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Cooling Energy Savings for A Campus Building Using Sustainable Envelope-Case Study.

Reda Y. M. Allam*, Rafik Belarbi, Madi Kabore and Sherif Sheta

KEYWORDS:
Cooling, materials, straw, thermal, performance.

Abstract— **Electricity consumption of the Egyptian building sectors has an increasing rate from 2014 until now according to annual report for electricity ministry [1].**

Hence, this research examines the common building envelope systems after increasing the thermal resistance of exterior envelopes to achieve high energy efficient buildings. That will be attained by:

1- field results for the case under study is used to validate numerical model. Then, the thermal performance for the case study is increased by exterior thermal insulation panels, reduced air infiltration through double glass windows instead of infiltrated single glass windows.

2-Three-dimensional numerical results - TRNSYS v17 program, which demonstrated that, only 0.35 m thick straw panels for the external walls, double glass windows with 1.5 m horizontal shading and 0.6 ach ventilation rate save 26.6 % cooling energy for the building under study. While 0.15 m and 0.2 m expanded polystyrene panels can save 24 % and 23 % respectively.

I. INTRODUCTION

In Egypt, the electricity consumption from the building sector reached 60.9%, 60.2 %, 57.6 % for 2014/2015, 2016/2017 and 2018/2019, as percentage of the total nation-wide consumptions[2]. The main reasons behind this high rate can be resulted from the population growth, the rapid urbanization, and the poor thermal performance of building envelopes [3]–[5]. Also, the inhabitants purchase and consume more mechanical devices to attain the thermal comfort in their indoor environments.

Also, climate changes and heat island effect - specially in highly populated cities - have resulted in much less comfort indoor environments within residential and commercial buildings.

As the cooling energy represents high percentage of the total consumed energy in buildings sectors, we can reach fewer cooling loads by using highly efficient buildings envelopes.

Hence, our study aims to reach the buildings assemblies with high energy performance.

The highly efficient thermal properties for sustainable waste materials like rice straw and soil increase the chance to be used with less initial cost, as it is observed with huge volumes in the Egyptian countryside. By applying these sustainable materials for existing and new buildings, we can reach highly efficient buildings with less energy consumption and high thermal comfort.

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****Corresponding Author:*** *Reda Y. M. ALLAM, Assistant Professor at Structural Engineering, Engineering Faculty, Mansoura University, Egypt (e-mail: ryma@man.edu.eg).*

Rafik BELARBI, Professor, Civil Engineering, La Rochelle University, France (e-mail rbelarbi@univ-lr.fr).

Madi KABORE, Assistant Professor, [3]DE/IRSAT/CNRST, Ouagadougou 03 BP 7047, Burkina Faso (e-mail madi_kabore@outlook.com).

Rafik BELARBI, Associate Professor, Architectural Engineering, Engineering Faculty, Mansoura University, Egypt (e-mail: sheriefsheta@man.edu.eg).

A. *Straw Panels in Previous Studies*

The previous studies presented the hygric and thermal performance for straw bales. For example, in Chuen Hon (Alex) Koh's review article, straw bales have a satisfactory thermal performance in warm climate and low moisture environments. They demonstrated that straw bales degrade with moistures contents more than 20 % and has high environmental impact lower than traditional thermal insulation materials[6].

Alessandro et al., performed laboratory and in situ tests to evaluate the thermal performance for straw buildings. They determined thermal conductivity laboratory to be 0.052 W/m K for 80 kg/m3 straw bales and 0.119 W/m2 K of thermal transmittance in situ test for 0.45 thick wall[7].

Omar Douzaine et al., provided hygrothermal performance for straw bale house built in France. They found that lime plaster regulate moisture and protect straw bales from degradation. Also, thermal comfort and high thermal performance can be attained in straw bales house[8].

Reeman Mohammed Rehan demonstrated the heat island mitigation strategies to reach cool cities with sustainable solutions: green roof, green infrastructure, urban water,..etc [9].

B. *Research Gab and Present Study*

This study presents the behavior of straw panels as an exterior insulation materials and the possible energy savings techniques. We can reach low cooling energy house using straw bales in hot dry climates like Egypt. This goal is achieved by sustaining the building envelopes for existing building with straw bales. That will be compared with traditional insulation material-expanded polystyrene, to determine the cost difference between two cases.

II. MATERIAL AND METHODS

To reach low cooling energy using straw panels, we:

- Specify hygrothermal properties for external walls and roofs materials.
- Capture field temperature and relative humidity values for the building under study to validate the numerical model.
- Use three-dimensional numerical analysis for the case study to reach low cooling loads.

A. *Hygrothermal Properties for External Walls and Roofs Materials*

Table 1 and Table 2 present the hygrothermal properties: thermal conductivity(λ), specific heat capacity (Cp), dry density (ρd), open porosity (n), water vapor resistance coefficient (μ) of the red brick materials and cement sand mortar [10]. While concrete, expanded polystyrene, bitumen and straw materials are taken from the literatures [11]– [16].

To reach highly efficient buildings, the thermal and hygric resistances for the envelope's materials-windows, external roofs, and walls must be increased.

For the building under study -Fig. 2, the thickness of external walls of 0.25 m which fabricated from fired red brick. With, the thermal conductivity (λ) for the red brick ranges from 0.6 m to 1.0 w/m. K (this value increases with moisture contents) [17]– [19]. Hence, the thermal resistance for the external walls will be 0.13 to 0.31 m2K/W without convective and radiative heat transfer.

The existing single glass windows have low thermal resistance and high infiltration rate due to air gabs between the frame and the walls [20]– [22].

B. *Model's Validation*

For Fig. 1 which demonstrates the simulated model for an educational building in Mansoura city, we validate the numerical model by capturing the field data for temperature (T) and relative humidity (RH) within and outside a building's room. The used sensors have small sizes with 3.0 mm width and 0.5 mm length, which has small effect on the hygrothermal behavior. It is calibrated to ±1.4% for RH values and ±0.5°C for Temperature degrees.

The test was performed in January 2019 for the chosen room under perfect closing for windows and doors. The temperature for outside and inside environments are captured for the south wall in the chosen chamber.

The real data and the simulated data from TRNSYS numerical program demonstrate the convergence between the field and numerical data by 1% to 10% for temperatures data-Fig.3 and 4 % to 24.5 % for relative humidity data-Fig.4. The root mean square error (RMSE) is determined to be 5% for temperature and 6% for relative humidity values.

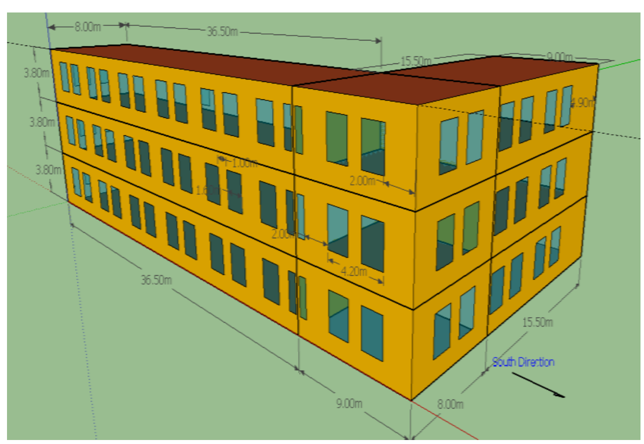

Fig. 1: Building's simulation dimensions.

TABLE 1
THERMAL AND PHYSICAL PROPERTIES FOR USED MATERIALS [6], [11]–[13], [15], [16], [23]–[25].

#	Thermal conductivity, λ (W/m K)	Specific heat, CP (kJ/kg K)	Dry density, ρd (kg/m3)	Open porosity, n [-]	Vapor resistance, μ [-]
Reinforced concrete (RC)	2	1	2450	0.18	248
Red brick (RB)	0.65	0.8	1900	0.31	15
Straw Panel (SP)	0.07	0.8	100	0.8	4.5
Cement plaster (CP)	0.72	0.83	1850	0.3	25
Expanded polystyrene (EP)	0.039	1.25	30	0.95	50
Bitumen sheet (BI)	0.17	1.0	1200	-	-
Lime plaster (LP)	0.87	1.0	1800	0.3	7
Sand layer (SL)	0.7	1.0	1800	0.3	1
Reinforced Concrete Block (RCB)	1.13	1.0	1.4	0.2	92
Steel Sheet (STS)	15	1.8	7800	-	
Timber Sheet (TS)	0.2	2.0	800	0.52	144
Ceramic for floor (CEF)	1.0	1.0	2000		
Clay Tiles (CT)	1.0	1.0	2000		
Gypsum Board (GB)	0.29	1.0	800	0.65	8.3
Air gab (AG)	Thermal resistance =0.17 m2 K/W	Infiltration and ventilation rate=0.6 ACH			

TABLE 2
HYGROTHERMAL PROPERTIES FOR FIRED CLAY BRICK AND STRAW PANELS [10], [6], [23], [24], [26].

Parameter	Fired clay brick	Straw panel
Sorption Isotherm (kg/kg)	Wufi©2D data base	$w_g = \frac{Cs}{1 + n * \left(\frac{K}{\varphi} - 1\right)^{i/3}}$
Water vapor resistance factor	$\mu = 15$	$\mu = 4.5$
Thermal conductivity (W/m K)	$\lambda = 0.65$	$\lambda = 0.07$
Dry specific heat capacity (KJ/kg K)	Cp=800	Cp=800
Dry Density (Kg/m³)	ρ_d=1900	ρ_d=100

Fig. 2: building under study-31.0422, 31.3592.

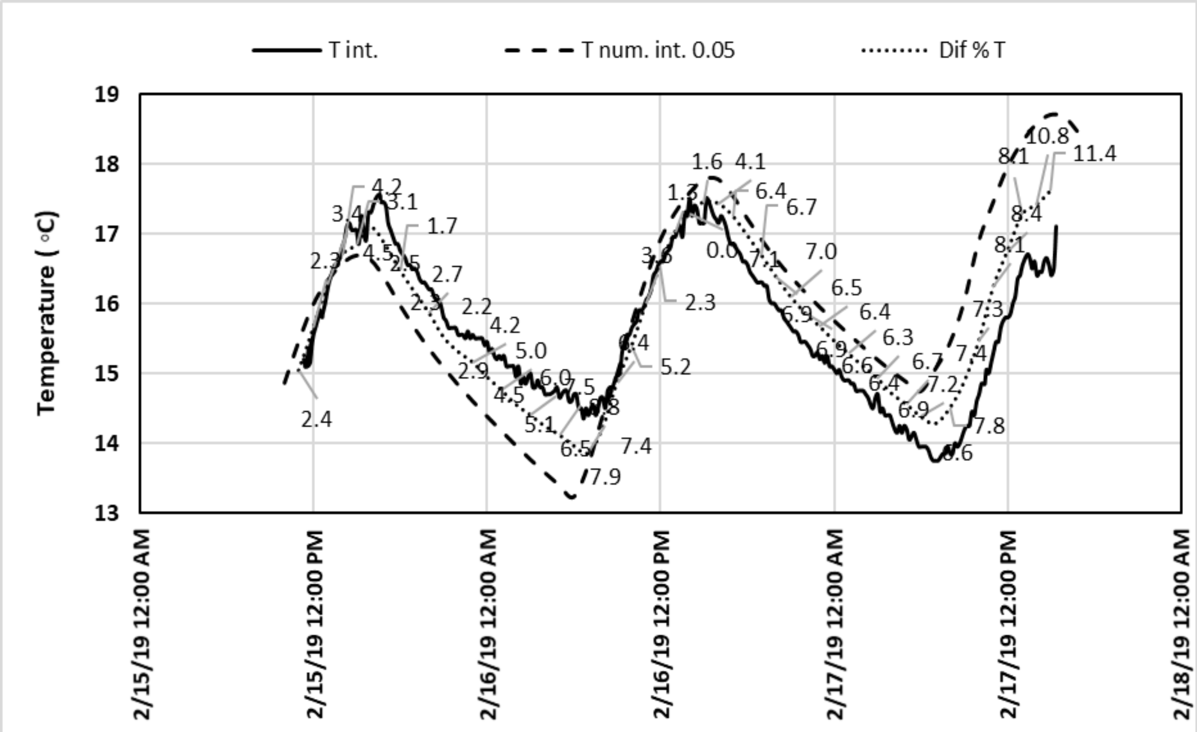

Fig. 3: The indoor temperature for the numerical and field data for south wall.

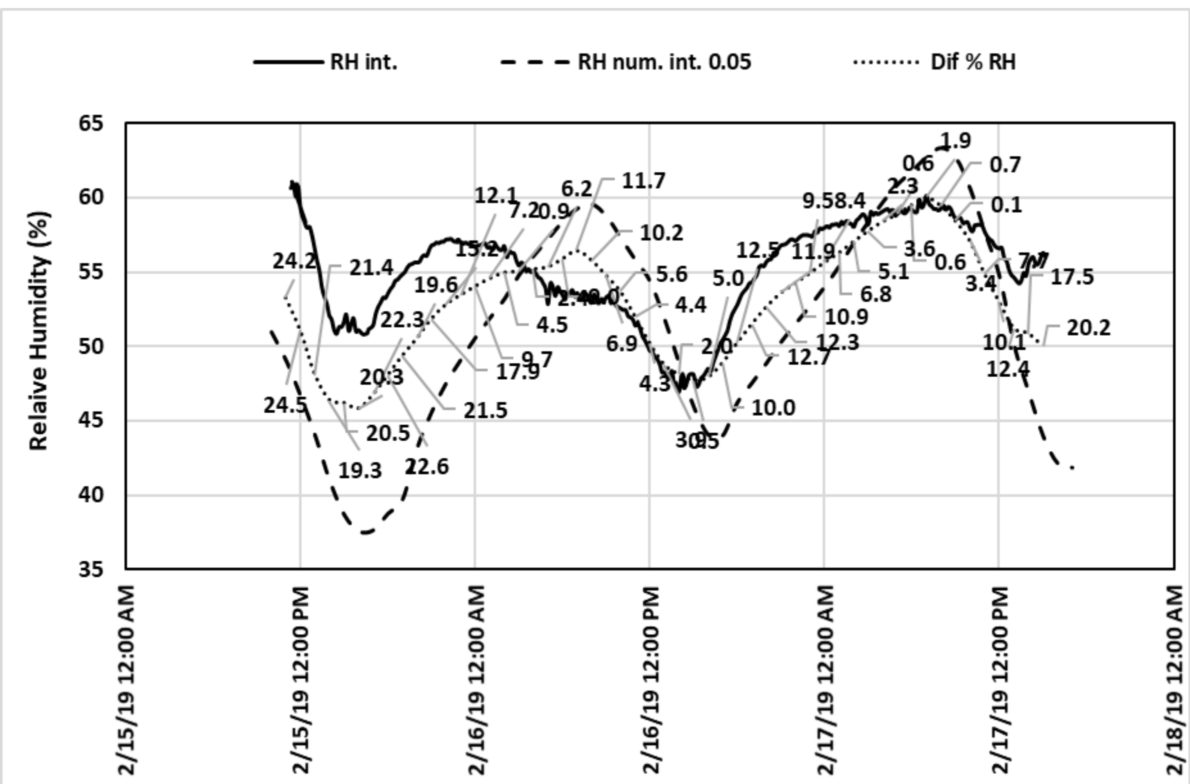

Fig. 4: The indoor relative humidity for the numerical and field data for south wall.

C. Study methods

The external envelope for the case study has low thermal resistance to reach the thermal comfort without cooling energy. So, this research studies the considered building with following suggested cases to reach low cooling energy with very small payback periods.

The four cases are presented in Table 4, as follows:

1. Case 1- the building under study: 0.24 m of red clay brick materials (RB) for external walls with 0.02 m inside and outside cement mortar (CP), for external roof, 0.01 m gypsum board (GB), 0.05 air gab (AG), 0.005 steel sheet (STS), 0.025 timber sheet (TS), 0.003 bitumen sheet (BI),0.03 cement mortar (CP), 0.03 clay tile (CT). While the windows consist of 6 mm single glass without any shading systems.

2. Case 2-suggested for case under study: 0.03 m lime plaster (LP), 0.35 m straw panel (SP), 0.001 vapor retarder (VR), 0.02 cement plaster (CP), 0.24 red brick (RB), 0.02 cement plaster (CP); for external roof, 0.01 m gypsum board (GB), 0.05 air gab (AG), 0.005 steel sheet (STS), 0.025 timber sheet (TS), 0.003 bitumen sheet (BI),0.03 cement mortar (CP), 0.03 clay tile (CT). While the windows consist of 4 mm double glass windows with 13 mm air gab.

3. Case 2-suggested for case under study: 0.03 m lime plaster (LP), 0.15 m polystyrene panel (PS), 0.001 vapor retarder (VR), 0.02 cement plaster (CP), 0.24 red brick (RB), 0.02 cement plaster (CP); for external roof, 0.01 m gypsum board (GB), 0.05 air gab (AG), 0.005 steel sheet (STS), 0.025 timber sheet (TS), 0.003 bitumen sheet (BI),0.03 cement mortar (CP), 0.03 clay tile (CT). While the windows consist of 4 mm double glass windows with 13 mm air gab.

4. Case 2-suggested for case under study: 0.03 m lime plaster (LP), 0.20 m polystyrene panel (PS), 0.001 vapor retarder (VR), 0.02 cement plaster (CP), 0.24 red brick (RB), 0.02 cement plaster (CP); for external roof, 0.01 m gypsum board (GB), 0.05 air gab (AG), 0.005 steel sheet (STS), 0.025 timber sheet (TS), 0.003 bitumen sheet (BI),0.03 cement mortar (CP), 0.03 clay tile (CT). While the windows consist of 4 mm double glass windows with 13 mm air gab.

Fig. 5 which presents TRAN Build model-type 56, in TRNSYS v17 is used to perform the numerical analysis for study cases. While climate data for Mansoura city - Fig. 6, are considered as the same region as Cairo City-Table 3.

The weather data are taken from National Renewable Energy Laboratory (NREL), Weather Data Sources, EnergyPlus [27].

The numerical analysis is performed for the building under study with 3 floors, 3.0 m floor's height, Widow wall ratio (WWR) and other constant parameters are shown in Table 5. Whereas U-values for the external roofs, external walls, floors, and other buildings assembly are demonstrated in Table 6.

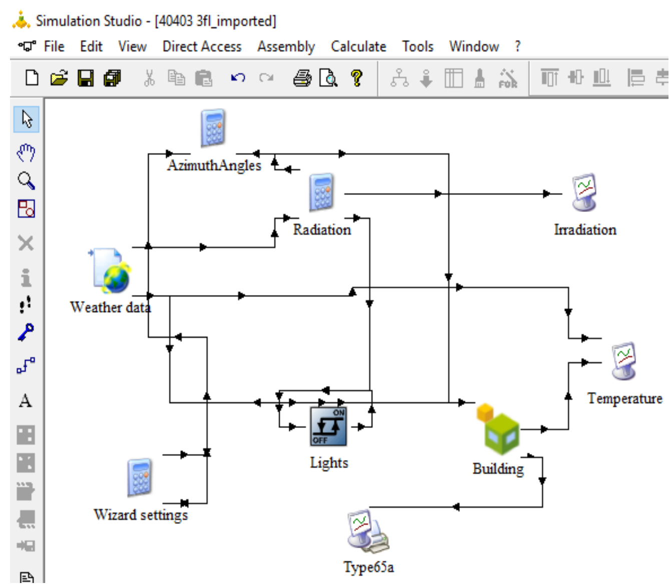

Fig. 5: TRNSYS model.

TABLE 3
CLIMATE DATA FOR MANSOURA CITY.

Parameter	Value
Average annual temperature °C	23
Average maximum annual temperature °C	28
Average minimum annual temperature °C	18
Average annual relative humidity (%)	54
Average annual wind speed (m/s)	3.5
Average solar radiation global (Wh/m^2)	231
Average annual precipitation (m)	0.003
Average annual wind direction (°)	160

Fig. 6: Mansoura city location for the building under study.

TABLE 4
BUILDING'S ENVELOPES LAYERS FOR STUDY CASES

#	Exterior Roof	Exterior wall	Windows	ground floor	Adjacent floor
1	*30CT +30CP +3BI+25TS+ 5STS+500AG+10GB	10CP+240RB+10CP**	6SG	10CEF+30CP+200SL+200RC	5CE+20CP+50SL+ 100RC+300RCB+20CP
2	*30CT +30CP +3BI+25TS+ 5STS+500AG+10GB	*30LP+350SP+1VR+ 10CP+240RB+10CP	4SG/16AG/ 4SG	10CEF+30CP+200SL+200RC	5CE+20CP+50SL+ 100RC+300RCB+20CP
3	*30CT +30CP +3BI+25TS+ 5STS+500AG+10GB	*30LP+15PS+ 10CP +240RB+10CP	4SG/16AG/ 4SG	10CEF+30CP+200SL+200RC	5CE+20CP+50SL+ 100RC+300RCB+20CP
4	*30CT +30CP +3BI+25TS+ 5STS+500AG+10GB	*30LP+20PS+ 10CP +240RB+10CP	4SG/16AG/ 4SG	10CEF+30CP+200SL+200RC	5CE+20CP+50SL+ 100RC+300RCB+20CP

*Exterior side subjected to outdoor environments, UNIT: mm.
** the adjacent walls have the same layers for external wall in case 1.

TABLE 5
CONSTANT PARAMETERS.

Parameter	Value	Parameter	Value
WWR (%)	20%	Longwave emission coefficient of the wall	0.9
Cooling Setpoint	26	Longwave emission coefficient of the roof	0.9
Internal gains for persons	1* persons/m^2-seated according to ISO 7730	Air infiltration and natural ventilation (1/hr)	2 for case1 and 0.6 for other cases
Internal gains for electric appliances	230 W*	Solar absorption of the roof	0.6
Internal gains for electric lighting	10 W/m^2*	Windows' frame area	30 % from windows area
Solar absorption of the wall	0.6	U value for windows frame	3.03 W/m^2 K
Windows' closing	total radiation >1111 W/m^2 K	Windows' opening	total radiation <1111 W/m^2 K
TRNSYS' model	type 56 -3d building	*Persons, appliances, and light schedules are existed from 8 AM to 18 PM.	

TABLE 6
U VALUE FOR STUDY CASES.

Case	Case 1	Case 2	Case 3	Case 4
Member	U*-value (W/m^2 K)	U-value (W/m^2 K)	U-value (W/m^2 K)	U-value (W/m^2 K)
Roof	1.822	1.822	1.822	1.822
*Adjacent ceiling***	1.622	1.622	1.622	1.622
External wall	1.764	0.177	0.224	0.174
Ground floor	1.651	1.651	1.651	1.651
Windows and doors	5.68	2.89	2.89	2.89
Windows shading	0	1.5 m horizontal		

*U value for external walls and roof includes total convective and radiative heat transfer coefficient 7.7 W/m2 K for indoor and 25 W/m2 K for outdoor.

**The external floor has the same layers for adjacent floors.

III. THEORY / CALCULATION

After, the numerical model is validated, we estimate the cooling energy loads for each case under three years' simulation to decrease the effect of initial conditions (20°C for temperature and 50% for relative humidity). The cooling demand for each case is determined to demonstrate the effect of suggested walls, roofs, windows, as follows:

- Analyzing the hygrothermal behavior for case 2 in two-dimensional analysis-Wufi2D 3.4 to check the moisture contents within the straw panels.
- Analyzing the case study with improved external envelope numerically in three-dimensional analysis-TRNSYS v17.
- Determining the cooling loads.
- Performing cost estimation for cooling demands and suggested assemblies to find the payback periods.

The simulated models in two- and three-dimensional numerical analysis assumes:

- Rain protection for the external walls to give 0 adhering rain factor using 0.3 m horizontal shadings.
- Simulation period is equal to three years to eliminate initial conditions effect.
- Constant ventilation and infiltration rate.

IV. RESULTS AND DISCUSSION

This section is divided into:

- Two -dimensional numerical analysis using Wufi@2D v3.4 program for the cases under study.
- Three-dimensional numerical analysis using TRNSYS v17 program for the cases under study.
- Cost analysis to specify the savings between the widely used assemblies and suggested assemblies.

A. Two-Dimensional Analysis-Wufi2D 3.4

To prevent the degradation within straw panels, the moisture content must be reduced to prevent degradation. Hence, we performed two-dimensional hygrothermal analysis for the external wall assembly to determine the moisture contents under chosen climate boundary conditions, assuming:

- Mean temperature value =21◦C with amplitude=1◦C -03 June maximum day and mean relative humidity value=50 % with amplitude=10% -16 August maximum day, for indoor conditions.
- Stucco, normal bright with short wave radiation absorptivity=0.4 and long wave radiation emissivity=0.9, Sd value=0.25 for indoor and outdoor surfaces.
- South oriented wall and roof with rain factor=0.0.

The values for relative humidity within building assemblies-case 2 presented in Fig. 7, within 43 % Average-Fig. 8.

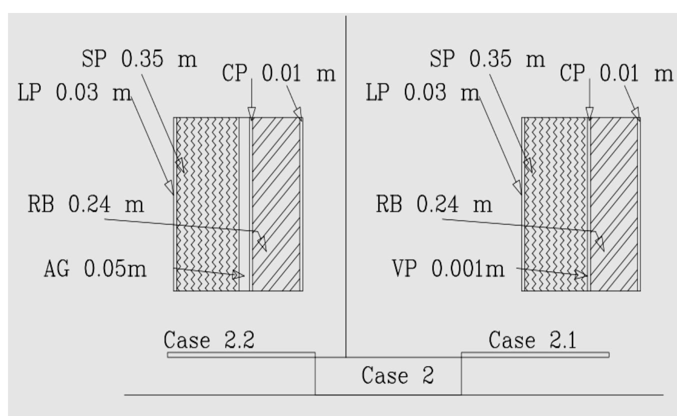

Fig. 7: Relative humidity in straw panels and lime plaster.

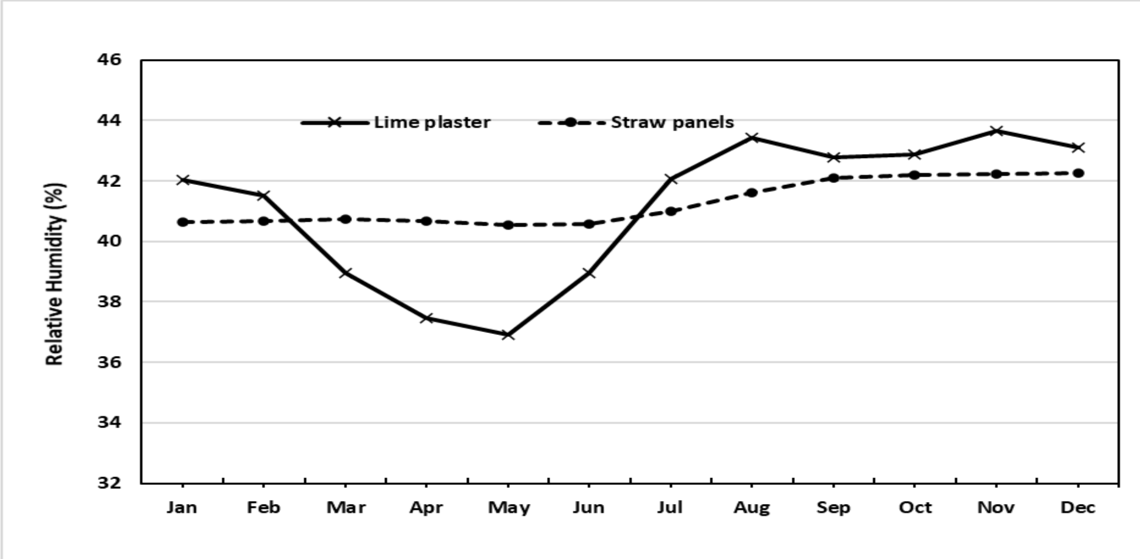

Fig. 8: Relative humidity in straw panels and lime plaster-case2.1.

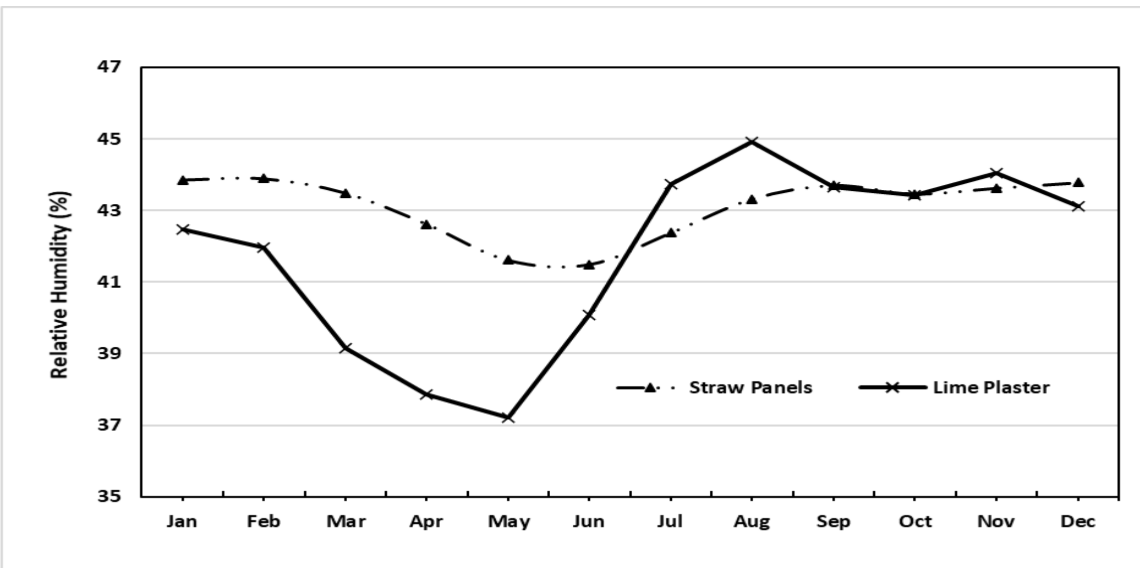

Fig. 9: Relative humidity in straw panels and lime plaster-case2.2.

B. Three-Dimensional Analysis-TRNSYS 17

For each case study, we determine:

- Cooling loads for conditioning buildings.
- Payback periods.
- Cooling energy savings.

The cooling loads for repeated and last floors which are demonstrated in Fig. 10 and Fig. 11, show that:

- Case 1 have the highest cooling loads due to the weak thermal resistance for the widely used walls, roofs, and windows.
- Case 2,3 and 4 which have the lowest cooling loads and nearly reach the same reduction effect for the cooling loads.
- The straw panels case 2 represents the highest reduction than expanded polystyrene case 3 and 4.
- The repeated floor cooling loads are lower than the last floors by 7 % due to direct solar radiations on last floors. although the high external surface area for walls and windows.
- May, June, July, August, and September months have the highest cooling loads and the other months all cases attain approximately same values.
- Straw panels case 2 has 26.6 % reduction in cooling loads. While 24 % and 23 % for expanded polystyrene cases 3 and 4 respectively.

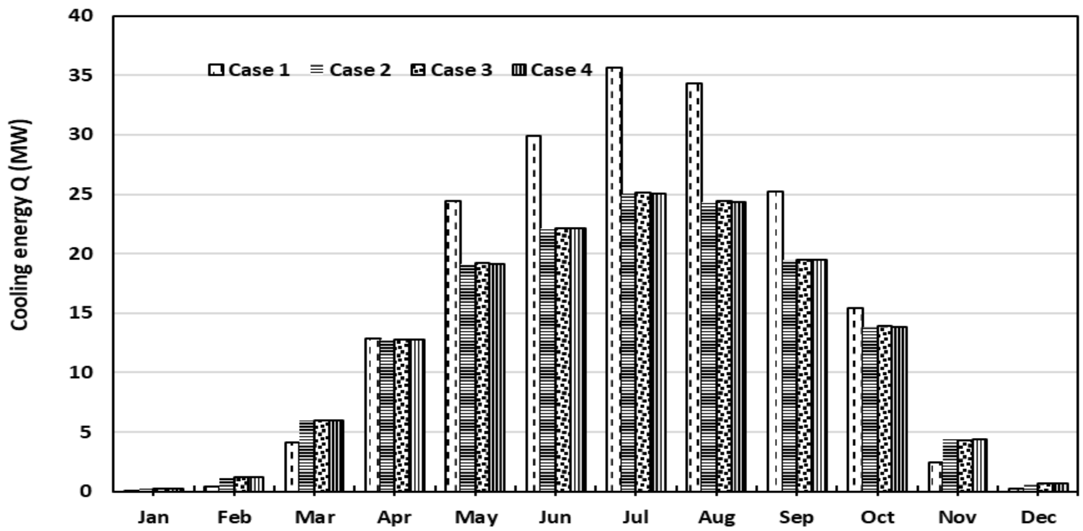

Fig. 10: Cooling energy consumption for last floor.

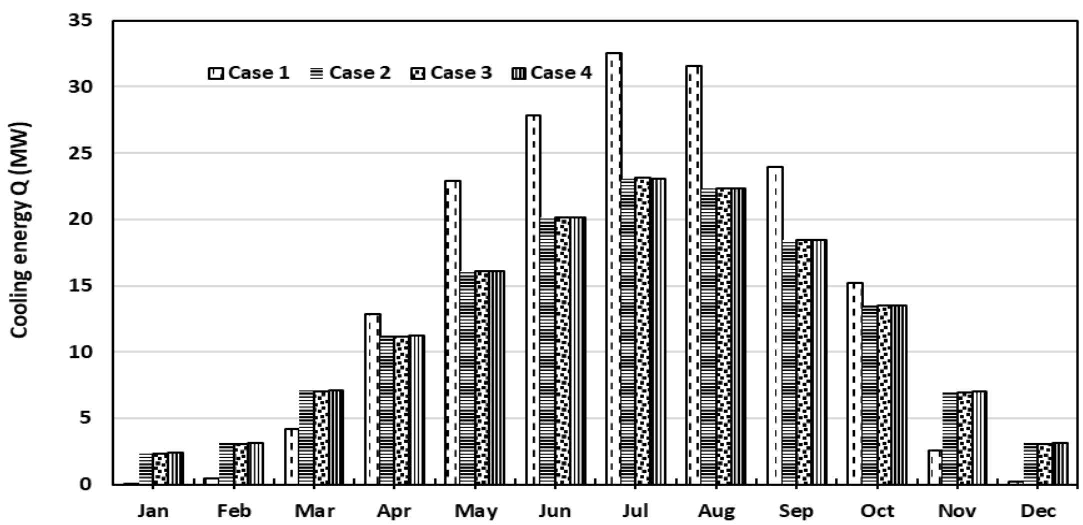

Fig. 11: Cooling energy consumption for repeated floor.

C. *Cost Analysis*

The cost function which is considered the life cycle cost (LCC) [22], [28]– [31]is given by the following Eq. (1);

$$LCC = \beta\,(N, R) * EC \tag{1}$$

Where, EC is the annual energy cost and β is the worth factor which depends on the annual discount rate R and the N Lifetime-Eq. (2).

$$\beta = \left[1 - \frac{1}{(1+R)^N}\right] / R \tag{2}$$

We considered 10 years lifetime and 10 % annual discount rate. The electricity cost is taken 1.45 EGP\kWhr [1]. While the insulation cost is taken from the Egyptian housing site [32].

The results in Table 6 and Fig. 12 demonstrate that 23 to 26.6 % cooling energy savings for the case study after increasing the thermal performance for the building envelope.

That means, increasing the thermal resistance for external assemblies with low infiltration rate for windows, horizontal shading, and double glass windows, reduce the cooling loads by 23 to 26.6 % with 2 to 6 months payback periods, as follows:

- Case 2: 0.35 m straw panels, 0.6 ACH air infiltration, 1.5 m horizontal shading and double glass windows 4 mm with 13 mm air gab attains 26.6 % energy savings with 2 months payback period.
- Case 3: 0.15 m expanded polystyrene panels, 0.6 ACH air infiltration, 1.5 m horizontal shading and double glass windows 4 mm with 13 mm air gab attains 24 % energy savings with 5 months payback period.

- Case 3: 0.2 m expanded polystyrene panels, 0.6 ACH air infiltration, 1.5 m horizontal shading and double glass windows 4 mm with 13 mm air gab attains 23.2 % energy savings with 6 months payback period.

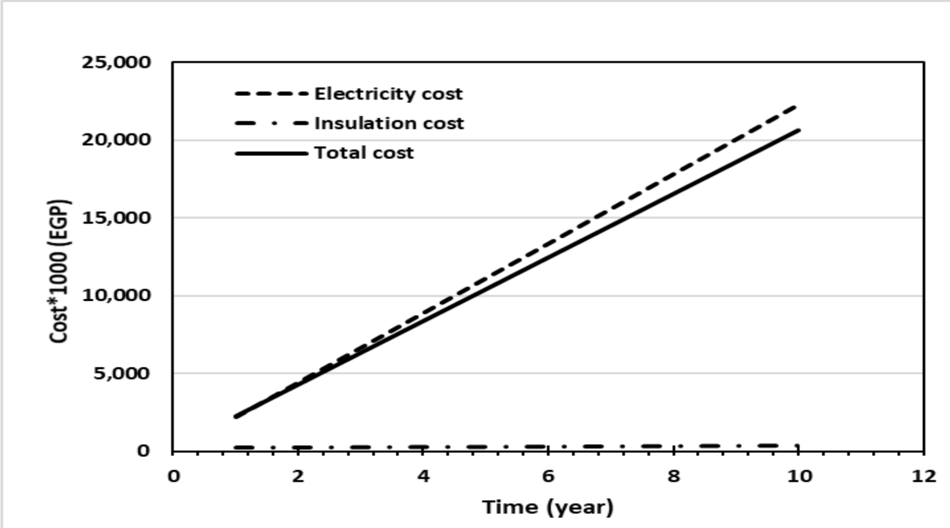

Fig. 12: Insulation, electricity, and total cost for case 2.

TABLE 6
ENERGY SAVINGS FOR DIFFERENT CASES

#	Cooling Load (KWhr/m2.yr)	Insulation cost (EGP/m3)	Electricity consumption (MWhr\year)	Cost of electricity*1000 (EGP\years)	Insulation cost*1000 (EGP)	% Percent saving
Case 1	1123	0	1399	2028	0	0.0
Case 2	814	295	1011	1466	229	26.6
Case 3	816	500	1012	1468	725	24.0
Case 4	814	3375	1011	1466	906	23.2

V. CONCLUSION

We conclude the following:

- By increasing the thermal resistances of the external assemblies with sustainable buildings materials and reducing the thermal losses for windows, the cooling loads can be reduced by 23 to 26.6 % with very short payback periods less one year.
- The cooling energy reduction can save high cost for large commercial buildings-like the case under study (5,386,819. EGP annually= 336,676 $).
- The straw panels are very convenient in Egypt’s south cities where the moisture is lower than Egypt’s north cities. Whereas the polystyrene panels are convenient for Egypt’s north.
- Future studies are recommended to concentrate on the real behavior of existing buildings with the straw panels for walls and roofs, combined with ground air heat exchanger ventilation system.

APPENDIX: A

LIST OF SYMBOLS

Symbol	Definition	Unit
U	Thermal transmittance	[W.K $^{-1}$m^{-2}]
WWR	Window wall ratio	[%]
PC	Plain concrete	[-]
RB	Red brick	[-]
SP	Straw panel	[-]
CP	Cement plaster	[-]
EP	Expanded polystyrene	[-]
BI	Bitumen sheet	[-]
LP	Lime plaster	[-]
AG	Air gab	[-]
SL	Sand layer	[-]
RCB	Reinforced Concrete Block	[-]
STS	Steel Sheet	[-]
TS	Timber Sheet	[-]
CEF	Ceramic for floor	[-]
CT	Clay Tiles	[-]
GB	Gypsum Board	[-]
VR	Vapor retarder	[-]

(Continued on the next page)

List of symbols: continued

Symbol	Definition	Unit
ACH	Air change per hour	[-]
ρ_d	Dry density	[kg.m^{-3}]
n	open porosity	[-]
$\boldsymbol{\mu}$	Water vapor resistance factor	[-]
C_p	Specific heat capacity	[J.kg^{-1}.K^{-1}]
Wg	Water content	[kg.m^{-3}]
RMSE	Root mean square error	[%]
λ	Thermal conductivity	[W.m^{-1}.K^{-1}]
T	Temperature	[K]
RH	Relative humidity	[%]
h_c	Convective heat transfer coefficient	[W.m^{-2}.K^{-1}]
LCC	Life cycle cost	[-]
EC	Annual energy cost	[EGP]
β	Worth factor	[-]
R	Annual discount	[-]
N	Lifetime	[-]
LCC	Life cycle cost	[-]
EC	Annual energy cost	[EGP]
β	Worth factor	[-]
R	Annual discount	[-]
N	Lifetime	[-]

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AUTHORS CONTRIBUTION

Contributions of authors to the paper are outlined as follow:

1. Conception or design of the work*: Reda Y. M. ALLAM, Rafik BELARBI.*
2. Data collection and tools: *Reda Y. M. ALLAM, Rafik BELARBI.*
3. Data analysis and interpretation: *Reda Y. M. ALLAM, Madi KABORE.*
4. Funding acquisition: *Rafik BELARBI.*
5. Investigation: *Reda Y. M. ALLAM, Sherif SHETA*
6. Methodology: *Reda Y. M. ALLAM, Sherif SHETA.*
7. Project administration: *Reda Y. M. ALLAM, Rafik BELARBI.*
8. Resources: *Reda Y. M. ALLAM, Rafik BELARBI*
9. Software: *Reda Y. M. ALLAM, Madi KABORE*.
10. Supervision: *Reda Y. M. ALLAM*.
11. Drafting the article: *Reda Y. M. ALLAM.*
12. Critical revision of the article: *Reda Y. M. ALLAM, Sherif SHETA.*
13. Final approval of the version to be published: *Reda Y. M. ALLAM, Sherif SHETA.*

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TITLE ARABIC:

٢٧ % توفير بطاقة التبريد لمبني تعليمي باستخدام غلاف مستدام ـحالة دراسة.

ARABIC ABSTRACT:

يزداد استهلاك الكهرباء في قطاعات البناء بمصر منذ ٢٠١٤، طبقا للتقرير السنوي لوزارة الكهرباء. ومن ثم كان هذا البحث يفحص مدي تأثير غلاف البناء الخارجي الشائع الاستخدام على كفاءة الطاقة في المباني بعد زيادة المقاومة الحرارية، وسيتم هذا من خلال:

- **تجارب موقعيه على للمبني تحت الدراسة للتحقق من النموذج العددي. ويتم زيادة الأداء الحراري للمبني بألواح العزل الحراري وتدفق تسريب الهواء من خلال نوافذ زجاج ثنائي بدلا من النوافذ ذات الزجاج المفرد والإطار المسرب للهواء.**
- **نتائج عددية من خلال نموذج ثلاثي الابعاد باستخدام برنامجTRNSYS v17 ، والتي بينت بان استخدام الواح من القش للحوائط الخارجية ونوافذ بزجاج ثنائي مظلل ب١,٥ م افقي ومعدل تهوية ٠,٦ /ساعة توفر ٢٦,٦ % من طاقة التبريد للمبني. بينما ٠,١٥ م الي ٠,٢٣ م من الواح البولسترين الممدد توفر ٢٤ % الي ٢٣%.**