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Shipping Containers as Flexible Components for Sustainable Buildings in Coastal Zone - Egypt

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ABSTRACT: Recently, a new concept has been developed over the world followed by many attempts in order to achieve sustainable and eco-friendly buildings. It depends on using shipping containers (SCs) blocks as structural components with a lot of advantages, such as energy efficiency, flexibility, sustainability and economy. Although architecture in Egypt is subjected to continuous change and proposing solutions for many unresolved problems such as population inflation, low land area and slums, shipping containers have not been commonly used in Egypt. As containers blocks are widely available in the Egyptian coastal zone; it has been selected to be our case study. In this paper, an outline of the usage of SCs as flexible components for residential buildings has been presented. Besides, some residential design solutions have been suggested for the coastal zone in Egypt. Then, a comparative assessment for their predicted environmental performance has been done. Finally, the most suitable design form with the highest energy performance based on SCs in the coastal zone in Egypt has been concluded.

KEYWORDS: Flexible component, Sustainable buildings, Shipping Containers, Housing in Egypt.

I. INTRODUCTION

Throughout history, Architecture has generated different ways for renewing itself through new concepts and materials. One of these concepts is shipping container architecture which uses wasted shipping container blocks as building components. It includes a variety of purposes and holds limitless possibilities for buildings' designs.

In Egypt, there is an urgent need for economic and flexible residential buildings which can cope with the increasing number of population and the current state of climate change. This could be achieved by using shipping containers (SCs), also known as an ISO shipping containers or Intermodal Steel Building Units (ISBU), as flexible components for residential buildings to create infinite solutions of sustainable building designs due to their characteristics presented in environmental features, cost, construction time limit and flexibility of moving and changing their locations.

This study focuses on presenting the idea of using shipping containers in residential buildings in the Egyptian coastal area. The aim of the paper is to suggest the best architectural design solutions suitable for this specific climate zone and

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can achieve the highest energy efficiency and thermal comfort for users by using shipping containers (SCs) as flexible components.

II. SHIPPING CONTAINERS (SCs) BLOCKS

A. Definition:

SC is a kind of transport equipment totally or partially enclosed to perform a chamber containing goods; it is designed for simultaneous handling, especially when being transferred from one mean of transport to another. [1]

Containers are designed to carry huge loads beside hold out hard environmental conditions for a lifetime of 15 years or more. [2]

B. History of appearance:

In 1956, Malcom Mclean presented the first container to international trade knowing as the cargo shipping container. The achieved success allowed him to enter marine transportation business. Ships in average can carry about 200000 individual pieces of SCs and take about a week to load and unload [3].

C. Types, Materials, Structure and standard Dimension for SCs:

The shipping container (SC) is known by many names such as "cargo container", "ISO container", or Intermodal Steel Bulding Unit "ISBU" when it is used as a construction component [4].

• Types of SCs

There are two sorts of SCs which are maritime and domestic. Maritime SCs are those essentially manufactured for use in vessels and logistics. These containers can be organized above each other up to ten high. Domestic SCs are manufactured for domestic purposes. They are only designed to be stacked three high. [5]

• Materials, Structure

Basic material which SCs are made of is weathering or corten steel, which has a good corrosion resistance. [6]

The SC unit consists of trapezoid metal panels to form walls, ceiling, edges of the box, and a mesh to support the laminate flooring. Deep corrugation supplies SCs greater rigidity and hardness. The thickness of the trapezoidal corten steel panels for walls and ceiling is 2 mm, and the depth of the corrugated steel panels is between 25 to 50 mm. These variations in size depend on the SC model. [7] The corners are hard-core elements that support SCs and allow for vertical or horizontal connections between containers. The door is placed on one of the smaller facades. The typical flooring in SCs is 28 mm thick plywood (Fig. 3).

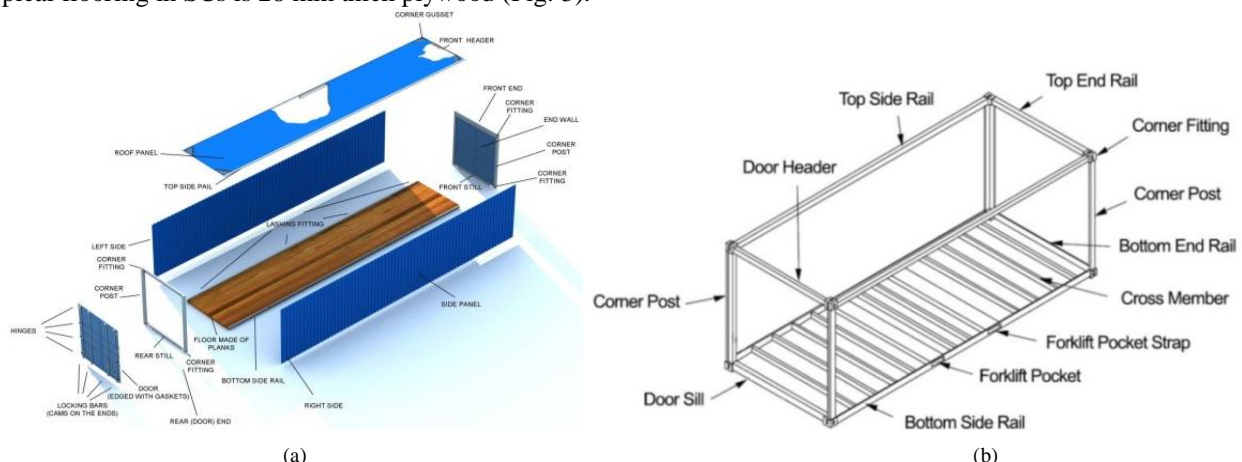


Fig.1: Analytical elements for SC (a) Typical structural components for ISO SC (b)

Source: <http://www.residentialshippingcontainerprimer.com/CONTAINER%20COMPONENTS%20AND%20TERMINOLOGY>

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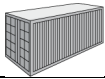
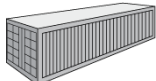
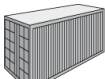
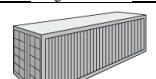
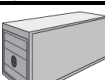

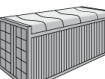
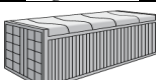
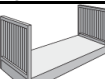

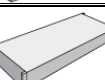

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• Standard Dimension for SCs

Table 1: Dimension for different models of SCs

Types			Length (interior)	Width (interior)	Height (interior)	Door Width	Door Height	Capacity	Max Payload
Dry Cargo Containers	20 ft		5.90m	2.34m	2.39m	2.34m	2.28m	33.1m ³	28 770kg
	40 ft		12.04m	2.34m	2.39m	2.34m	2.28m	67.6m ³	28 800kg
High Cube Containers	20 ft		5.90m	2.34m	2.71m	2.34m	2.57m	37.4m ³	28 130kg
	40 ft		12.04m	2.34m	2.71m	2.34m	2.57m	76.4m ³	28 620kg
Refrigerated Containers	20 ft		5.43m	2.28m	2.26m	2.26m	2.22m	28.0m ³	27 490kg
	40 ft		11.49m	2.27m	2.20m	2.28m	2.16m	57.4m ³	28 580kg
Open Top Containers	20 ft		5.89m	2.31m	2.35m	2.29m	2.18m	32.0m ³	21 600kg
	40 ft		12.03m	2.35m	2.35m	2.34m	2.27m	66.4m ³	26 630kg
Flat Rack Containers	20 ft		5.62m	2.20m	2.23m	--	--	--	21 470kg
	40 ft		12.08m	2.44m	2.10m	--	--	--	39 000kg
Plat Form Containers	20 ft		6.06m	2.44m	2.23m	--	--	--	24 000kg
	40 ft		12.18m	2.40m	1.95m	--	--	--	39 200kg

Source: <https://www.scmdaleel.com/category/freight-forwarding/187>- Adapted by the researchers

• Stacking

SCs vertical stacking requires structural design calculations for each case and appropriate strengthening at the necessary points. [8] There is an opinion says that the limit of SCs stacking capacity ranges between 9 when fully loaded and 16 when empty [9].

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• Costs for SCs

Naturally, costs vary from one country to another. The average expense is about USD 1,500 for an old SC and USD 6,000 for a new one. In China, the average cost of a new 20' HC SC is about USD 4,000 and about USD 6,000 for a 40' HC SC. There are some factors that affect the cost of old SCs [10]:

- (1) The condition of the container regarding to its need for maintenance.
- (2) The age of the container, as many companies sell the container if the duration of its use exceeds ten years regardless of its condition.
- (3) The structural damage of the container, which reduces its selling price.
- (4) The model of the SC, for example when using a 40' HC SC instead of a 20' HC would achieve cost savings and provide more space.
- (5) The distance between the original site and the delivery location.

III. SHIPPING CONTAINERS ARCHITECTURE(SCA)

SCA can be defined as a type of architecture using steel intermodal containers as structural components. It is one of the ways for achieving sustainability and flexibility at the same time. It has special characteristics as mobility and durability that give the opportunity to obtain an unlimited number of architectural designs.

Besides, reusing the container as a building component can contribute in decreasing the embodied energy, carbon emissions and waste materials [11].

The reuse of SCs for architectural purposes is not limited to certain types of buildings but extends from small private homes to skyscrapers. SCs offer infinite possible assemblies based on their modularity and are used for all types of buildings such as social, domestic, and commercial buildings. [12]

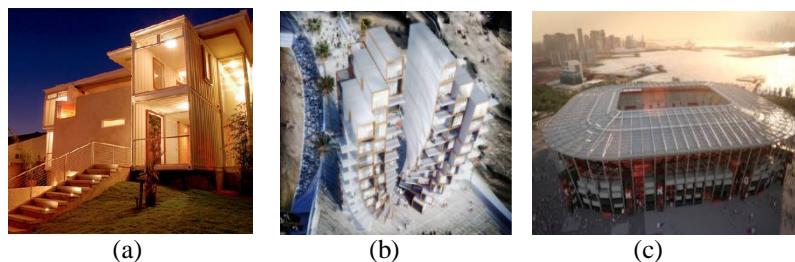


Fig.2: Some examples for SCA: (a) Redondo Beach House in USA [13], (b) Hotel in Las Vegas [14], (c) Ras Abu Aboud Stadium in Qatar [15]

A. SCs as flexible components in residential buildings:

The most common types used in residential buildings due to the height that fit the residential purpose are shown in Table 2.

Table 2: Popular SCs using in residential buildings

Model	Length (m)		Width (m)		Height (m)		Volume (m3)
	internal	external	internal	external	internal	external	
20'	5.9	6.1	2.34	2.4	2.71	2.89	37.4
40'	12.04	12.2	2.34	2.4	2.71	2.89	76.4

Source: <https://www.scmdaleel.com/category/freight-forwarding/187>- Adapted by the researchers

Reusing SCs as a sustainable flexible component helps in residential sector by providing buildings in the areas that suffers from lack of housing and giving many solutions to solve the problem of slums and population congestion while at the same time achieving sustainability, flexibility and beauty in design [16].

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Although there are many advantages of reusing SCs in many architectural designs, there are some disadvantages that can be improved by applying some strategies towards sustainability.

• Advantages [17]:

- 1) Strength and durability: SCs afford high loads and stand against difficult environmental conditions.
- 2) Flexibility: SCs are very flexible due to their modularity and mobility.
- 3) Transportable: They are easy to be moved from one place to another.
- 4) Availability: SCs are practically everywhere.
- 5) Cost: due to their mass production; new and used shipping containers are relatively cheap.
- 6) Short construction time: SCs construction time limit is less by 40% to 60% comparing with traditional systems.
- 7) Sustainable resource: SCs play an important role in buildings' constructions as recyclable materials.
- 8) Personal style statement: The biggest benefit is that anyone can obtain the exact type that he needs.

• Disadvantages [18]:

- 1) Temperature and humidity: SCs need effective procedures to insulate structural and protect them from moisture.
- 2) Labor: Dealing with containers requires skilled workers and that is difficult to be achieved.
- 3) Construction site: steel sets are to be suited in flat than irregular sites.
- 4) Acoustics: SCs need for acoustic insulation.
- 5) Building permits: buildings that use SCs are evaluated as non-standard structures which mean more paperwork.

B. Shipping containers Architecture (SCA) in Egypt:

Till now, SCs are not widely used in Egypt. They have mainly been used in military camps as well as public bathrooms, portable halls, and moving restaurants. Qubix Studios has taken the lead of SCs construction in Egypt [19]. Fig. (3) illustrates some of their work.

This limited usage is due to lack of knowledge and skills in this type of construction and an ignorance of the effectiveness of SCs in ensuring a comfortable indoor environment in the different climates of Egypt.



Fig.3: First SCs buildings by Qubix Studios in Egypt

Source:<http://cairoscene.com/Business/Qubix-Egyptian-Entrepreneurs-Building-Incredible-Houses-Shipping-Containers>

IV. OBJECTIVES OF THE STUDY

- 1- Developing the traditional form of the economical residential buildings in Egypt.
- 2- Suggesting different types of residential units according to what every family needs (area- privacy - number of spaces) by using SCs.
- 3- Predicting the environmental performance of each design type by using simulation programs.
- 4- Concluding which design would achieve the highest environmental performance.

V. METHODOLOGY

This paper has proposed six different residential models by using Shipping containers (SCs) with an area of approximately 90 m² which is the minimum area required for economic housing in Egypt. Then, a comparative simulated assessment has been presented by using Design Builder program according to their environmental performance. Finally, the most suitable design based on SCs for the North Coastal Zone in Egypt has been suggested.

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A. Specification of simulation models

As the containers have different types and dimensions, the paper takes the 40 feet high cube container as the base of construction as it is mostly available in the coastal ports in Egypt (area of study), and in addition, it is cheap and ideal for use in economic residential purposes. The container' external dimensions are 12.12*2.4 m length & width and 2.89m height.

B. Design parameters of SCs residential simulation models

Specific Information about the residential unit based on SCs:

- Structural details:

- The area is approximately 90m² which is suitable for 5 occupants.
- Every model consists of three SCs of 40feet HC putting in one level as a typical story.
- Each unit includes one living room, toilet, kitchen and three bedrooms as this is the minimum area required for economic housing in Egypt.

- Materials details:

All models have steel 20 mm- air gap 28mm - with internal insulation ESP insulation 35mm [34] for roof and wall - the wall has U value 0.42 w/m2k - the roof is adiabatic - the floor is 28 mm marine plywood on cross-section steel members on sand- the windows are made of single glazed with dimensions (1.2m × 1.2m).


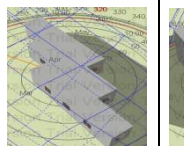
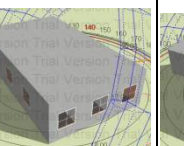
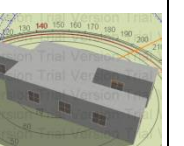
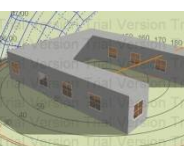

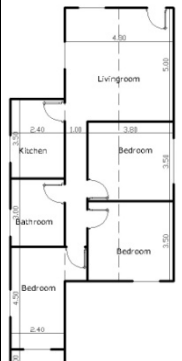
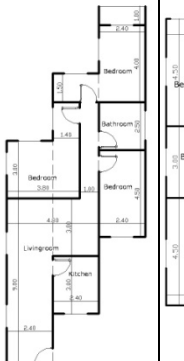
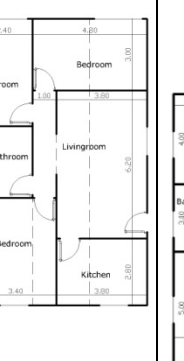

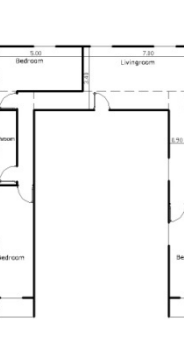
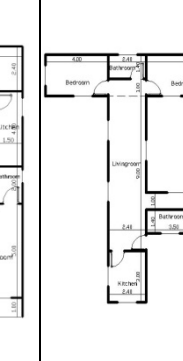
- Environmental details:

The models are designed to be suitable for the North Coastal Zone in Egypt. (moderate climate) depending on the passive solar design. Mechanical ventilation could be used only if necessary. Natural ventilation is allowed all time. Most openings are oriented to north to achieve the best thermal comfort.

C. Simulation for suggested residential models using SCs in Egypt

Based on to the general requirements of economic housing design in Egypt and the design criteria of residential buildings, several residential design models have been suggested by using SCs units stacked together in different ways. Among these models, six designs which achieved better zoning and orientation have been chosen. Then, an environmental evaluation by using Design Builder program has been accomplished in order to determine the most suitable designs with the highest environmental performance.

Table 4: Suggested six design models for the SCs residence

Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
					
					

Source: the researchers

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D. Comparative Analysis between different building types

The environmental evaluation process of each building type is classified according to the following parameters:

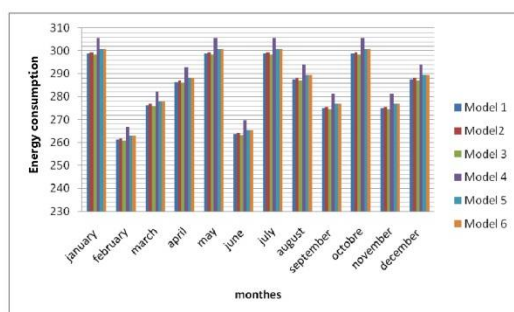
- Energy consumption (kwh)
- Operative temperature($^{\circ}$ C)
- CO₂ emissions (kg)
- Pierce PMV SET

Table 5: Comparison of results of the six different models throughout the whole year

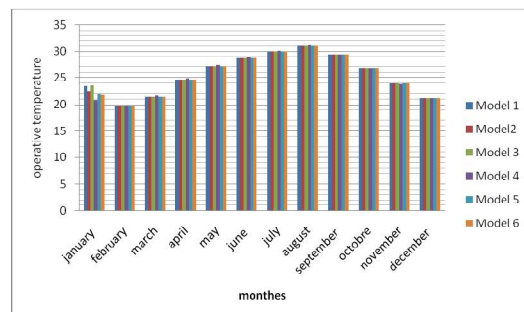
model 1	january	february	march	april	may	june	july	august	september	october	november	december	model 1
Energy consumption (kWh)	299.01	261.26	276.24	286.43	299.01	263.66	299.01	287.63	275.04	299.01	275.04	287.63	3409.0
Operative Temperature ($^{\circ}$ C)	23.41	19.68	21.42	24.59	27.08	28.75	30.03	31.1	29.47	26.8	23.87	21.24	25.6
CO ₂ (kg)	378.53	329.91	347.57	362.32	378.53	331.36	378.53	363.05	346.84	378.53	346.84	363.05	4305.1
Pierce PMV SET ()	0.67	0.49	0.74	0.42	0.92	1.45	1.94	2.27	1.73	1.77	1.22	0.71	1.2
model 2	january	february	march	april	may	june	july	august	september	october	november	december	model 2
Energy consumption (kWh)	299.61	261.78	276.79	287	299.61	264.18	299.61	288.2	275.59	299.61	275.59	288.2	3415.8
Operative Temperature ($^{\circ}$ C)	22.43	19.68	21.42	24.59	27.08	28.75	30.03	31.1	29.47	26.8	23.87	21.24	25.5
CO ₂ (kg)	379.28	330.56	348.26	363.04	379.28	332.02	379.28	363.77	347.53	379.28	347.53	363.77	4313.6
Pierce PMV SET ()	0.46	0.27	0.57	0.28	0.76	1.28	1.77	2.1	1.56	1.62	1.06	0.53	1.0
model 3	january	february	march	april	may	june	july	august	september	october	november	december	model 3
Energy consumption (kWh)	298.46	260.78	275.73	285.9	298.46	263.17	298.46	287.1	274.54	298.46	274.54	287.1	3402.7
Operative Temperature ($^{\circ}$ C)	23.59	19.68	21.42	24.59	27.08	28.75	30.03	31.1	29.47	26.8	23.87	21.24	25.6
CO ₂ (kg)	377.83	329.3	346.93	361.65	377.83	330.75	377.83	362.38	346.2	377.83	346.2	362.38	4297.1
Pierce PMV SET ()	0.71	0.57	0.81	0.43	0.95	1.5	1.98	2.29	1.72	1.75	1.19	0.75	1.2
model 4	january	february	march	april	may	june	july	august	september	october	november	december	model 4
Energy consumption (kWh)	305.6	267.0	282.3	292.8	305.6	269.5	305.6	294.0	281.1	305.6	281.1	294.0	3484.3
Operative Temperature ($^{\circ}$ C)	20.9	19.8	21.7	24.9	27.3	28.9	30.2	31.2	29.5	26.7	23.8	21.3	25.5
CO ₂ (kg)	386.9	337.2	355.3	370.3	386.9	338.7	386.9	371.1	354.5	386.9	354.5	371.1	4400.2
Pierce PMV SET ()	0.2	0.0	0.3	0.2	0.7	1.3	1.8	2.1	1.5	1.6	0.9	0.3	0.9
model 5	january	february	march	april	may	june	july	august	september	october	november	december	model 5
Energy consumption (kWh)	300.93	262.93	278.01	288.26	300.93	265.35	300.93	289.47	276.81	300.93	276.81	289.47	3430.8
Operative Temperature ($^{\circ}$ C)	21.97	19.68	21.42	24.59	27.08	28.75	30.03	31.1	29.47	26.8	23.87	21.24	25.5
CO ₂ (kg)	380.95	332.02	349.79	364.64	380.95	333.48	380.95	365.37	349.06	380.95	349.06	365.37	4332.6
Pierce PMV SET ()	0.37	0.19	0.46	0.26	0.74	1.25	1.73	2.06	1.51	1.6	1.03	0.45	1.0
model 6	january	february	march	april	may	june	july	august	september	october	november	december	model 6
Energy consumption (kWh)	300.93	262.93	278.01	288.26	300.93	265.35	300.93	289.47	276.81	300.93	276.81	289.47	3430.8
Operative Temperature ($^{\circ}$ C)	21.79	19.68	21.42	24.59	27.08	28.75	30.03	31.1	29.47	26.8	23.87	21.24	25.5
CO ₂ (kg)	380.95	332.02	349.79	364.64	380.95	333.48	380.95	365.37	349.06	380.95	349.06	365.37	4332.6
Pierce PMV SET ()	0.33	0.16	0.44	0.24	0.72	1.23	1.71	2.04	1.48	1.56	0.98	0.41	0.9

Source: the researchers

VI. RESULTS AND DISCUSSION



(a)



(b)

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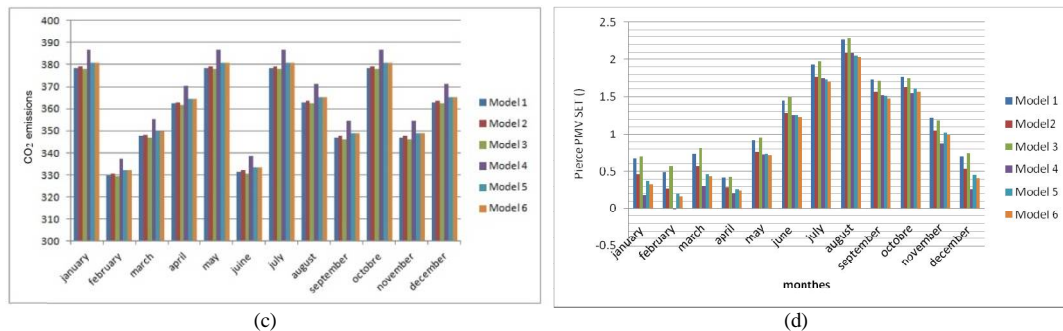


Fig.4: Comparison among the suggested models throughout the year of: (a) energy consumption, (b) operative temperature, (c) CO₂ emissions, (d) Pierce PMV SET (the most important simulation of thermal comfort).

The previous charts show that mostly all models nearly have the same value of operative temperature. Model (4) achieved the best PMV value with the highest value of energy consumption and CO₂ emissions. On the other hand, models (1) and (3) achieved the lowest value of energy consumption and CO₂ emissions with the highest value of PMV, which means that these design models will not attain the required thermal comfort for users.

VII. CONCLUSION

This paper proposed shipping containers (SCs) as flexible structural elements for residential buildings in the north coastal zone of Egypt. By using SCs in residential buildings, many design solutions could be suggested with acceptable environmental performance. Six design models have been suggested based on using SCs arranged together in different ways according to the design criteria of residential buildings. General requirements of economic housing design in Egypt were also been considered.

According to the analysis previously shown, model (4) achieved the best thermal comfort throughout the year. Thus, it could be suggested as the best design model of residential buildings in this specific climate zone. On the other hand, models (1) and (3) are not recommended as design models unless some modifications are added in order to achieve better results.

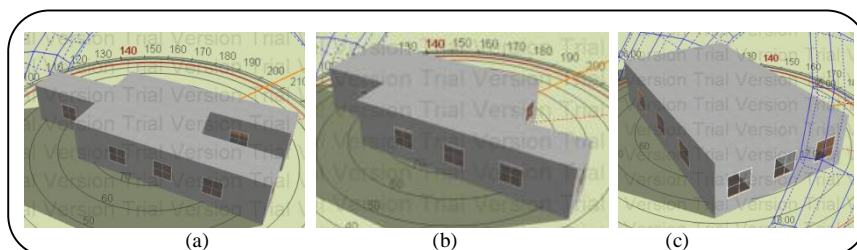


Fig.5: (a) model 4 is the best design model of residential buildings, (b) - (c) models 1 & 3 are the worst design model of residential buildings

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