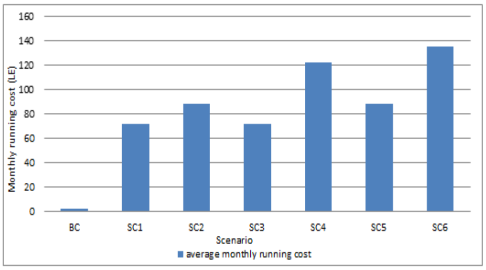


Fig. 13. Results of annual energy consumptions for all scenarios Vs. BC

Figure 13 shows that the BC has zero energy consumption as it has no active cooling system integrated. SC1and SC3 are having a lower energy consumption among all scenarios as they consume energy just for supplying and exhausting fans embedded in the concrete core slab. They consume annually the same amount of energy, which is about 1079 kWh. SC2 and SC5 are consuming energy in supplying and exhausting fans embedded in the concrete core walls. These systems are having more fans than in SC1 and SC3, so they consume the same energy for air forcing; they consume about 1321 kWh. SC4 is considered more effective than SC1, SC2, and SC3, however, it consumes more energy than the previous scenarios for pumping the air to the ground cooling tubes and then to the slab, it consumes about 1830.54 kWh. Finally, SC6 is the most effective scenario as it has the minimum values for internal air temperature, PMV, and annual discomfort hours. Nevertheless, it has the highest energy consumption among all scenarios as it consumes about 2030.38 kWh.

3.5. Average monthly running cost for cooling systems

The running cost depends mainly on the amount of energy consumed. Hence, according to the Egyptian Electric Utility and Consumer Protection Regulatory Agency, the average electricity cost is 0.4 P.T/kWh for educational buildings for the year 2016 [13]. By calculating the monthly energy consumption, Fig. 14 depicts the average monthly running cost.

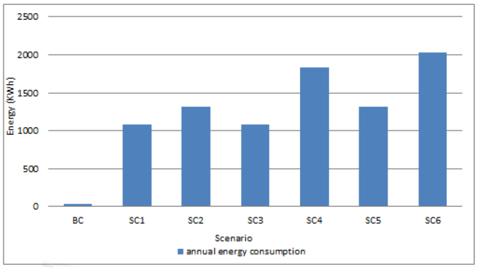


Fig. 14. results of average monthly running costs for all scenarios Vs. BC

The BC has zero energy consumption value, as it has no active cooling system integrated to it; therefor it has a zero-running cost. SC1 and SC3 are having the lowest energy consumption among all discussed scenarios. Thereby, their average running cost, during the summer occupancy time, is about 71.89 L.E./month. SC2 and SC5 are consuming energy in supplying and exhausting fans embedded in the concrete core walls; hence, they consume more energy for air forcing. They have an average running cost of about 88.05 L.E./month. SC4 is considered more effective than SC1, SC2, and SC3; thus, it consumes more energy than all the previous scenarios so it has more average running cost in summer occupancy time about 122 L.E./month. However, SC6 is the most effective; it has the highest energy consumption and running cost among all scenarios. Its average running cost in summer occupancy time is about 135.5 L.E./month.

4. Conclusion and recommendations

This paper is considered a detailed investigation for the integration of air based active thermal mass strategies into a classroom in an Egyptian school building. Air-Based Thermo Active Structure (A-TABS) system is modeled and integrated into the base case classroom model. In order to evaluate the system performance, six different scenarios were simulated; annual simulation results were presented and compared with the base case thermal performance. Based on the result of the numerical result, the A-TABS system can decrease the incoming supply air by a range from 0.8°K to 3.2°K in very hot summer. Moreover, the A-

TABS system can decrease the PMV model from 2.35 to reach about 1.58 for the most efficient performance scenario. In addition, results indicate that the annual discomfort hours can be decreased up to 36.5% less than the base case. However, the annual energy consumption is within the range from 1078.4kWh to 2030.38 kWh with an average monthly running cost ranging from 71.89 L.E./month to 135.5L.E./month (electricity costs for the year 2016).

The results in this paper demonstrate the efficiency of A-TABS as a cooling system when integrated into the building structure. Therefore, this system can be applied to classrooms in in hot arid climate in Egypt, they will not be extended to another stage without further simulation, and future work is needed to examine the system experimentally. The following recommendations are needed for integrating the A-TABS system into future Egyptian buildings:

- Architects should consider the active thermal mass strategies from the first stages of the design of new buildings taking into account the environmental design guide lines in order to gain the most efficiency.
- Moreover, architects should use computer modeling and simulation tools before constructing the building integrated with A-TABS systems to ensure its effectiveness and to calculate its thermal performance in different locations.
- Engineers should accurately calculate the internal heat gain in order to select the most appropriate scenario into the building.

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التحقق من كفاءة دمج الكتلة الحراريه النشطة المعتمده على الهواء في المباني المدرسية القائمة في مصر

ملخص

سابقا، أثبتت الدراسات كفاءة الاستخدام السلبي للكتلة الحرارية في المباني على نطاق واسع في مجال زيادة الراحة الحرارية وتقليل أحمال التبريد. في حين أن استخدام الكتلة الحرارية النشطة في المباني من الممكن أن تعزز الأداء الحراري في الأماكن المغلقة و تخفض احمال التبريد مع الاستهلاك القليل للطاقة. تبحث هذه الدراسة كيفية تحقيق التكامل بين استراتيجيات الكتلة الحرارية النشطة في المباني التعليمية، و كدراسة حالة، تم الإشارة إلى الفصول الدراسية في مدرسة حكومية . في هذه الورقة، سوف يتم التركيزعلى أستخدام المحاكاه العددية للتحقق من الأداء الحراري لدراسة حالة الفصول عندما يتم دمج هيكلها إلى، النظام المقترح، الكتلة الحراريه النشطة على أساس الهواء. طيه، يتم تنفيذ مجموعة من سيناريوهات محاكاة مختلفة. في هذه الحالة، يتم دراسة كل سيناريو للنظام على حدة من أجل التحقق من أدائه على حدة ولسهولة مقارنة النتائج

وتشير النتائج إلى أن، من خلال دمج نظام الكتلة الحراريه النشطة في نموذج الفصول الدراسية وفي ظل ظروف نموذجية الشهور الصيفيه. لوحظ أن درجة حرارة الهواء في الأماكن المغلقة يمكن انخفاضها بمقدار يتراوح بين ٠.٨ درجة مئوية إلى ٣.٢ درجة مئوية. بالإضافة إلى ذلك، تم رصد وجود زيادة في الراحة الحرارية أيضا مع أقل استهلاك الطاقة وتكاليف التشغيل بالمقارنة مع أنظمة التكييف التقليدية.