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A PROPOSAL FOR DESERT HOUSE DESIGN IN EGYPT USING PASSIVE GROUND COOLING TECHNIQUES

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Abstract **-** An area less than 5.5% of Egyptian territory is where most of Egypt's population lives. A narrow strip of land forms the Nile Valley and Delta sector.

The National Project for Desert Hinterlands is one of the urban projects targeting rehabilitation of the poor in alternative villages in the near desert to stop urban sprawl over agricultural land and decrease congestion in the old habitats. Low cost energy efficient houses are the aim of the architect in similar projects taking in consideration the high electricity consumption of Egypt's residential sector.

Based on a literature review, this paper presents a proposal for designing desert dwellings that accommodate the hot dry climate by incorporating passive elements and using stabilized earth blocks as a local building material. Furthermore, simulation is used to test alternative proposals. The results show that an underground constructed house with a sunken courtyard incorporating an Earth to Air Heat Exchanger System (EAHE) can reduce between 42-72% of energy consumption used to achieve thermal comfort compared to contemporary desert housing projects.

Keywords **-** Earth Sheltered Houses, Earth to air heat Exchangers, Earth cooling Tubes, low cost energy efficient desert house.

I. INTRODUCTION

The need has arisen to undertake extensive projects for redistributing the population. The Desert Hinterlands Villages is one of these projects to establish low cost desert housing. These projects should be low cost energy efficient to avoid the increasing energy demand due to cooling needs.

Farouh and Amer [1] explored the main passive and hybrid design techniques for low cost energy efficient housing in hot arid climate. They highly recommended using the technique of "cooling by thermal earth inertia". This was the starting point for this research in which an approach - to implement these techniques - was examined by computer modeling using Design Builder Program experimenting a proposed Earth sheltered Building with a sunken courtyard and using Underground Earth Tubes.

1. Aim of the Study

The authors constructed this work on implementing passive ground cooling techniques as a proposal for enhancing thermal performance of desert houses in Egypt. The aim is to examine the ability of this proposal in saving energy and achieving thermal comfort in low cost desert housing in Egypt.

2. Egypt's Background

A quick look at Egypt's conditions related to our study.

3. Egyptian electricity consumption

The Building Sector consumes most of the electricity (See Fig.1) due to the increased consumption of the air conditioning machines [2], [3].

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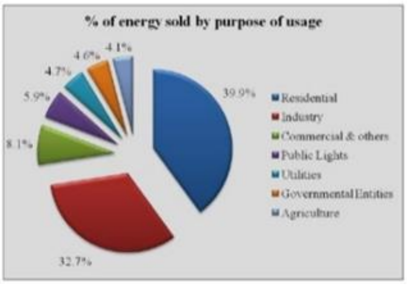

Fig .1. Egyptian electricity consumption-The most consuming areas are the residential ones. The Egyptian Electricity Holding Company Annual Report 2009/2010. Egyptian Electricity Holding Company, Cairo, Egypt, 2010.

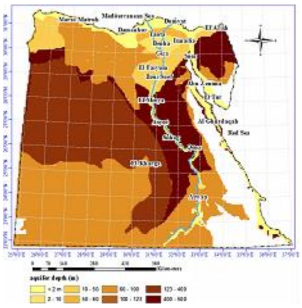

Fig .2. Classification of aquifer depth in Egypt. M. Salim, Selection of Groundwater Sites in Egypt. Journal of Advanced Research, 2012

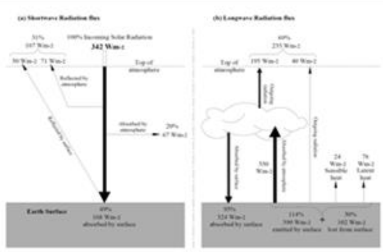

Fig .3. Earth's energy budget diagram showing the short-wave (a) and long-wave (b) energy fluxes. Banks, David. An Introduction to Thermogeology: Ground Source: Heating and Cooling. Wiley-Blackwell, 2012.

A. Groundwater levels

The ground water is found far below the ground surface in most Egypt's desert area [4] (See Fig. 2). Therefore, excavations are implemented easily without the need for water proof materials.

B. Type of soil:

Most Egypt's desert land is a sandy soil and easy to construct on. Thermal characteristics of soil affect the underground temperatures, which is a major factor in energy saving by earth inertia as will be explained later.

II. LITERATURE REVIEW : PASSIVE GROUND COOLING

The concept of ground cooling is based on heat dissipation from a building to the ground which, during the cooling season, has a temperature lower than the outdoor air. This dissipation can be achieved either by direct contact of a significant areas of the building envelope with the ground (Earth shelters), or by injecting air that has been previously circulated underground into the building by means of earth-to-air heat exchangers (EAHE).

Heat Storage Capacity of the Earth Subsurface

The rocks at the subsurface have high value of volumetric heat capacity but low value of thermal conductivity. Therefore, the heat is rather stored than diffuses through the soil in the upstream [5].

When averaged globally and annually, about 49% of the solar radiation striking the earth and its atmosphere is absorbed at the surface [6] (See Fig. 3).

1. Earth Shelters

Researchers, including Anselm [6], found that earth sheltered houses maintain heating energy consumption lesser by up to 75% compared to conventional above-ground house.

A. Definition

Earth shelters can be defined as structures built with the use of earth mass against building walls as external thermal mass [7].

B. Potential energy savings:

Based on several physical characteristics: [9]

- The reduction of heat loss due to conduction through the building envelope.
- Less heat conduction into the house due to reduced temperature differential.
- Building protection from the direct solar radiation.
- The reduction of air infiltration within the dwelling.

(a) One of the partially buried homes in Siwa

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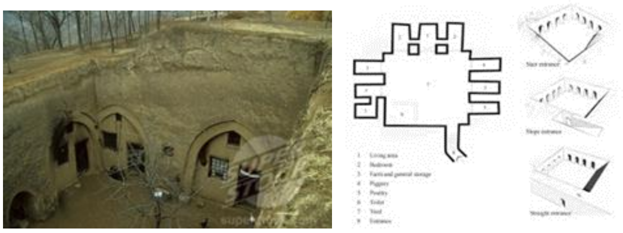
(b) Aerial view of a typical Matmata earth shelter dwelling.



(c) A typical earth shelter home in North-western China

(d) The Goreme Valley of Cappadocia in central Turkey

Fig .4. Historical Earth sheltered homes [8-10]

C. *Historical background and examples*

Earth sheltered homes were primarily developed for shelter, warmth and security for the earliest human dwellers. Most of the recorded cases of these shelters are found extensively in areas like Asia and Northern Africa.

- **In Egypt:** [8] such as: Nazlet Elsemman in Giza (for historical conservation reasons), Paris village in Upper Egypt & Siwa oasis in western desert (for climatic protection reasons).
- **In Tunisia:** [Dry Desert climate]: Residents of Matmata and in Bulla Regia, use of the sunken courtyard concept [9].
- **In China:** [Humid subtropical climate]: Yaodongs cave houses carved out of a hillside or excavated horizontally from a central "sunken courtyard" An estimated 40 million people live in Yaodongs [10].
- **In Turkey:** The Goreme Valley of Cappadocia [Dry Steppe climate]: 260km2 with 200+ underground villages complete with hidden passages, secret rooms and ancient temples (See Fig. 4).

D. *Typology*

- **Bermed earth shelter:** Earth is piled up against exterior walls and heaped to incline downwards away from the house. The roof may, or may not be, fully earth covered. Other variations are the elevational and in-hill. As in Turkey (See Fig. 4).
- **Envelope or True underground earth shelter:** The house is built completely below ground on a flat site, with the major living spaces surrounding a central outdoor courtyard or atrium which provides light, solar heat, outside views, and access via a stairway from the ground level,as in Tunisia and China (See Fig. 4).

About 50% of the elevational structures exterior façade is in direct contact with the earth mass, while the ratio is 80% of Atrium design and hence becomes an underground building type which offers better indoor conditions for both summer and winter temperatures [8], [11].

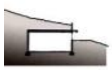
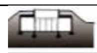
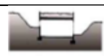
On the Hillside	Bermed	Underground	Relation to Surface
			Openings
			Chamber
			Atrium
			Elevational
			Penetrational

Fig. 5. Typology of Earth sheltered Buildings. Source: Hassan, H. Analytical Study of Earth-Sheltered Construction and its Suitability for Housing Projects in the Egyptian Deserts. Thesis, Egypt. 2009.

E. *Worldwide earth sheltered houses:*

Will be explored to explain the typology of earth sheltered houses and enrich the knowledge of key projects of these types.

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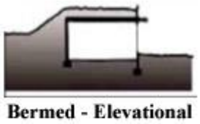
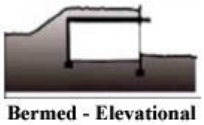
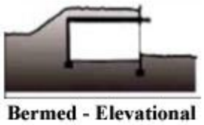
Table 1 . Some Worldwide Earth Sheltered Housing Units

	Project	Ecology House Marstons Milss, Massachusetts, USA,1972.
	Architect	John E. Barnard Jr.
	Climate	Hemiboreal
	Type	
	Notes	One-fifth normal heating cost, 25% lower building cost, privacy from neighbors.
	Project	Underground-house-welsh-coase Druidston, Pembrokeshire, UK, 1998.
	Architect	Future Systems
	Climate	Maritime temperature
	Type	
	Notes	The basic design is: one room inside, divided by prefabricated colored pods.
	Project	A home built in a cave in Missouri, USA.
	Architect	Curt and Deborah Sleeper
	Climate	Hot Summer Continental
	Type	
	Notes	This house was made in an existing cave in the small town of Festus, Missouri.
	Project	the Earth House Estate Lättenstrasse Dietikon, Switzerland, 1993.
	Architect	Peter Vetsch
	Climate	Tundra
	Type	
	Notes	The organic construction consists of shotcrete, with a 25 cm layer of polymer bitumen and recycled glass foam on top.

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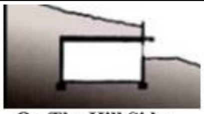
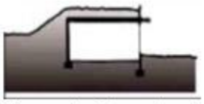
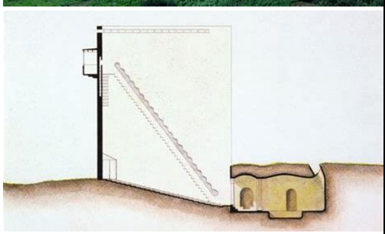
	Project	Underground-home. Located in the Swiss village of Vals.
	Architect	SeARCH and Christian Muller Architects
	Climate	Tundra
	Type	 On The Hill Side
	Notes	The introduction of a central patio into the steep incline creates a large façade with considerable potential for window openings.
	Project	Earthship Prototypes
	Architect	Michael Reynolds
	Climate	Implemented in many climates including hot desert and maritime temperature of London.
	Type	 Bermed - Elevational
 	Notes	Off- grid prototypes •Constructed using cans, bottles and tires (reuse) with natural adobe materials. • Heat and cool themselves naturally via solar/thermal dynamics • Collect their own power from the sun and wind • Harvest their own water from rain and snow melt • Contain and treat their own sewage on site (water is used and reused at four cycles).
 	Project	Spiritual house| Sevilla, Spain, 1980.
	Architect	Emilio Ambasz
	Climate	Dry-summer subtropical
	Type	 Underground - Elevational
	Notes	An underground "canopy" of fiberglass panels extends horizontally as a ten-foot cornice from the wall's top to keep water from soaking the ground around the house.

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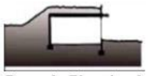
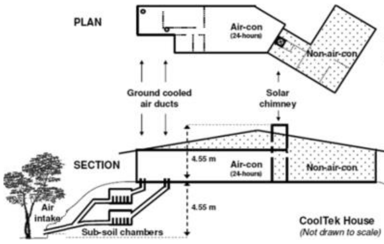
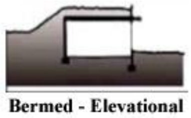
	Project	Earth House Republic of Korea, 2009.
	Architect	Byoungsoo Cho, Yangpyeong-gun, Gyeonggi-do
	Climate	Hot Summer Continental
	Type	 Underground - Elevational
	Notes	Used a geothermal cooling system with a radiant floor heating system under the rammed clay, concrete floor.
	Project	Woodland Home London, UK.
	Architect	Reardon Smith Architects
	Climate	Maritime temperature
	Type	 "Non Earth" Roof  Bermed - Elevational
	Notes	Skylight in roof lets in natural feeling light.
 	Project	Aloni House Greece, 2008.
	Architect	decaArchitecture
	Climate	Dry-summer subtropical
	Type	 Underground - Atrium  Bermed - Penetrational
	Notes	The house's sides disappear into the ground, blending the structure into the landscape. There are five internal courtyards, which flood the rooms with light and shield windows and doors from stormy rainwater.
	Project	Bolton Echo House- North West England, UK, 2009.
	Architect	Make Architects
	Climate	Maritime temperature
	Type	 Bermed - Penetrational
	Notes	Designed to consume less energy than it uses; a ground source heat pump, photovoltaic panels and a wind turbine will generate on-site renewable energy.

	Project	CoolTek House in Malacca, Malaysia.
	Climate	Hot Humid
	Type	
	Notes	The original concept was to have the heat passively ventilated out by solar chimney and draw in the cooled air from ground cooled duct.
	Project	UK's first earth-sheltered social housing scheme at Honingham (Harrall, J., 2007).
	Climate	Maritime temperature
	Type	
	Notes	It comprises four two-bed, four-person, earth-sheltered, passive solar design (PSD) bungalows.

F. Ventilation system and air infiltration:

To avoid sick building syndrome and ensure a desirable and healthy environment, the underground building units are usually incorporated with various types of passive induced ventilation techniques [12].

G. Advantages and disadvantages- Advantages:

Underground homes provide a safer living environment [13] [14], energy Efficiency compared to aboveground homes [15] [16], reduced maintenance-operating costs, and construction efficiencies. In addition to minimal visual impact, dual land use, and lower noise [17].

Disadvantages: Social acceptance: Golany stated that there are some social and psychological problems to overcome in earth-sheltering [18]. But Al-mumin found that in Kuwait the occupants agreed to live underground and sunken courtyards are preferred [19]. Thus negative aspects could be avoided by a good efficient design and a sufficient exposure to sunlight through elevations or sunken courtyards.

H. Construction cost:

Al-Mumin concluded that underground courtyard homes are almost the same if not less expensive than aboveground ones [19]. The reduction is due to savings in the exterior cladding, wall materials, and thermal insulation, we must consider the running costs and thus the sunken courtyard concept may win [20]. However, additional studies are needed to investigate and to prove this point.

Advantages	Disadvantages
Minimal visual	Lack of outside
Thermal efficiency	Public
Increased open	Lack of thermal
Lower noise	Higher excavation
Reduced	Water drainage
Safer living	Ventilation *
Construction	Design constrains
Reduced life cycle	
(*) means could be avoided by aspects of good design	

I. Construction considerations

- **Climate:** In dry climates with high temperature extremes – as in Egypt's Desert - earth-sheltered houses can be more cost-effective [20].
- **Site's topography and microclimate:** Flat sites – as in Egypt's desert - is the most demanding for excavations [20].
- **Type of soil:** Sandy soils are the best for earth-sheltered houses because they compact well for bearing the weight of the construction materials and allow water to drain quickly ,which protects the underground constructions [20].
- **The groundwater level:** underground water exerts pressure against underground bearing

walls so it is important to build above the water table [20].

J. Construction materials

Earth sheltered houses require heavy duty, more enduring construction materials that can resist the pressure and moisture of the surrounding ground [due to their good waterproofing and insulation properties]. Concrete, reinforced masonry, steel, and wood can be suitable.

In developing countries, local materials have been used widely for their advantages economically, ecologically, and good energy performance. Examples are cob, adobe, straw bale, brick, wood, cordwood, and stone [21]. Here's some recently proposed materials for low cost housing in Egypt:

Rice-straw based cement brick: The rice-straw has replaced part of the aggregates used in the normal cement brick to generate a stable blend after which mechanical and thermal experiments have been conducted [22]. It showed promising energy savings but this material is presented mainly as a solution for recycling rice wastes and has not been widely approached in Egypt.

"**Rammed Earth**" is constructed by using a pneumatic tamper to ram a mix of earth and cement, into wall forms to produce walls, foundations and floors. The soil should have some silt and clay to act as binders and allow soil compaction which are not available in desert soils as the case in this research. Also, rammed earth cannot be used for constructing ceilings. Actually there is a lack of knowledge and access to tools for using this material in Egypt [23].

The compressed stabilized earth block

Using a steel press to compress the moisturized soil - raw or stabilized-producing CSEB blocks. Sandy soil is more suitable than clayey one.

Cement is preferred as a stabilizer for sandy soils to accelerate the strength. The ratio of cement should be around 5%.

A finished m3 of CSEB masonry is always cheaper than fired bricks: 19.4% less than country fired bricks and 47.2 % less than wire cut bricks [24].

In addition to its advantages, stabilized earth blocks also introduce a solution for reusing the excavated soil from basement in underground courtyard homes so the research recommends stabilized earth blocks as a building material for earth sheltered houses in Egypt's desert.

Table 3. .Advantages of "CSEB"[24]

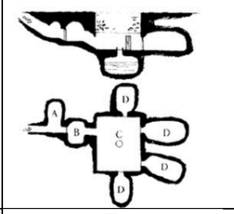
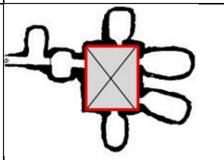
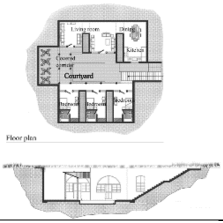
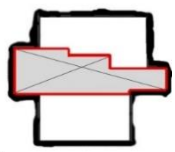
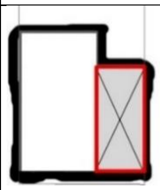
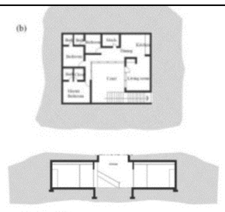
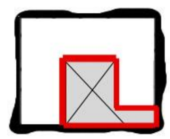
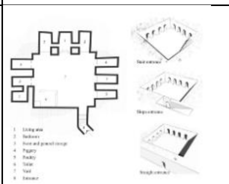
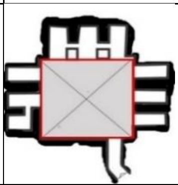
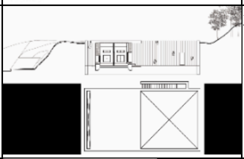
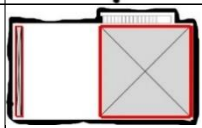
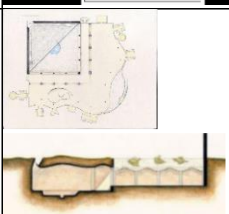
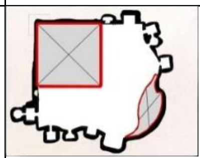
A local material	Socially accepted Flexible production scale
A bio-degradable material	
An adapted material: Produced locally	Cost efficiency
A transferable technology	Energy efficiency and eco friendliness: The energy consumption in a m3 can be from 5 to 15 times less than a m^3 of fired bricks. The pollution emission will also be 2.4 to 7.8 times less than fired bricks
A job creation opportunity	
Market opportunity: Cheaper than fired bricks	
Reducing imports	

K. Underground courtyard houses [Constructing case studies]

The courtyard plan is best suited in flat terrain sites that have permeable, dry or well- drained soils which are far from a ground water source [27] With reference to the traditional underground building which is constructed in arid climatic regions. Some do not even require any supporting walls because of the land conditions [12]. This is the case in Egypt's desert. Underground courtyard type is represented in historic underground homes and there are fewer examples of contemporary ones.

In the next table 4, some underground courtyard houses will be shown. They are classified according to the courtyard number in each house and its proportions. Consequently, design guidelines will be deduced in order to help in constructing research case studies later.

Table 4. Sunken courtyard house examples and types

Project	Plans and Sections	sheltered Area m2	Courtyard Area m2	Courtyard / Area sheltered Area %	Courtyard / Width Length %	Courtyard Typology
Underground House, Southern Tunisia		82	66	80%	1:1.25	
Underground House, Source: [9]				56%*	1:3.25*	
Sunken Courtyard by: Gestalten, Melbourne, Australia http://www.archdaily.com/259160/sunken-courtyard-gestalten		73	30	240%	1:2.5	
Underground House, Source: [9]		132.5	52	40%	1:1.2	
A Typical Earth Sheltered Home , Northern Western China				170%*	1:1.25*	
Earth House by BCHO Architects, Seoul, Korea.		32.5	69.5	210%	1:1.15	
Casa De Retiro Espiritual by Emilio Ambasz, Spain		280	173	62%	1:1	

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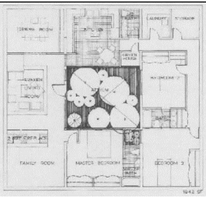
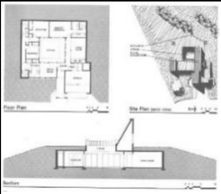
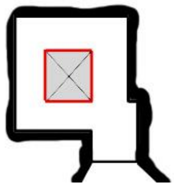
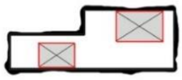
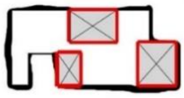
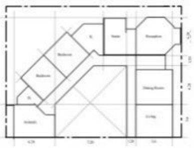
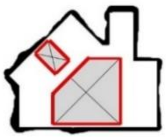
Source: Unknown		180	36	20%	1:1	
Clark House, Oregon, USA. Norman Clark 1977 (Sterling, R.,et al.)		190.5	41	21%	1:1.1	
An underground House, UK Architect: Journeyman draughting + Design http://plans-design-draughting.co.uk/recent-projects/		190	75	40%	1:1.6	
The National Project for Desert Hinterlands Villages, Egypt Aswan Prototype**		85	48	56%	1:1.5 1:1.15	
The National Project for Desert Hinterlands Villages, Egypt Fayoum Prototype**		105	55	52%	1:1 1:1.5	

Note: * Concluded from the plans' drawings
** Above ground prototypes from the National Project For Desert Hinterlands Villages, Egypt as guidelines for houses needs in Egypt. Source: Researcher

From the scanning of habitable underground houses the researchers concluded that there are three courtyard types:

- One Square Courtyard type. (Recommended a 40m2 court for 80-120 m2 earth sheltered area)
- One Rectangle Courtyard type with aspect ratio 1:1.25.
- Multiple courtyards (two or three) with aspect ratio ranging from 1:1 to 1:1.6.

From the previous literature eight Residential building types were proposed taking into consideration the low cost Egyptian rustic dwellings' needs, with the following criteria:

- Low rise. (One or two floors). [In order to measure the influence of coupling the building with the ground on the thermal performance of the house]
- Have an internal court. (From literature: most appropriate for underground houses in desert climate).
- Low cost. (Rural house).
- (Area from 70 to 150 m2 + using local materials and local building roofing techniques such as domes and volts).

The researchers also authenticated the zero-level in all the eight cases due to building services issues.

Placing the building services at zero level to avoid using a sewage pump for sewage disposal, which represents a non-affordable cost for low cost houses.

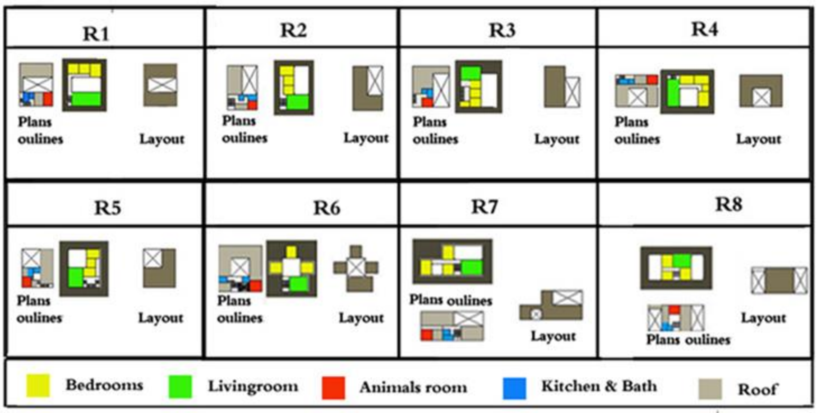


Fig. 6. Deduced eight types of courtyard houses which represent the case studies
Source: Researchers.

2. The principle of ground cooling by indirect contact:

A long buried pipe – at a calculated depth for best efficiency - that have an end for fresh outside air intake and the other end for inside cooled air released in the building, this is the main idea of The Earth Pipe Cooling system. This system uses the ground as a heat sink for cooling in warm countries where the intake air, in the buried pipe, loses excess heat to the earth by convection. Adequate air flow into the buried pipe is a must to get cooled air for occupants' thermal comfort. A fan blower is needed at air intake if there is deficiency in air flow

A. Factors that affect Earth Pipe Cooling performance

As a conclusion from various published literature, the performance of Earth Pipe Cooling are affected by four main parameters and they are:

- **Pipe length:** A parametric study using different pipe lengths : 10m, 30m, 50m,70m, 90m concluded that the longer the pipe, the better the performance of the earth tube [28], [29].

- **Pipe radius or diameter:** The smaller the radius of the pipe the more decreased inlet temperature.

- **Depth of the pipe inserted into the ground:** As the pipe depth increases, the inlet air temperature decreases in all climate conditions [28].

- **Air flow rate inside the pipe:** as the air flow rate increases, the inlet air temperature increases [28], [31] and the coefficient of performance (COP) reduces [32] (See Fig. 7).

Other factors that could affect the performance of Earth Pipe Cooling system is

- **The surface condition of the ground:** Bare or shaded.
- **Soil type:** sandy soil is much preferable than other soil types [33].
- **The choice of pipe materials:** different pipe materials have minor effects on the Earth Pipe Cooling system performance [34].

B. Application of Earth Pipe Cooling

Models of Earth to Air Heat Exchanger System (EAHE) made of low cost material like PVC pipes and exhaust fans
- a duct system suitable for small houses
- have been examined. Models show [35] temperature reduction of 10-15ºC than outside during summer.

This system can effectively reduce the energy consumption between 50 % and 60 %, which is consumed by building cooling (Air conditioning) and warming systems.

COP is a term used in refrigeration and air conditioning to describe the performance of a system. Normally, heating and air conditioning systems have average year-round COPs of about 2.0. The COPs of the systems utilizing underground air tunnels are much higher. For open and closed loop systems, the COP can be as high as 10 [33].

The higher the COP, the higher the efficiency of the equipment [29].

Table 5. Some Applications of Earth Pipe Cooling [29]

Researcher	Location	Buried Pipe Design	Ambient T, °C	Energy Saving
Goswami and Biseli (Summer, 1993)	Florida, USA	0.305m dia, 30.5m long pipe. 2.7m deep. 0.184kW fan blower and 2 ½ ton heat pump	Summer:23.9°C to 33.1°C	Open Loop COP= 12 COP (air-cond) = 1 to 4 With Heat Pump COP = 13
Pfafferott (2003)	DB Netz AG			COP = 88
	Fraunhofer ISE			COP = 29
	Lamparter			COP = 380

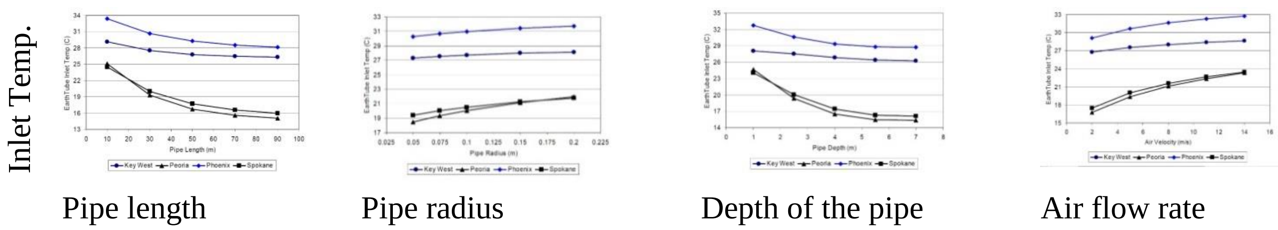


Fig. 7. Factors that affect Earth Pipe Cooling performance [28]

C. *Limitations*

The risk of condensation in the buried pipe: to avoid his problem the pipe may be tilted slightly to allow the water condensed to drain away through a tiny hole [30], [37]. This is a preference to the arid climate of Egypt.

D. Hybrid design for enhancement of ground cooling system

Maerefat and Poshtiri introduced and investigated integrated EAHE-SC system. They showed that the solar chimney can be perfectly used to power the underground cooling system during the daytime, without any need for electricity [39].

The air is heated up in the SC by the solar energy, and by natural convection mechanism the outside air is sucked-in through the earth–air pipe.

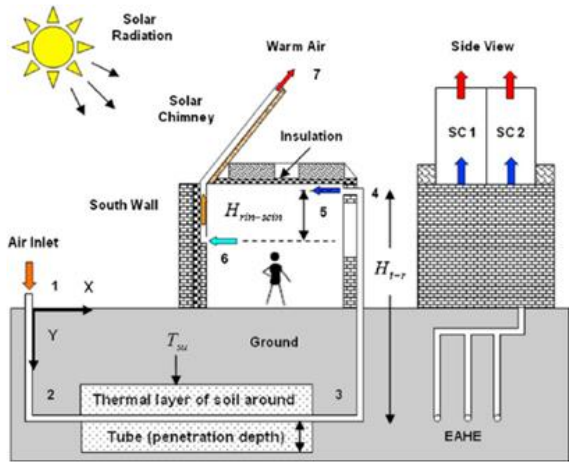


Fig. 8: Schematic diagram of integrated earth to air heat exchanger and solar chimney (Maerefat, M., Poshtiri, A., 2010)

Poshtiri, et al., [40] examined SC-EAHE system. The results show that proper configurations could provide good indoor condition even at poor solar intensity of 100 W/m2 and high ambient air temperature of 50°C. Comparative survey shows the SC-EAHE system is the best choice for buildings with poor insulation at day time.

Hammadi and Mohammed investigated the Solar Chimney (SC) together with earth to air heat exchanger (EAHE) as a low-energy consuming technique. A numerical program "FLUENT 6.3 code" of an earth to air heat exchanger (EAHE) was used for predicting the outlet air temperature and cooling

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potential of these devices in Basrah climate which is hot arid. Theoretical analyses have been conducted to investigate the ventilation in a solar chimney [41].

The results have shown significant temperature reductions at the buried pipe outlets from their inlets. Maximum temperature drop through the buried pipe was found to be 11ºC. In both seasons. The performance of the buried pipe increases with increasing pipe length only up to 70m and with small pipe diameters and the best velocity is 1 m/s.

E. Geothermal energy researches in Egypt

Hassan and El-Moghasy, carried their field experiments using air as the working fluid in a pipe-air cooler. The results showed a reduction of the air temperature of about 12°C when it flowed for 50m of the pipe-air cooler when the inlet air temperature and relative humidity of 35, and 30%, respectively [42].

Ali, M. investigated experimentally the effect of the layout of the horizontal ground heat exchanger - using water instead of air - from being straight or spiral [43]. The results showed that the effect of depth of the amount of heat extracted by the straight heat exchanger is weak when compared with that of the entering water temperature; both of the previous works were laboratory based ones. The real systems did not exist and it is required to have further research in which the real circumstances and actual systems are utilized.

3. Computer Modelling

A wide range of scientifically validated Building Performance Simulation tools BPS is available internationally. Attia mentioned ten major BPS tools: ECOTECT, HEED, Energy 10, Design Builder, eQUEST, DOE-2, Green Building Studio, IES VE, Energy Plus and Energy Plus-Sketch Up Plugin (Open Studio) [25].

Energy Plus which will be used as a simulation tool in this research was developed based on two existing programs: DOE-2 and BLAST. It includes a number of innovative simulation features [26].

4. Soil Temperatures

It is essential when researching the earth sheltered buildings or the (EAHE) system to calculate the ground temperature of the location because it strongly affects the performance of these systems. [38]

Heat transfer in soils is governed by a number of variables which tend to fluctuate according to the changes in moisture content and other soil texture, structure and composition parameters.

Several mathematical models were developed to evaluate the temperature of the ground, such as those of Morland, Kusuda, and Labs [45]. Their models present a solution of the equation of heat transfer of a semi-infinite solid whose variation in the external temperature is sinusoidal.

Moustafa et al, Ben Jmaa and Kanoun, Al-Ajmi et al., Sharan and Jadhav, Ogunlela, Mihalakakou et al, Al-Temeemi A.,and Harris D.J., Gouda, A., Nofziger, D. all worked to develop an empirical model for the prediction of soil temperature as a function of soil depth and time of the year and generate a subsurface temperature profile for various locations around the world using Labs equation [11], [32], [44-51].

To evaluate the temperature of the ground, the soil is regarded as a semi-infinite solid. It is expressed according to the depth and time. Labs equation predicts the long-term annual pattern of soil temperature variations as a function of depth and time for various soil properties.

$$T_{(x,t)} = T_m - A_s e^{-x\sqrt{x/365\alpha}} \cos\left\{\frac{2\pi}{365}\left[t - t_0\left(\frac{x}{2}\right)\left(\sqrt{\frac{365}{\pi\alpha}}\right)\right]\right\}$$

Table 6: Lab's Equation variables: [11]

T(x,t)	Temperature of soil at depth x and on day t of the year (ºC)
x	Depth below surface [m]
t	time of year in days (Jan 1 = 1)
Tm	Mean annual ground surface temperature (ºC) [adding 1.7 to the average annual air temperature].
t0	The phase constant, [corresponding to the day of minimum surface temperature (days) The phase of the solar radiation wave lags behind the cyclic wave of the surface temperature by 1/8 of a cycle or 46 days].
As	Amplitude of surface temperature wave (ºC). [adding half of the difference between July and January average monthly air temperatures+ 1.1ºC]
e	Euler's number (constant) = 2.71828
α	The thermal diffusivity of the soil (m2/day) [by dividing K (conductivity w/mk) over [p (soil density kg/m3) multiplied by c (specific heat J/kgk)]. [α= K/pc] [11].

III. METHODOLOGY

For the proposed eight residential types [R1-R2-……R8] (See fig. 6), a one zone building [The house can be considered as one zone due to assumed sufficiently uniform thermal conditions, Source: ISO 52000-1:2017] will be simulated using Energy plus/Design Building program to measure: yearly discomfort hours for unconditioned cases and energy consumption assumed condition cases, as follows:

1. Design Variables:

- **Location template,** two options of the cities' weather files inputs (Aswan and Ismailia).
- **Orientation:** 0° – and 90°.
- **Building level:** with two options: Above ground or underground.
- **Earth Air Tubes:** with two options: Yes or No.

For each specific building type and orientation there are four plans or (arrangements):

1- (PO): Above ground.
2- PA): Aboveground + EAHE.
3- (PB): Underground with 0.50 m earth layer above it
4- (PC): Underground + EAHE.

2. Building Specifications:

Occupancy density (m2/pp.)	20m2/pp
Number of floors	1
Height per floor	3.5

Table 7: Openings & R values: (According to the Egyptian Energy Efficiency Code for buildings)

Elevation	WWR	R value
North	≤30%	1.00
East & West	≤20%	1.3
South	20-30%	1.00

Table 8: Building Activity Options, assumed

Activity	Domestic Lounge
Density	0.08 p/m2
Heating set point temp.	21
Heating setback temp.	12
Cooling set point temp.	25
Cooling setback temp.	28
Target Illuminance (Lux)	150
Computer & Cattering	On

Table 9: Building Assemblies, assumed

Above Ground Walls	
Cement plaster	.025m
Brick burned	0.12m
Cement plaster	.025m
U Value : 2.6 W/m2K	
Underground Walls	
Compressed cement stabilized Earth blocks (CSEB).5% cement.	0.12m
Bitumen pure	0.025m
Compressed cement stabilized Earth blocks (CSEB).5% cement.	0.05m
Cement plaster	0.025m
U Value : 0.76 W/m2K	
Above Ground Building Floors	
Concrete tiles	0.02m
Cement plaster	0.025m
Sand and gravel	0.05m
Reinforced concrete	0.12m
Gypsum plaster	0.025m
U Value : 3.13 W/m2K	
Above Ground Building Roofs	
Plaster ceiling tiles	0.02m
Sand and gravel	0.05m
Cast concrete	0.075m
Bitumine	0.02m
(CSEB).5% cement.	0.14m
Gypsum plaster	0.025m
U Value : 1.38 W/m2K	

Note: Bottom and vertical boundary conditions were set at the edges of a domain 15 m under a slab and next to the walls. It follows the hints of the European Standard EN ISO 13370 “Thermal performance of buildings – Heat transfer via the ground – Calculation methods”.

Table 10. Used Building Material

Used Building Material	Walls	Roofs	λ(Coefficient of conductivity)	Compression strength	Tensile strength
Compressed Cement Stabilized Earth Blocks (CSEB).5% cement.	24*24*13 cm blocks	14*7*7cm blocks for domes and vaults.	0.65 W/m ºC	6Mpa	1.5Mpa
Notes Source: [52]				1Mpa = 10 Kg/cm2	

Table 11. Glazing Type, assumed

Window Type	Blends	WWR	Window Height	Still Height	Window Spacing	Frame	SHGC and SGR
Single Clear 0.006m Glazing	internal blends	30%	1.50m	0.80	5.00	Painted Wooden	don't count

3. EAHE simulation inputs

Table 12. Variables of EAHE System, assumed.

Values	**Schedule Name**
Fan Blower 24 hours	Design flow rate
0.0334m3/s	Min. Zone temp. when cooling
20oC	Max. zone temp. when heating
30oC	Earthtube type
Intake	Fan pressure rise
520 Pascal	Fan efficiency
0.85	Pipe radius
0.15 m	Pipe thickness
0.01 m	Pipe length
30m	Pipe thermal conductivity
0.19 W/mK (PVC),	Pipe depth under ground surface
4m	Soil condition
Light and dry	Average soil surface temp.
24.9oC (at 4m depth)	Amplitude of soil surface temp.

IV. RESULTS

1. Underground and Air Temperatures

Using Labs' equation underground temperatures were calculated for the whole year for depths (0.5m, 2m, and 4m) which is very important for subsurface buildings simulations.

Max Av. Air Temp. in Aswan reaches 42°C in June while Min. Av. descends to 10°C in January with 32°C range. While at depth 4m Temp. ranges from 25°C and 29.8°C with only 4.8°C range. In Ismailia this range is also only 4°C.

Table 13. Variable Used for Aswan Soil Temp. Calculation

Variables	Calculated values for Aswan
Tm	27.45ºC
As	10.6ºC.
t0	Day 36.
α	0.064

Table 14. Variable Used for Ismailia Soil Temp. Calculation

Variables	Calculated values for Ismailia
Tm	23.18ºC
As	8.96ºC.
t0	Day 65.
α	0.064

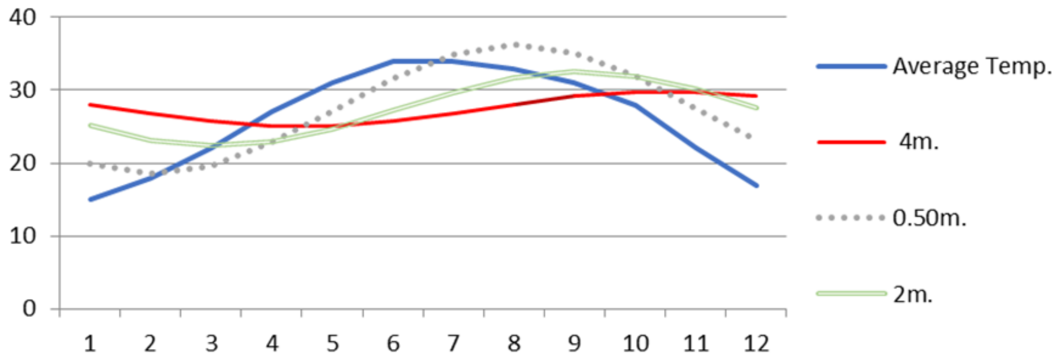

Fig.10. Average monthly temp. compared to calculated soil temp.in Aswan
Source : Researchers

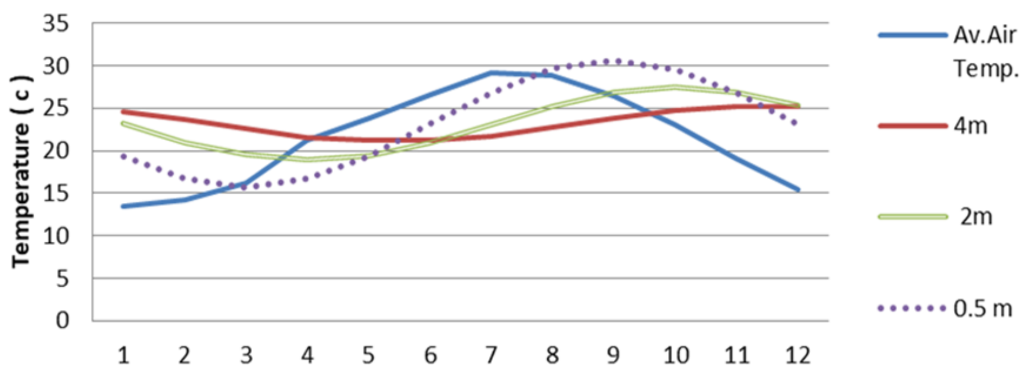

Fig. 11: Average monthly temp. compared to calculated soil temp.in Ismailia
Source : Researchers

2. Thermal Comfort Analysis and Comparisons

Thermal comfort was monitored in simulated eight types (R1….R8) - two orientations each - per each of the four plans or (arrangements): PO, PA, PB, PC by calculating yearly discomfort hours as an indication for thermal comfort as there is counter relation between discomfort hours and thermal comfort.

Yearly Discomfort Hours reached 2193h in above building base case in Aswan [plan (PO) for Type R6] and Min. of 1291h in [plan (PC) for Type 3] which is an underground building with a EAHE. In Ismailia Yearly Discomfort Hours reached 2351h in plan (PB) (underground building for type R6) and Min. of 850h in [plan (PC) for (Type3)], which is an underground building with an EAHE.

In both Aswan and Ismailia: the average readings point out that above ground (PO) are the highest discomfort hours, while underground with EAHE are the least. Meanwhile underground (PB) in Ismailia showed rise in discomfort hours due the time lag which needs further research and simulation (See fig. 12).

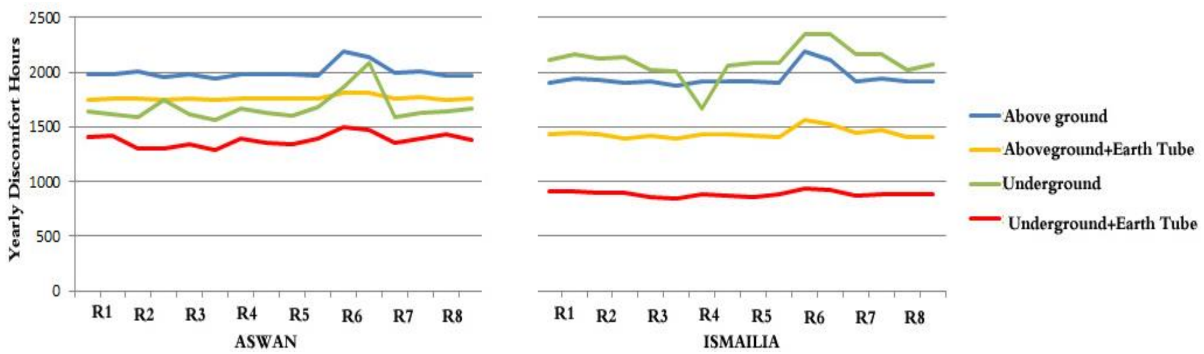

Fig. 12. Yearly discomfort hours [Measured for the four plans(arrangements): (O-A-B-C)] Source: Researchers

3. Energy Consumption

Was monitored in simulated eight types (R1….R8) - two orientations each - per two plans or (arrangements): Plan PO [aboveground building with common building specification in new urban settlements in Egypt] and plan PB [Underground building with proposed (CSEB).5% cement construction], both plans were assumed to be full conditioned in order to be able to calculate energy consumption to reach comfort conditions.

Energy consumption reached 343 KWh/m2 in the above building base case (R6 type-d2) in Aswan and Min. of 104 KWh/m2 in plan (PB) (R3 type-d2). In Ismailia Yearly Energy Consumption 187.5 KWh/m2 in above building base case (R6 type-d2) and reached 42 KWh/m2 in plan (PB) (R3 type-d2).

Note: All calculations were made for both building directions 0 & 90 for each eight building types for each city climate with a total of 96 readings.

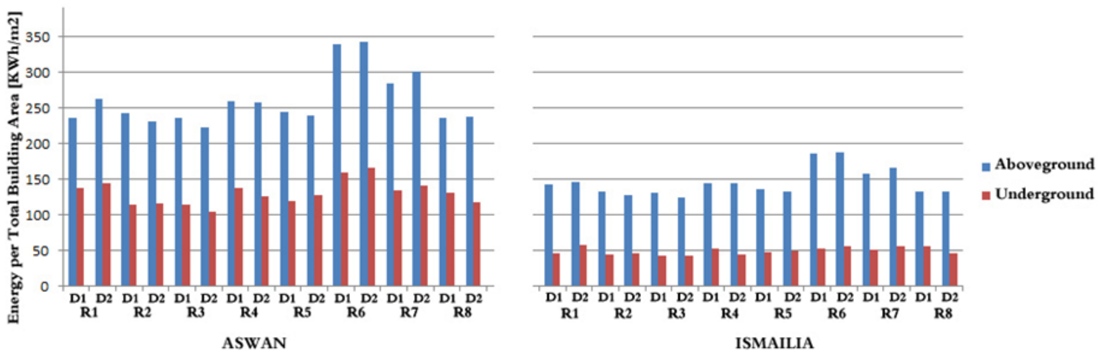

Fig. 13. Energy consumption to reach thermal comfort [Measured for the two plans: [P (O- B)]. Source: Researchers

V. DISCUSSION AND CONCLUSION

- As mentioned before, calculated underground temperatures for both Aswan & Ismailia showed a sinusoidal behavior and the cyclical temperature wave that becomes more flat with the increases in depth. Ismailia has more time lag (65 days) than Aswan (36 days).

- For all eight types R1-R8, and two building orientations D1& D2 the researchers can conclude that:

- In Aswan Discomfort hours decrease between 28% and 34% in the above ground building plan (PO) compared to the underground building with an EAHE plan (PC), while energy consumption decreases between 42% and 53% for the previous comparison.

- In Ismailia Discomfort hours decrease between 24% and 29% between the above ground building plan (PO) and the underground building with a EAHE plan (PC), while energy consumption decreases between 57% and 72% for the previous comparison.

In plan [arrangement (PB) (underground without EAHE)], it is noticed that discomfort hours are the highest although there is less energy needed to achieve thermal comfort (See. Fig. 13). This may be due to long time lag, which indicates that the earth keeps and loses the heat delayed 65 days than aboveground ambient air, which causes more discomfort hours while the standard deviation in temperature differentiation between aboveground and underground is small so that energy needed to achieve comfort is still low. (So further investigations on other climate regions within Egypt are needed to prove these assumptions).

VI. CONCLUSION

- The research concludes that earth-sheltered courtyard house constructed using CSEB and combined with an EAHE system is one of the promising passive solutions for saving energy in desert houses in Egypt.

- Energy consumption in Ismailia is more than in Aswan due to the higher time lag between ground temperature and air temperature.

- Best case for Aswan with maximum decrease in both discomfort hours and energy consumption is R3/D2, which is the max in the compacted plan.
- Ismailia's best case is R6/D1, which has the max. area contact with earth.

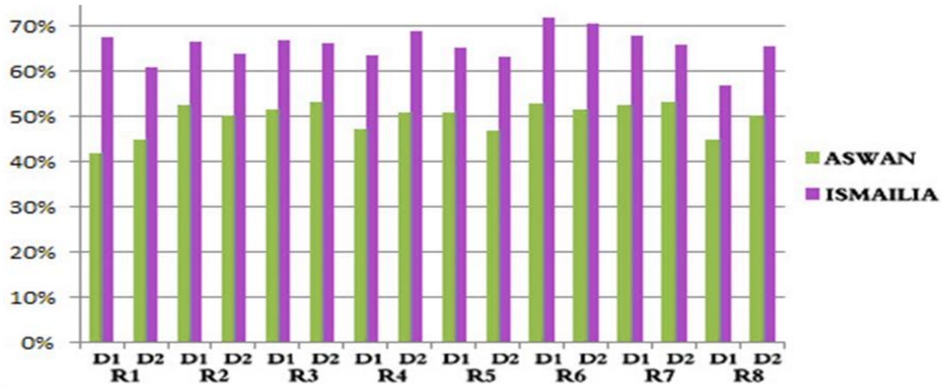

Fig. 14: % Decrease in energy consumption (% Difference between plan PO& PB) for the two directions of the eight types. Source: Researchers

VII. RESEARCH RECOMMENDATIONS

Taking into account the arid climate, the dry soil, the deep ground water levels of Egypt's desert and the need for low cost energy efficient housing; a design proposal is presented according to the research:

- Locating the building underground level with 0.50 m earth layer above it, (This protects the roof from direct solar radiation while decreasing the dead loads on the roof).
- Using sunken courtyard about 40 m^2 with buried area 80-120 m^2 to provide ventilation, light, solar heat, outside views, and access via a stairway from the ground level.
- The research recommends stabilized earth blocks as a sustainable low cost material that also helps to reuse the excavated soil resulted from basements with dome and vaults for roofing.
- Locating the service area above ground level can avoid using pumps for sewage.
- Using an (EAHE) system with cheap irrigation tubes placed in the building foundations or on the underground bearing walls will be cost effective because the digging cost will be avoided as the basement was already dug.
- The soil surface to be shaded or vegetated to obtain cooler soil temperature for better energy performance.
- Calculating ground temperatures - using Labs' equation- is essential when modeling the efficiency of the underground house.
- Compact underground building is more effective in Aswan, while more building earth contacted areas is more efficient in Ismailia.
- Future detailed studies for more cities with different weathers in Egypt are recommended.
- Further structural, economical, architectural refinements and users' acceptance studies for the suggested building types are recommended.
- The researchers recommend further studies on integrating SC with EAHE system in earth sheltered homes.

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- **List of Figures**

Fig.1: Egyptian electricity consumption (most consuming) is the residential. The Egyptian Electricity Holding Company Annual Report 2009/2010. Egyptian Electricity Holding Company, Cairo, Egypt, 2010.

Fig.2: Classification of aquifer depth in Egypt. Source: M. Salim, Selection of Groundwater Sites in Egypt. Journal of Advanced Research, 2012.

Fig.3: Earth's energy budget diagram showing the short-wave (a) and long-wave (b) energy fluxes. Source: Banks, David. An Introduction to Thermogeology: Ground Source Heating and Cooling. Wiley-Blackwell, 2012.

Fig.4: Historical earth sheltered homes. Source:
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Fig.5: Typology of earth sheltered buildings. Source: H. Hassan. Analytical Study of Earth-Sheltered Construction and its Suitability for Housing Projects in the Egyptian Deserts. Thesis, Egypt. 2009.

Fig.6: Deduced eight types of courtyard houses which represent the case studies
Source: Reasearchers.

Fig.7: Factors that affect earth pipe cooling performance. Source: K.H. Lee and R. Strand. "Implementation of an earth tube system into energy plus program," Energy and Buildings, vol.40, 2006.

Fig.8: Schematic diagram of integrated earth to air heat exchanger and solar chimney. Source: M. Maerefat and A. Poshtiri, 2010.

Fig.9: a.R1 Model in Energy Plus Program, b. R1-R8 house types Source: Researchers.

Fig.10: Average monthly temp. compared to calculated soil temp. in Aswan. Source: Researchers.

Fig.11. Average monthly temperatures compared to calculated soil temp.in Ismailia. Source: Researchers.

Fig.12: Yearly discomfort hours [Measured for the four plans (O-A-B-C)] Source: Researchers.

Fig.13. Energy consumption to reach thermal comfort [Measured for the two plans, P (O- B)]. Source: Researchers.

Fig.14: % Decrease in energy consumption (% Difference between Plan PO& PB) for the two directions of the eight types. Source: Researchers.