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Impact A`ssessment of Reused Straw Bales as Alternative Building Materials

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ABSTRACT

The aim of this study is to analyze thermal properties of straw bale house in 6th October in Egypt by ECOTECT. It has been found that; reused straw bale' U-Value matches with the Egyptian code. Additionally, comparing straw bale house with masonry brick house; as one of traditional building materials, it is showed that, discomfort degree hours for straw bale house are less by 40 % , energy consumption is less by 82%, and CO2 emissions are less by 80% than masonry brick house. Furthermore, the results of comparing straw bale house efficiency in Egyptian climatic regions concluded that straw bale house is more effective in arid region 'Cairo" then, in hot arid region "El Arish".

Keywords: CO2 Emissions, Egyptian Code, Energy, ECOTECT, Reusing, Straw Bale

1. Introduction

According to the Egyptian Ministry of Agriculture; the straw bales production in most northern Egyptian governorates exceeds more than 4 million tons annually [1]. The dangerous of straw bale waste is disposed by burning, which causes black cloud on the atmosphere [2]. In Egypt, burning straw bales releases large amounts of air pollutants that cause serious environmental problems [3]. Until now, the largest straw producing countries all over the world have not been able to utilize it for productive work up like China, India and other agricultural country [2]. Therefore, it is important to find effective and safe disposal for straw bales waste as much as possible.

One of the most effective solutions to the major environmental problem resulting from burning straw bale waste is recycling it to be used in building process [3]. Straw bale construction is a featured example of ideals green building. As it is affirmed that, using biomaterials such as straw, and timber technologies for construction houses to reduce CO_2 emissions towards net zero [4]. Reusing straw bale waste starts 1890 in Nebraska as wall building materials such as churches, schools, officials and grocery stores [2].

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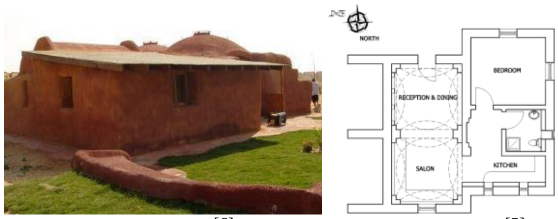
2. Case Study Description

Straw Bale House, in 6th October, Cairo; is constructed by Garas et al., [6] and the national research center. As Garas et al., manages to reuse straw bale waste, as alternative building material for a house to provide thermal comfort that is required in the arid desert area, and save the environment, as shown in Fig.1.



a). Straw bale house [6] b). Straw bale plan [5]

Fig 1: Straw Bale House in Egypt

The house is constructed with area 100 m^2 by load bearing walls system of reused standard straw bale units with dimensions 1.00×0.50×0.50 m [5], as shown in Fig.1.

Three types of roofing systems are used in this house. The first one is domes for salon and reception zones, which are supported by six corners of recycled cementitious brick, and the second is vaults for bathroom and kitchen zone, both of them are from burned clay bricks. The last one is joists and beam wood for Bedroom zone [5], as shown in Fig.1.

3. Analysis Methodology

The case study “straw bale house” is modeled in ECOTECT by entering the follows input data:

- **Weather File**

Entering the weather file for the location of case study “Cairo”, which contains wind speed, humidity, and temperature, as shown in Fig.2.

- **Zones**

Drawing the house as zones in the program according to function of each zone such as bedroom, bathroom, salon, etc, as shown in Fig.3.

- **Zone Management**

Setting zone management that complies occupancy and operation. This will be handled for each zone according to users’ occupancy in standard weekday and weekend.

- **Layers of the House Elements**

Entering layers for each house elements such as ceiling, walls, and windows, as shown in Fig.4.

- **Thermal Lag**

After calculating thermal properties, thermal lag value should be calculated manually for each building element by the following equation after that; thermal lag value is entered manually.

$$\text{Thermal Lag} = 1.38 \times L \times \text{SQRT}(1/\alpha) \text{ hrs} \quad [7]$$

$\alpha = K / (P \times C)$

L = Thickness (m)

α = Thermal Diffusivity (m2/s)

K = Thermal Conductivity (W/(m.k))

P = Density (Kg/m3)

C = Specific Heat Capacity (J/(kg.k))

For example: calculating thermal lag for straw bale walls layer as follows:

L = 0.52 (m)

K = 2.471 (W/(m.k))

P = 4040 (Kg/m3)

C = 2680 (J/(kg.k))

Thermal Lag = 1.38 x 0.52 x SQRT (4040*2680/2.471) = 1502 hrs

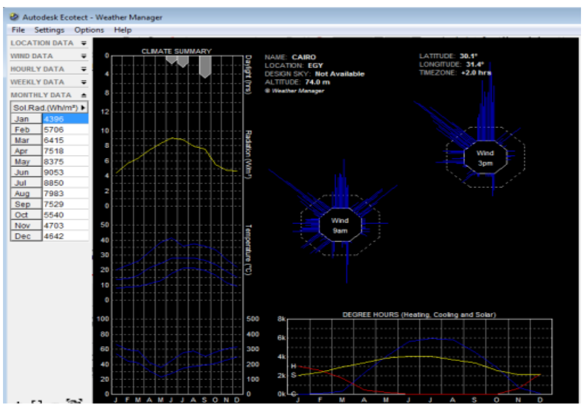


Fig 2: Cairo weather data file

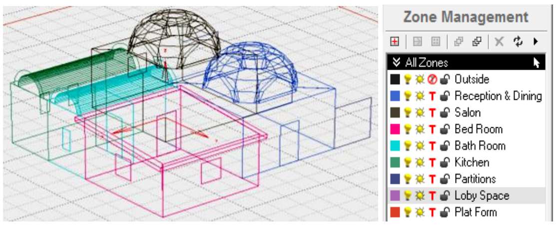
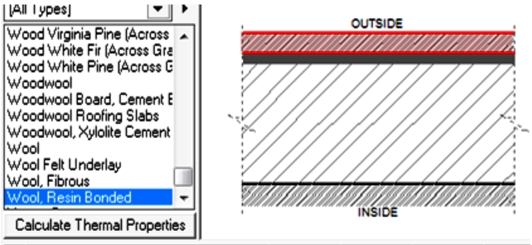
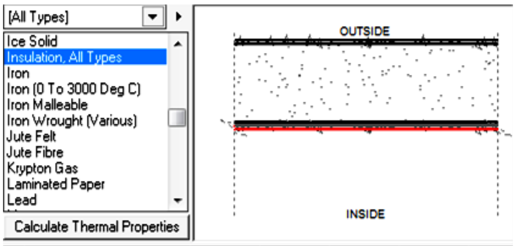


Fig 3: Case study zones in ECOTECT



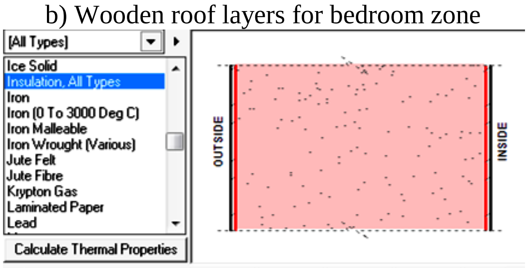
	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Alluvial Clay, 40% Sands	20.0	1960.0	840.000	1.210	25
2.	Reflective Coat	10.0	2300.0	1700.000	1.200	85
3.	Brick Egyptian Fire	120.0	950.0	732.200	0.314	25
4.	Alluvial Clay, 40% Sands	20.0	1960.0	840.000	1.210	25

a) Domes and vaults layers for reception, salon, bathroom and kitchen



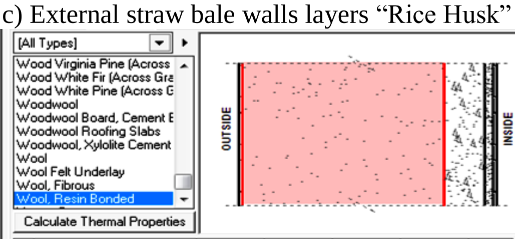
	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Plaster	10.0	1200.0	840.000	0.520	35
2.	Wood Pine (With Grain)	200.0	550.0	2301.000	0.343	115
3.	Insulation, All Types	10.0	1000.0	1700.000	0.200	85
4.	Plaster	10.0	1200.0	840.000	0.520	35
5.	Air Gap	200.0	1.3	1004.000	5.560	0

b) Wooden roof layers for bedroom zone



	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Alluvial Clay, 40% Sands	10.0	1960.0	840.000	1.210	25
2.	Rice Husk	500.0	120.0	1000.000	0.051	115
3.	Alluvial Clay, 40% Sands	10.0	1960.0	840.000	1.210	25

c) External straw bale walls layers “Rice Husk”



	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Alluvial Clay, 40% Sands	10.0	1960.0	840.000	1.210	25
2.	Rice Husk	500.0	120.0	1000.000	0.051	115
3.	Cement	100.0	1860.0	840.000	0.720	35
4.	Rice Husk	20.0	120.0	1000.000	0.051	115
5.	Alluvial Clay, 40% Sands	10.0	1960.0	840.000	1.210	25

d) Double walls layers for vaults

Fig. 4: Straw bale model layers

After calculating the straw bale model, the analysis methodology is divided into three levels as shown in Fig. 5:

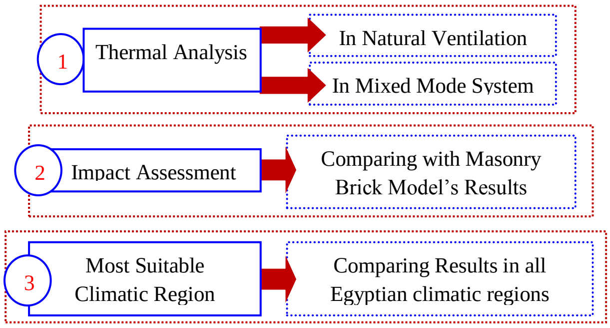


Fig. 5: Analysis Methodology of Case Study

4. Thermal Analysis of Straw Bale Model

After entering all the simulated model data and calculating the model, analyzing follows output data:

This step includes analyzing all output data. It is divided into two stages: the first one; by using natural ventilation mode for the house, which analyzes the following:

4.1 U-Value

Table.1 shows the all elements' U-Value, which the program is calculated, and comparing it with Egyptian code.

Table 1: Comparing U- Value with Egyptian Code

T	Straw Bale Model	U–Value kW/m²		
		Out Put	Egypt. Code [8]	
Ceiling	Domes and Vaults	1.66	0.4	
	Wooden Roof	1.02		
Walls	Straw bale Walls	0.1	N 1.4	0.9
			E/W 0.9	
			S 1.3	
	Double walls for vaults	0.09	N 1.4	
			E/W 0.9	
			S 1.3	
Win	Windows	5.1	3.5	

U- Value is total thermal transmittance in a surface, this mean that a lower U-Value, a higher thermal resistance of this surface [9]. After comparing the results with Egyptian code, it is obvious from Table.1 that , U-Value for straw bale walls matches with Egyptian Code in, but the ceiling and windows do not match with the code. This means that, straw bale walls have a higher thermal resistance.

4.2 Hourly Temperature Profile

By using natural ventilation mode, the hottest day is 7 June, the hottest hour is at 03:00 PM, the coldest day is 17 January, and the coldest hour is at 05:00 AM.

Table.2 shows that, the hottest temperature degree is 33.7 C^0, and the coldest temperature degree is 11.7 C^o.

Table 2: The hottest and the coldest degree at the hottest and the coldest day for each zone of straw bale model

Zones	Hottest Day		Coldest Day	
	Indoor	Insulation	Indoor	Insulation
Reception & Dinning	33.7	- 9.3	12.6	+ 4.6
Salon	32.8	- 10.2	12.5	+ 4.5
Bedroom	33.5	- 9.5	13.1	+ 5.1
Bathroom	31.2	-11.8	13.4	+ 5.4
Kitchen	32.0	- 11.0	13.2	+ 5.2
Lobby	32.1	- 10.9	11.7	+ 3.7
Max 33.7		**Min 11.7**		

According to Egyptian Code for Improving Buildings Efficiency, the thermal comfort zone for Egypt is located between 30 C^0 and 21.8 C^0 [10]. It is obvious from Table.2 that, the hottest temperature is a little far from the comfort zone, but the coldest temperature is so far, as shown in Fig.6.

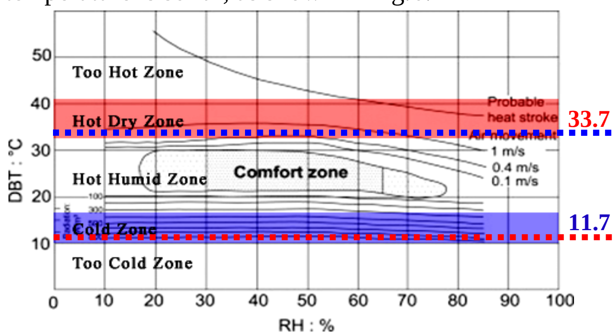


Fig.6: Thermal comfort zone for straw bale house

4.3 Hourly Heat Gains and Loss

One of the program output data is hourly heat gains and loss, which shows the main natural causes of heat gain and loss. Fig.7 shows that; the entire house roofs exposure directly to solar all the daytime. In addition to, sol air "hot air that result from the sun" and conduction affect heat gains and cause heat infiltration.

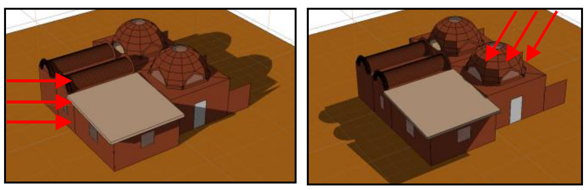


Fig.7: Sun path on the house at 7:00 Am to 03:00 PM

This heat infiltration happens because of slots. These slots' U-vale does not match with the Code, as shown in Fig.8. In addition to, domes' U-Value are not match with the Code.

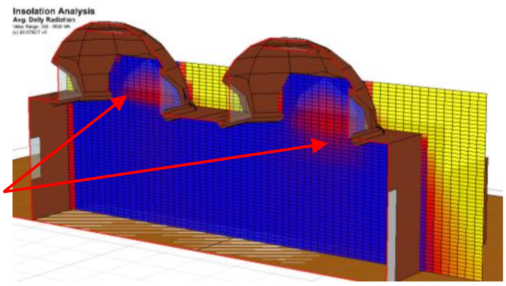


Fig. 8: Thermal infiltration through windows

4.4 Passive Gain Breakdown

Passive gain breakdown also analyzes the reasons related to building envelope, which, cause heat gain and loss.

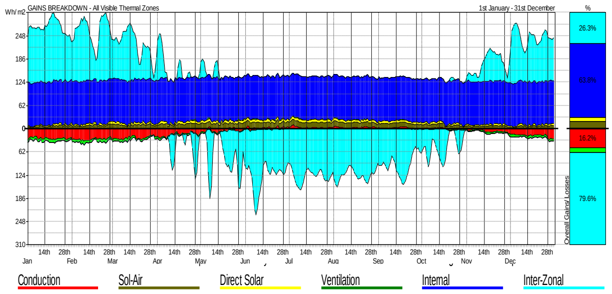


Fig. 9: Passive gain breakdown for case study

It is obvious from Fig.12 that; the main factor for heat gains above zero level is **Internal** factor with a percentage of **63.8 %** because of thermal infiltration between outdoor and indoor spaces. The second factor is **Inter zonal** with a percentage of **26.3 %** because of infiltration between internal zones, which also causes heat loss with a percentage of **79.6 %**. The least affecting factor is **Conduction** "Fabric" with a percentage of **16.2 %**.

4.5 Discomfort Degree Hours

By using natural ventilation Mode, the case study has discomfort degree hours, as shown in Fig.10.

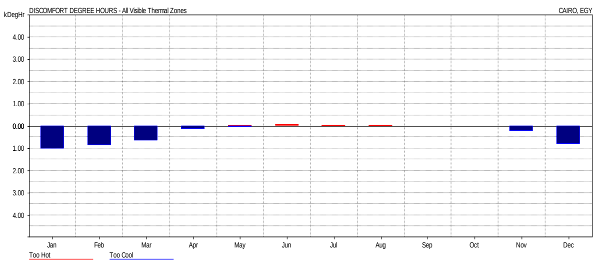


Fig.10: Discomfort degree hours

Fig.11 shows that; total discomfort degree hours are 4010.6 degree hours. The heating degree hours are **167.5** degree hours, which concentrate in June and July. The discomfort cooling degree hours are **3843.1** degree hours which, concentrate in winter months.

In spite of the discomfort degree hours are few, but it shouldn't be neglected. Therefore, the straw bale house needs **Mixed Mode System** "heating and cooling". After changing the thermal properties and replacing **Natural Ventilation Mode** with **Mixed Mode System** in zone management, analyzing the following items:

4.6 Heating and Cooling Loads

Using Mixed Mode System needs heating and cooling loads.

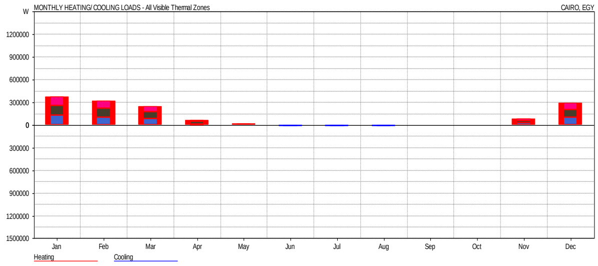


Fig.11: Monthly heating and cooling loads for case study by using mixed mode system

It is obvious from Fig.12 that; the annual loads of the house are **1448.1** KWh, **44.5** KWh are cooling loads, and **1403.6** are heating loads. In spite of hot degree hours heating are **167.5** Deg Hrs, but the cooling loads are neglected, as shown in Fig.11.

4.7 Resources Consumption

Resources consumption analysis contains the energy consumption of heating and cooling, the resulted CO_2 emissions by using mixed mode system.

4.7.1 Energy Consumption

The energy consumption of heating and cooling loads, as shown in Fig.12, are **1435.8** KWh annually divided into **1402.3** KWh of heating and **33.5** KWh of cooling.

4.7.2 CO_2 Emissions

CO_2 emissions are **45.9** tons annually; **44.8** tons are resulted from heating energy**,** and **1.1** tons are resulted from cooling energy, as shown in Fig.13.

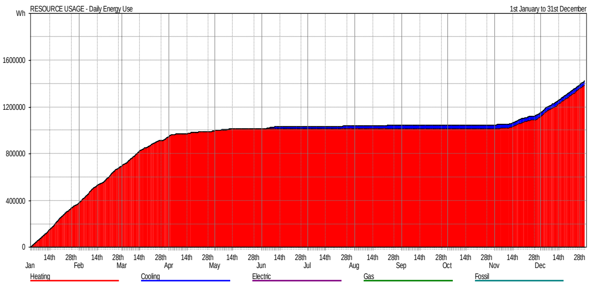


Fig.12: Energy consumption by using mixed mode system

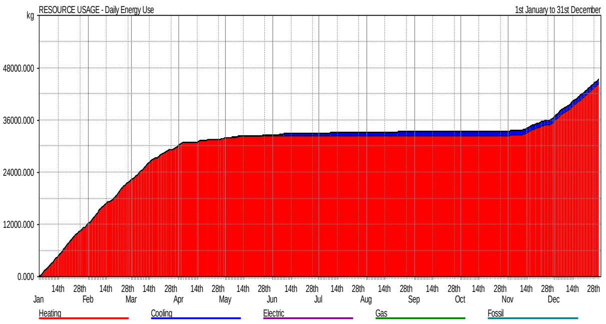


Fig.13: Energy consumption as CO_2 Emissions

5. Impacts Assessment of Straw Bale Model

To conduct the impact assessment of the straw bale as alternative materials, replacing straw bale wall materials with 50 cm thick masonry brick as one of traditional building materials, as shown in Fig.14.

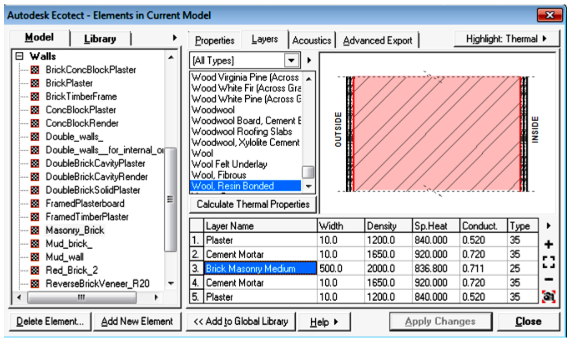


Fig.14: Wall layers from Masonry brick for traditional house

By executing the previous steps, we obtain the following results comparison:

5.1 U-Value

After calculating thermal properties, the masonry brick' U-Value is 1.06 W/m^2.K, as shown in Fig.15.

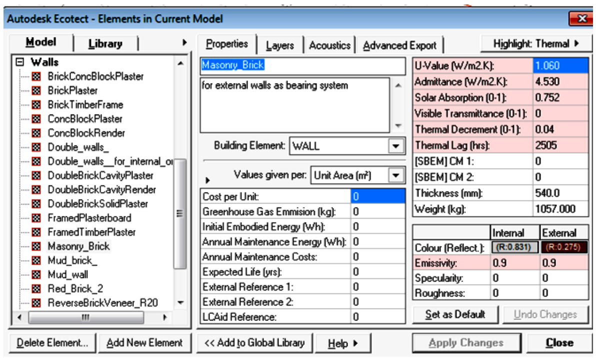


Fig.15: Masonry Brick Walls U-Value

From table.3 it is obvious that; masonry brick wall' U-Value matches with Egyptian Code in north and south elevations, and do not match in east and west elevations.

Table .3: Comparing U-Value of straw bale and masonry brick walls

T	Straw Bale Model	U–Value kW/m^2			Traditional Materials Model
		Out Put	Egypt. Code [7]	Out Put	
Walls	Straw bale Walls	0.1	N 1.4	1.06	Masonry Brick Walls
			E/W 0.9		
			S 1.3		

In spite of, masonry brick' U-Value matches with the Egyptian code in north and south elevation, but U-Value of straw bale walls is better than this of masonry brick walls.

5.2 Discomfort Degree Hours

By comparing the discomfort degree hours of straw bale house and masonry brick house, discomfort degree hours for both of them are as shown in Table.4. It is obvious that; the discomfort degree hours of straw bale house are less by 40 % than masonry brick house.

5.3 Heating and Cooling Loads

By using mixed mode system of the two houses, heating and cooling loads are as shown in Table. 4. It is obvious that; the heating and cooling loads of straw bale house are less by 82 % than masonry brick house.

5.4 Energy Consumption

The used energy in the two houses is as shown in Table.4. It is obvious that; the energy consumption of straw bale house is less by 82 % than masonry brick house.

5.5 CO_2 Emissions

The CO_2 emissions that are resulted of the used energy for the two houses are as shown in Table.4. It is obvious that; CO_2 emissions of straw bale house are less by 82 % than masonry brick house.

6. Straw Bale Model Efficiency in Egyptian Climatic Regions

Comparing straw bale house in the other two climatic regions in Egypt; such as El Arish as Hot Humid, and Aswan as Hot Arid". This is done to find out in which climatic region, straw bale is more effective and capable to reduce energy consumption for operation phase and CO_2 emissions resulting from this energy. This comparison includes the following items:

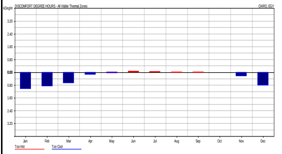
A. Discomfort Degree Hours
B. Heating and Cooling Loads
C. Resources Consumption

Table.4: Comparison results of straw bale model and traditional material model

	Straw Bale	Masonry Brick

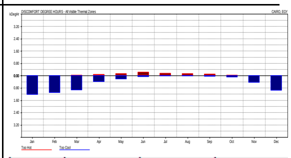
Discomfort Loads

Straw Bale:



MONTH	TOO HOT (DegHrs)	TOO COOL (DegHrs)	TOTAL (DegHrs)
Jan	0	1034	1034
Feb	0	874	874
Mar	0	674	674
Apr	1	148	149
May	17	52	69
Jun	66	0	66
Jul	37	0	37
Aug	33	0	33
Sep	13	0	13
Oct	1	3	4
Nov	0	247	247
Dec	0	812	812
TOTAL	167.5	3843.1	4010.6

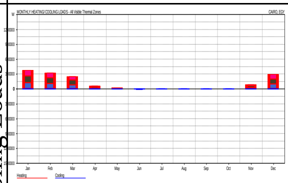
Masonry Brick:



MONTH	TOO HOT (DegHrs)	TOO COOL (DegHrs)	TOTAL (DegHrs)
Jan	6	1235	1241
Feb	21	1116	1137
Mar	28	953	982
Apr	81	394	475
May	138	240	378
Jun	234	77	310
Jul	168	46	214
Aug	128	26	153
Sep	101	61	162
Oct	49	118	167
Nov	20	458	477
Dec	10	979	989
TOTAL	983.2	5702.3	6685.5

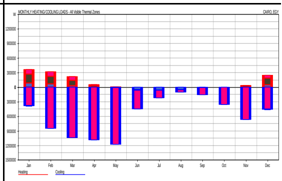
Heating and cooling Loads

Straw Bale:



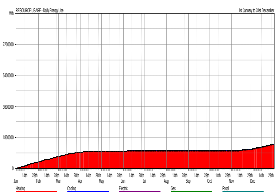
MONTH	HEATING (Wh)	COOLING (Wh)	TOTAL (Wh)
Jan	372106	3058	375164
Feb	318648	2620	321268
Mar	250481	2048	252529
Apr	63143	813	63956
May	21564	4463	26027
Jun	276	13500	13776
Jul	231	7053	7284
Aug	213	5962	6176
Sep	89	1935	2024
Oct	865	7	872
Nov	85714	665	86379
Dec	290276	2371	292646
TOTAL	1403605	44494	1448099

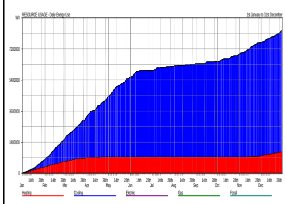
Masonry Brick:



MONTH	HEATING (Wh)	COOLING (Wh)	TOTAL (Wh)
Jan	346157	389006	735164
Feb	293486	856811	1150298
Mar	188959	1032109	1221068
Apr	45018	1072239	1117257
May	8953	1169631	1178585
Jun	329	451220	451548
Jul	230	223206	223436
Aug	204	106590	106795
Sep	84	151239	151323
Oct	10	346285	346295
Nov	33352	672728	706080
Dec	229564	460563	690128
TOTAL	1146348	6931630	8077977

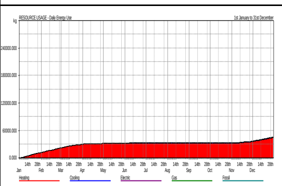
Energy Consumption

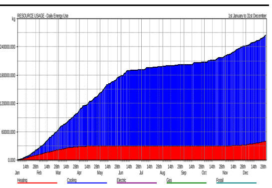




	Straw Bale	Masonry Brick
Energy Consumption	**1435.9** KW	**8066.0** KW

CO_2 Emissions





	Straw Bale	Masonry Brick
CO_2 Emissions	**45.9** Tons	**257.7** Tons

6.1 Hot Humid Region (El Arish)

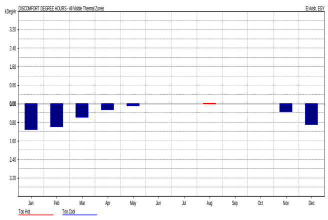
El Arish is one of the cities that is located in hot humid region, and analyzing the following:

A. Discomfort Degree Hours

Total discomfort degree hours are **4484.7** degree hours, **29.2** are too hot (red color) and **4455.5** are too cold (blue color), as shown in Fig.16.

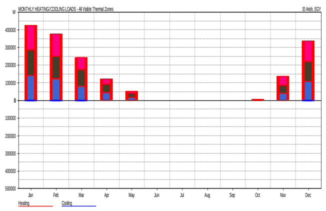
B. Heating and Cooling Loads

By using mixed mode system, the total heating and cooling loads are **1706.9** KWh annually, **1692.3** KWh (*red color*) are heating loads, and **14.6** KWh (*blue color*) are cooling loads, as shown in Fig.17. Noting that, cooling loads are neglected due to little hot degree hours (**29.2 H**).



MONTH	TOO HOT (DegHrs)	TOO COOL (DegHrs)	TOTAL (DegHrs)
Jan	0	1132	1132
Feb	0	1016	1016
Mar	0	602	602
Apr	0	300	300
May	0	112	112
Jun	1	4	4
Jul	9	0	9
Aug	15	0	15
Sep	4	0	4
Oct	0	6	6
Nov	0	367	367
Dec	0	917	917
TOTAL	29.2	4455.5	4484.7

Fig.16: Discomfort degree hours in El Arish



MONTH	HEATING (Wh)	COOLING (Wh)	TOTAL (Wh)
Jan	424163	3378	427540
Feb	377194	3038	380232
Mar	241686	1844	243530
Apr	120603	902	121505
May	50355	340	50695
Jun	932	13	945
Jul	73	0	73
Aug	120	957	1077
Sep	29	404	433
Oct	4626	12	4637
Nov	136120	1015	137135
Dec	336480	2680	339160
TOTAL	1692380	14583	1706962

Fig.17: Annual heating and cooling loads in El Arish

C. Resources Consumption

- Energy Consumption

Using mixed mode system consumes **1693.5 KWh** annually, as shown in Fig.18. It is obvious that, cooling energy is neglected.

- **CO_2 Emissions**

CO_2 emissions are **54.14** tons annually, **0.04** ton of heating energy, and **54.1** ton of cooling energy, as shown in Fig.19.

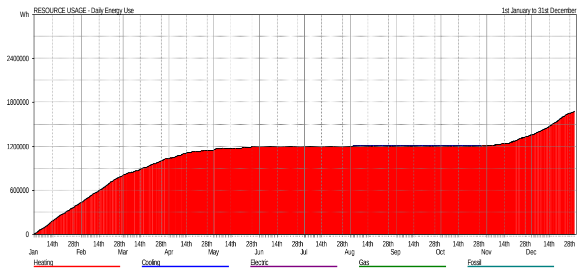


Fig.18: Energy consumption in El Arish

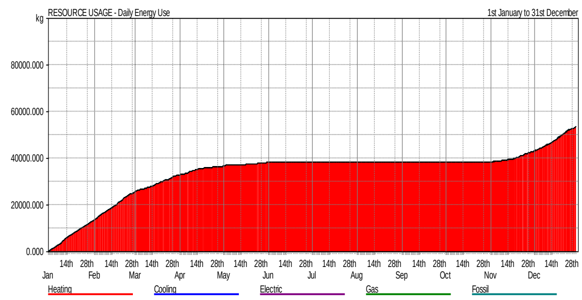


Fig.19: Energy consumption as CO_2 emissions in El Arish

6.2 Hot Arid (Aswan)

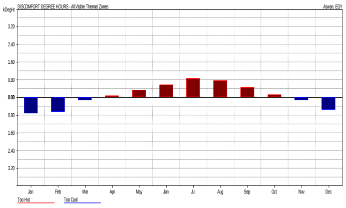
Aswan is one of the cities that is located in hot humid region, and analyzing the following:

A. Discomfort Degree Hours

Total discomfort loads are **5357.1** degree hour, **3142.5** (*red color*) are too hot, and **2214.6** (*blue color*) are too cold, as shown in Fig.20.

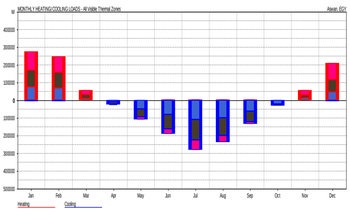
B. Heating and Cooling Loads

By using mixed mode system, the total loads are **1867.2** KWh annually, **851.6** KWh (*red color*) are heating loads, and **1015.6** KWh (*blue color*) are cooling loads, as shown in Fig.21.



MONTH	TOO HOT (DegHrs)	TOO COOL (DegHrs)	TOTAL (DegHrs)
Jan	0	722	722
Feb	0	657	657
Mar	2	138	139
Apr	73	0	73
May	332	0	332
Jun	573	0	573
Jul	852	0	852
Aug	760	0	760
Sep	438	0	438
Oct	111	0	111
Nov	2	142	144
Dec	0	556	556
TOTAL	3142.5	2214.6	5357.1

Fig.20: Discomfort degree hours in Aswan



MONTH	HEATING (Wh)	COOLING (Wh)	TOTAL (Wh)
Jan	273092	2121	275214
Feb	247099	1952	249051
Mar	56602	421	57023
Apr	274	25868	26142
May	1200	109470	110670
Jun	2010	190948	192959
Jul	2860	281310	284170
Aug	2618	236933	239551
Sep	1687	134202	135889
Oct	511	30429	30940
Nov	54826	345	55171
Dec	208845	1580	210425
TOTAL	851625	1015579	1867204

Fig.21: The annual heating and cooling loads in Aswan

C. Resources Consumption

- Energy Consumption

Using Mixed Mode System consumes **1849.59** KWh of energy annually, **840.43** KWh are heating energy, and **1009.16** KWh are cooling energy, as shown in Fig.22.

- **CO_2 Emissions**

CO_2 emissions of used energy are **59.09** tons annually, **26.85** ton of heating loads, and **32.24** tons of cooling loads is, as shown in Fig.23.

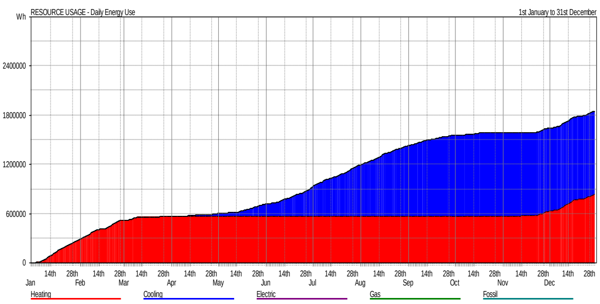


Fig.22: Energy consumption in Aswan

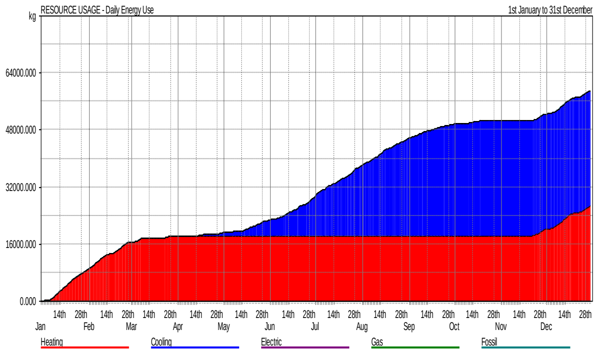


Fig.23: The used energy as CO_2 emissions in Aswan

7. Results

7.1 Straw Bale Model Analysis

- **U-Value**

Straw bale walls' U-Value matches with the Egyptian code U-Value without any insulation materials. For wall section, straw bale as building materials is better than masonry brick. The other sections such as; roof and windows do not match with the Egyptian code U-Value.

7.2 Comparing Straw Bale Model With Masonry Brick Model

This part includes comparing of the following results:

7.2.1 Discomfort Degree Hours

It is obvious from Table.5 that; the discomfort loads for straw bale house is less than traditional building material by **40** % hours annually.

Table .5: Discomfort degree hours comparison

Discomfort Degree Hours	Straw Bale House	Masonry Brick House
Total	4010.6 Deg Hrs	6685.5 Deg Hrs
Hot	167.5 Deg Hrs	983.2 Deg Hrs
Cold	3843.1 Deg Hrs	5702.3 Deg Hrs

7.2.2 Heating and Cooling Loads

It is clear from Table.6 that; the heating and cooling loads by using mixed mode system in straw bale house are less by 82 % than the heating and cooling loads for traditional building material house.

Table .6: Heating and cooling loads

Heating and cooling Loads	Straw Bale Model	Masonry Brick Model
Total Loads	1448.1 Wh	8077.9 Wh
Heating Loads	1403.6 Wh	1146.3 Wh
Cooling Loads	44.5 Wh	6931.6 Wh

7.2.3 Energy Consumption

It is clear from Table.7 that; straw bale house saves **82** % energy consumption than traditional building house "*Masonry Brick*".

Table .7: Energy consumption comparison

	Straw Bale	Masonry Brick
Energy Used	**1435.9** KW	**8066.0** KW

7.2.4 CO_2 Emissions

It is obvious from Table.8 that; straw bale house also saves **80** % **CO_2** emissions than masonry brick house.

Table .8: CO2 emissions comparison

	Straw Bale	Traditional Materials
CO_2 Emissions	**45.9** Tons	**257.7** Tons

7.3 Comparing Straw Bale Results' in Egyptian Climatic Regions

7.3.1 U- Value Comparison

After analyzing straw bale house in 6th October city in three different climatic regions in Egypt, Table.9 shows a comparison between the three climatic region analysis results.

Table .9: Straw bale house results in the Egyptian climatic regions

	Discomfort Hours			Heating and cooling Loads		Energy	CO^2
Region	Total	Hot Deg/H	Cold Deg/H	Heating KWh	Cooling KWh	KWh	Tons
Hot Humid "El Arish"	4484.7	29.2	4455.5	1692.3	14.6	1693.5	54.14
Moderate "Cairo"	4010.6	167.5	3843.1	1403.6	44.5	1435.8	45.9
Hot Arid "Aswan"	5357.1	3142.5	2214.6	851.6	1015.6	1849.6	59.1

7.3.2 Discomfort Degree Hours

After comparing the results of discomfort degree hours of all the climatic regions, it is obvious from Fig.25 that, arid region (**Cairo**) has the least discomfort degree hours annually, and hot arid region (**Aswan**) has the biggest discomfort degree hours.

7.3.3 Heating and Cooling Loads

When using a mixed mode system for heating and cooling the house to achieve thermal comfort in all climatic regions, there are heating and cooling loads for this system. Fig.24 shows that, arid region (**Cairo**) has the least loads, and Hot Arid region (**Aswan**) has the biggest loads annually.

Although, as evidence from Fig.24 that; the arid region (**Cairo**) has the least loads **1448.1** KWh annually divided to **1403.6** KWh heating loads, and **44.5** KWh cooling loads. Following by Hot Humid Region (**El Arish**) has annually **1706.9** KWh loads divided to **1692.3** KWh heating loads, and **14.6** KWh cooling loads. Then Hot Arid (**Aswan**) has annually **1867.2** KWh loads divided to **851.6** KWh heating loads, and **1015.6** KWh cooling loads.

7.3.4 Energy Consumption

Fig.24 also evidences that the arid region (**Cairo**) is the least one in energy consumption with **1435.8** KWh annually. Hot Arid region is the biggest region in energy consumption as (**Aswan**) consumes **1849.6** KWh of energy.

7.3.5 CO_2 Emissions

Fig.24 evidences the arid region (**Cairo**) is the least region in emitting **CO_2 45.9** tons annually. Hot Arid region is the biggest region in **CO_2** emissions as (**Aswan**) emits **42.8** tons.

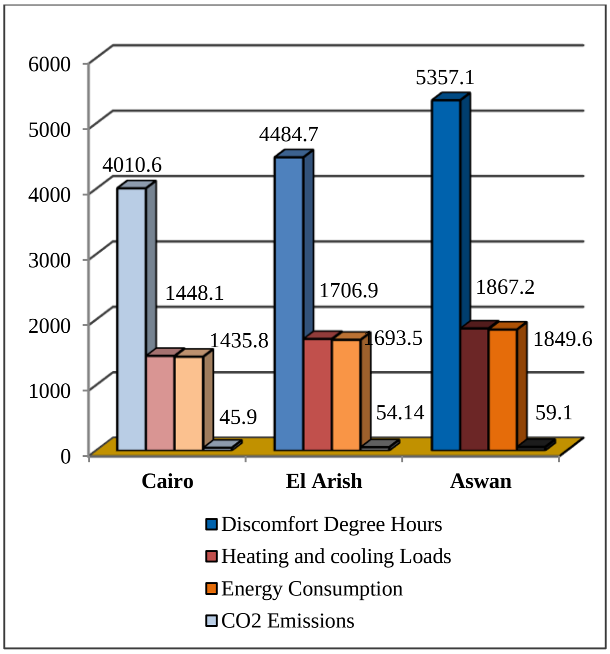


Fig. 24: Comparison of straw bale house results in all climatic regions

9. Conclusion

Reusing straw bale waste as building materials is one of the most effective solutions instead of burning it.

Reused straw bale as building material has many benefits such as follows:

- Matching with Egyptian Code U-Value for walls.
- Discomfort degree hours for straw bale house are less by 40% than masonry brick house.
- Heating and cooling loads for straw bale house are less by 82 % than masonry brick house.
- Saving energy consumption by 82 % than traditional materials house “Masonry Brick”.
- Saving the environment by reducing CO_2 emissions 82 % than masonry brick house.

Straw bale house also is suitable in arid region “Cairo”, as it has the least results for discomfort degree hours, heating and cooling loads, energy consumption, and CO^2 emissions. Straw bale house is not suitable in hot arid region “Aswan”, as it has the highest results for discomfort hours, heating and cooling loads, energy consumption, and CO^2 emissions. Straw bale house is effective in arid region “Cairo”, following by hot humid region “El Arish”.

10. Recommendations

Reused straw bale as a building material; can be used for slum housing, as it is cheaper. Besides, it needs unskilled labors, resulting in reducing construction costs and opens community participation especially in slum areas. Reused straw bale can be used for:

- New cities with low density.
- Economic housing.
- New cities with horizontal expansion area such as “Sinai”, Egypt.
- Tourist villages.
- Lightweight constructions facilities such as camping, insurance army facilities, exhibitions, high way facilities, and kindergartens buildings.

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