Wind Catcher Earth Air Tunnel for Passive Cooling: Annual Energy Performance of Residential Home in New Cites of Egypt

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Abstract
Wind catcher Earth air tunnels systems are proposed to be used in modern buildings to minimize the consumption of non-renewable energy. A tunnel in the form of a heat exchanger burns at a depth of about 4 m below the ground level will acquire the near temperature as the surrounding earth. Therefore, when the ambient air passes through this tunnel, it will be cooled in summer and warmed in winter seasons. This study explore the effect behaviour of using Wind catcher Earth air tunnel in designing energy efficient home with renewable energy utilizations during early stages of the planning of new societies in Egyptian desert cities. A prototype home for single-family detached houses of 240 m^2 in two floors, each floor of 120 m^2 with best utilization of the available renewable energies resources is proposed. This prototype home can be suggested to be the design for new single-family detached homes for Egyptian new towns. In order to achieve the above objective, this paper presents a reviewing for passive cooling techniques used in hot arid areas. Then a detailed analysis of the Wind catcher Earth air tunnel used in the suggested energy efficient home. The present study showed that using natural ventilation in the efficient home design for single-family detached houses in new societies in Egypt could save home energy bill and regulate the indoor air movement to achieve indoor thermal comfort, consequently, reduce the need for an electric mechanical means for indoor air movement.

Keywords: Egypt new cities, New societies of Hot arid areas, Wind Catcher Earth Air tunnel, Energy Efficient Homes, Passive Cooling/heating

1. Introduction

Wind catcher as a natural ventilation system is increasingly used in modern buildings to minimize the consumption of non-renewable energy and reduce the harmful emissions. Height, cross section of the air passages and also place and the number of openings are the main factors which affect the ventilation performance of a wind catcher structure **Montazeri, 2011[1].** Natural ventilation has been a fundamental approach to the design of low energy buildings and it is well known that in low-rise buildings this is mainly achieved by wind-driven air flow through windows and openings. Purposefully designed and positioned openings are able to draw in and expel air. A wind catcher or wind tower is a single device to facilitate the supply and extract of air. They have been used in the Middle East countries for centuries to produce natural ventilation and passive cooling in buildings. **Yuehong et al, 2008 [2].**
A wind-catcher functions as a solar chimney in an environment with no significant wind or available water. A solar chimney, which creates a pressure gradient, is a vertical duct or passage employing solar energy to heat up the air. Thus, the air rises through the passage as a result of convection. This convection of heated air is able to improve the natural ventilation of buildings and create passive cooling and natural ventilation. **Tavakolinia, 2011[3].**
Earth to air heat exchanger (EAHE) as Indirect Ground Air Cooling systems mainly depend on the high thermal capacity of the soil allows the temperature below a specific depth to remain constant throughout the year; a temperature that is near the annual average ambient temperature. In summer, the soil would act as a heat sink because the ambient temperature is higher than the ground temperature, whereas in winter the earth serves as a heat source. **Alanezi, 2012[4]** . Earth–air heat exchangers are one of the fastest growing applications of renewable energy in the world, with an annual increase in the number of installations with 10% in about 30 countries over the last 10 years. ***Bisoniya et al*, 2013 [5].**
It is widely perceived that the indoor comfort of buildings is accomplished at the expense of increased energy consumption due to active cooling utilization; passive cooling contributes to reducing or eliminating this expense. Buildings can be cooled by passive schemes through heat discharge to natural heat sinks such as the ambient air, sky and soil. The appropriateness of any passive cooling system not only depends on the indoor conditions but also on the building type and the site microclimate. **Alanezi, 2012[4]**

2. Passive cooling techniques in energy efficient building of hot arid areas

Incorporate solar passive techniques in a building design to minimize load on conventional systems (heating, cooling, ventilation and lighting) Passive systems provide thermal and visual comfort by using natural energy sources and sinks e.g. solar radiation, outside air, sky, wet surfaces, vegetation, internal gains etc. Energy flows in these systems are by natural means such as by radiation, conduction, convection with minimal or no use of mechanical means. The solar passive systems thus, vary from one climate to the other e.g. in a cold climate an architects' aim would be design a building in such a way that solar gains are maximized, but in a hot climate his primary aim would be to reduce solar gains, maximize natural ventilation and so on**, Majumdar [6]**

Employing natural or passive cooling system can be an alternative way to maintain a cool house or reduce air-conditioning load. A passive cooling system employs non-mechanical procedures to maintain suitable indoor temperature. Ingenuity of ancient architectures has showed how a rational use of traditional passive techniques, along with a smart design, was involved in having desired summer comfort without a need to pursue mechanical cooling systems. Recently, there is much inclination toward these systems, especially due to economic and environmental reasons. **Maerefat & Haghighi, 2010 [7].**

Passive heating and cooling systems are known for their advantage of consuming no or very less energy as compared to active heating and cooling systems**.** **Bansal *et al*, 2012 [8].** The passive cooling of buildings is broadly categorized under three sections (i). Heat prevention /reduction,(Reduce heat gains) (ii).Thermal moderation(Modify heat gains) and (iii). Heat Dissipation(Remove internal heat). The various methods adopted for each of these, are further classified **Geetha & Velraj,2012 [9],** And given in Fig. 1.

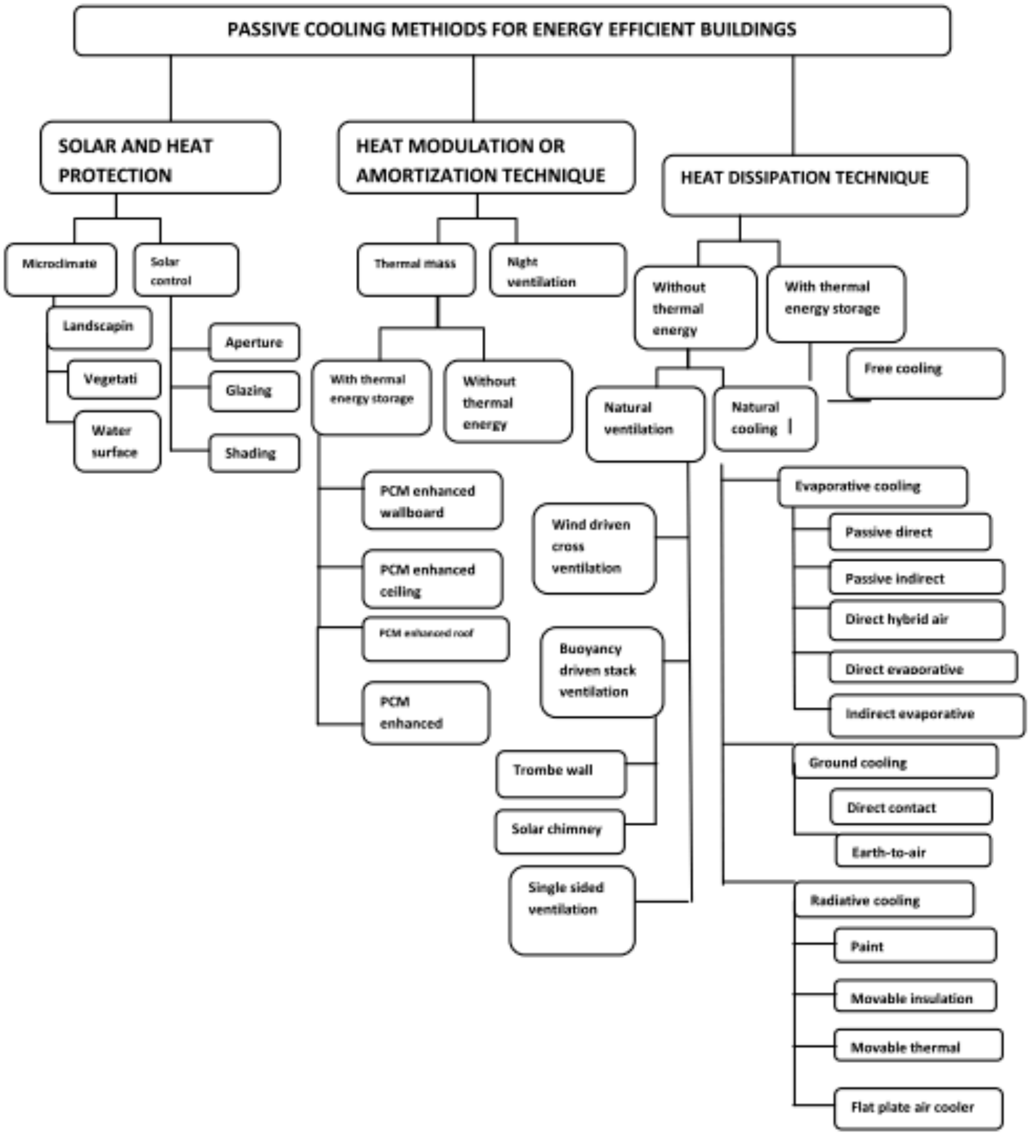

Figure 1: Classification of passive cooling methods in energy efficient buildings. **Geetha & Velraj, 2012[9]**

The concept of Wind catcher is normally a tall structure with the height from 5 to 33 m mounted over the building roof. With taller tower capturing winds at higher speeds and with less dust. **Dehghan *et al* , 2013[10]**.The number of directions in which Wind catcher face is different; therefore these towers are often classified to the number of their openings. One-sided, two-sided, four-sided (triangular cross section) and six-sided (hexagonal cross section) Fig. 2 shows several old Wind catcher with different number of openings. **Montazeri *et al*, 2008[11]**

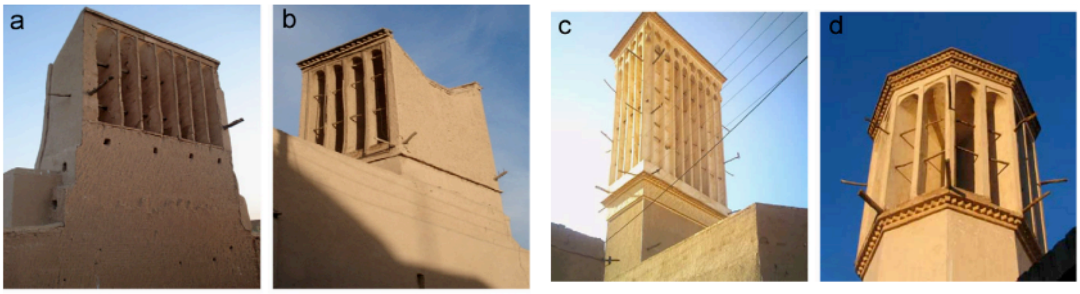

Figure 2: Several old Wind catcher with different number of openings,
(a) one-sided(b) two-sided (c) four-sided and (d) octahedral- wind catchers.
Montazeri *et al*, 2008[11]

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 section of the building envelope with the ground, or by injecting air that has been previously circulated underground into the building by means of earth-to-air heat exchangers. **Geetha & Velraj, 2012[9].** The earth temperature fluctuation reduces with depth and almost dies down at about 4 m. The temperature at this depth approximately equals annual average ambient temperature, as shown in Fig. 3. **Samuel *et al*, 2013[12]**

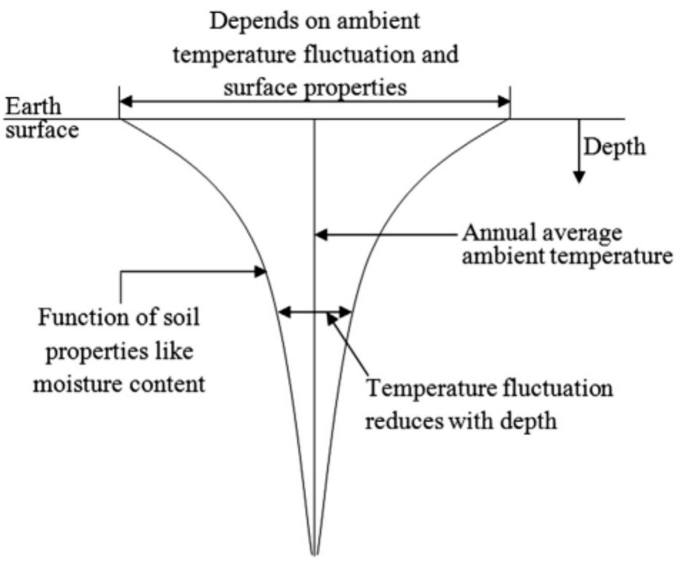

Figure 3: Earth temperature fluctuation with depth. **Samuel *et al*, 2013[12]**

A solar chimney on the other hand, is a good configuration to implement natural ventilation in buildings where solar energy is available. **Maerefat & Haghighi, 2010 [13],** An appropriate design of a solar chimney for cooling includes providing an air gap in a south facade or in the roof of the building that causes stack effect exists between the solar chimney and the inlet of the building. The stack effect operates between the high temperature and high pressure developed in the solar chimney and the low pressure and low temperature at the inlet. If the openings are provided at the inlet of the building and at the outlet of the solar chimney, air will enter into the building due to the difference of air densities and pressure gradient and move through the building before exit from the outlet of the solar chimney. **Chungloo & Limmeechokchai, 2007 [14].**

3. Wind catcher earth air tunnel: a tool for passive cooling for the suggested renewable energy efficient home for new cites in Egypt

Passive cooling is being employed as a low-energy consuming technique to remove undesirable interior heat from a building in the hot seasons. There are numerous ways to promote this cooling technique, and in the present study the use of Wind catcher together with earth to air heat exchanger (EAHE) and solar chimney (SC) is introduced. As this study aim is to design energy efficient home with maximum possible renewable energy utilizations at early stage of planning of new societies in Egyptian desert, therefore, a prototype house for single-family detached houses of 240 m^2 in two floors, each floor of $120m^2$ - as shown in Figs. 4 &5. the proposed prototype is making use of the maximum possible utilization of the available renewable energies resources with high efficiency technologies of the house is sited - as shown in Figs. 6 &7. This suggested prototype house is design for new single-family detached houses for Egyptian new cities which consider as a key for Egypt future in the habitation of people in new towns.

Figure 4: Suggested prototype house for single-family detached houses planes and perspectives

Figure 5: Suggested layout for prototype house mass plane and perspectives.

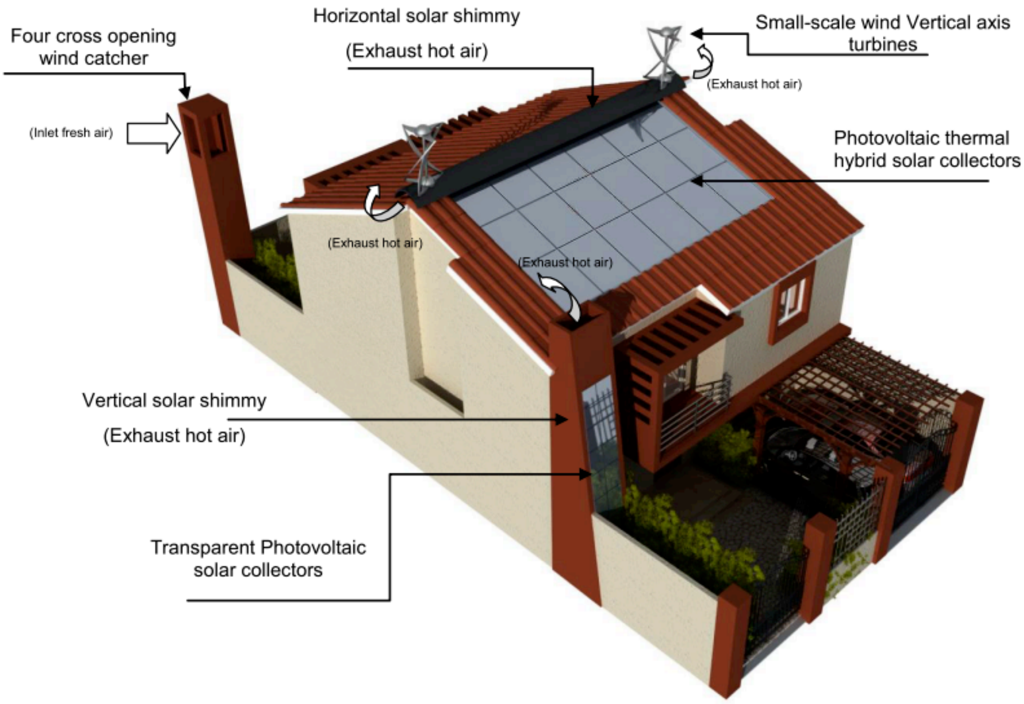

Figure 6: Renewable energy technologies used in suggested prototype smart house

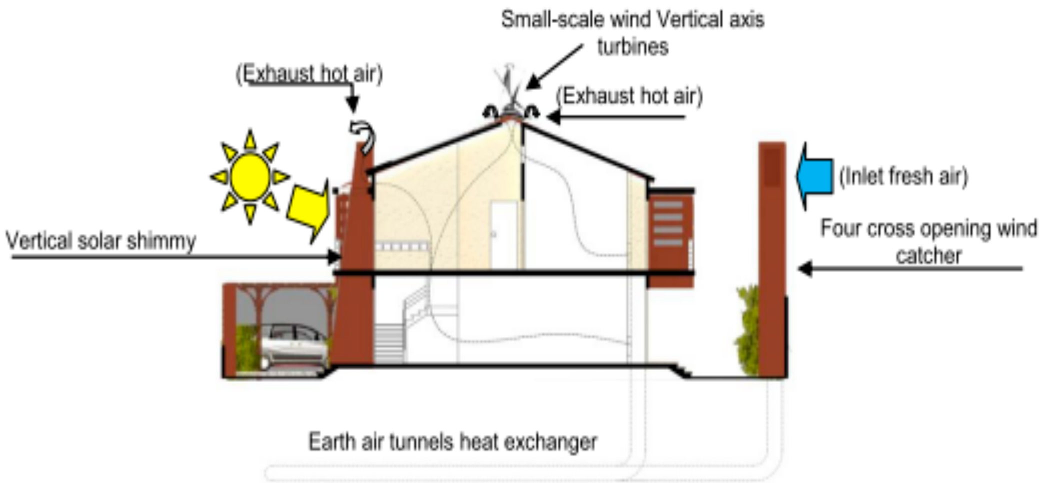

Figure 7: Suggested prototype smart house cross section.

In the suggested house, is proposed to use four cross opening wind catcher Earth air tunnels as a source for fresh air cooling supply, also a horizontal and vertical solar shimmy collector for hot air exhaust as shown in figures 8, 9&10.

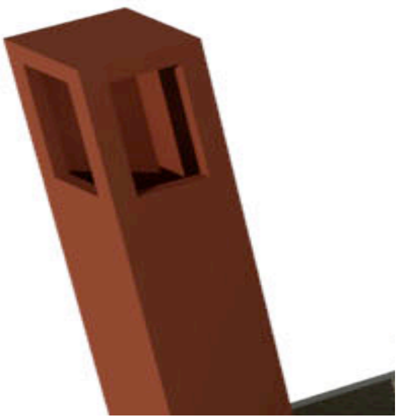

Figure 8: four cross opening wind catcher for the Suggested prototype house.

Figure 9: horizontal solar shimmy for the Suggested prototype house.

Figure 10: vertical solar shimmy for the Suggested prototype house.

The opening face of a wind-catcher is away from prevailing wind. When wind blows over this wind-catcher, it creates lower air pressure on the windward side. Since the air pressure inside the building is higher than the outside, the tendency of higher pressure air traveling to the lower pressure region causes the air to be drawn upwards. The wind-catchers using this method are usually combined with an underground earth cooling tunnels. In Figure7, the hot air is drawn down into the tunnels and is cooled by coming into contact with the cold earth. The cold soil helps the air become even cooler. This cool air is then drawn upward through the tunnel and ventilates the entire building.

The solar-chimney component can be integrated with an underground earth tunnel. If the incoming air goes through an underground pipe, the cooling effects can be significantly increased. Fig.7. shows that when the solar chimney warms up by solar radiation, while the warmed air is trying to escape through the solar-chimney duct, it will replaced by cooled air coming from the wind catcher through the underground tunnel.

Also using hybrid Photovoltaic thermal solar collectors as a source for electric power and Solar thermal energies is shown in fig. 11.The electricity flows into an inverter for use in the building or export to the grid as per a standard PV configuration. The temperature is regulated via a control sensor and the coolant is transferred using a pump to a heat exchanger which heats water in a storage tank for use in the hot water, heating and optional cooling systems. The system provides hot water for any kind of usage such as sanitary use, domestic applications (such as dish and clothes washing) and any other required usage. The heating output can be used for room heating and cooling as well as pool heating and other heating equipment

Moreover, it's proposed using Small-scale wind Vertical axis turbines, as a source for electric power also. Small-scale wind Vertical axis turbines are particularly suited to urban situations and to being integrated into buildings. Presently, there are several versions of vertical axis machines available in the market. It is suggested to use the most common vertical axis machine is the helical turbine as seen at the Earth Centre as shown in fig. 12, Doncaster. In that instance it is mounted on a tower but it can also be side-hung on a building. This technology can generate power from 1 kW to megawatt capacity.

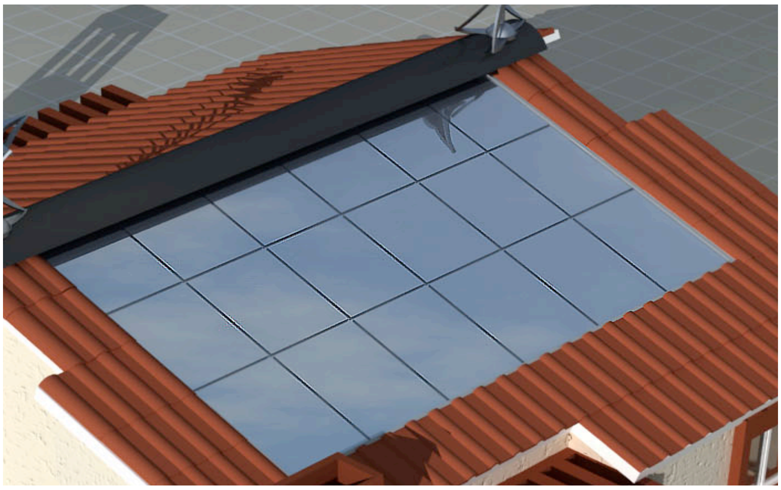

Figure 11: Photovoltaic thermal hybrid solar collectors

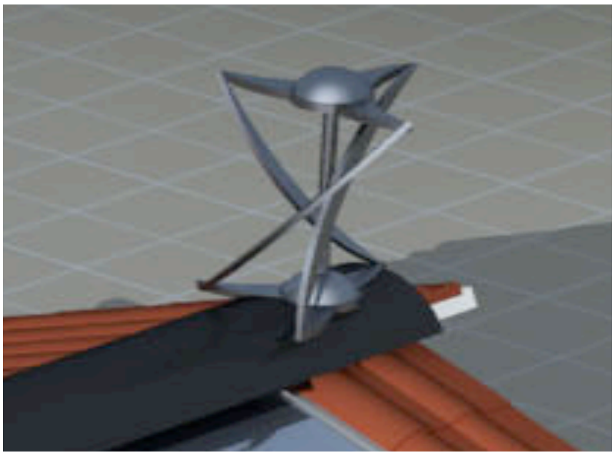

Figure 12: Small-scale wind Vertical axis turbines for the Suggested prototype house

The house required power is obtained from two sources through a smart meter used in the smart house energy management system; the power grid and the proposed electric supplier using renewable energy technologies systems mentioned before. The solar cell and small-scale wind vertical axis turbines energy is stored in battery system and then inverted to AC power form. The battery can be charged from the solar cell whenever the sun is shining, after the battery reach its full capacity during the day time, the system can supply the generated electric power to the public grid through the smart meter. The suggested home will obtain the electric power from the public grid during the off-peak hours if needed through the smart meter.

To calculate the annual energy performance of the suggested prototype house, ENER-WIN Software for building energy analyses had been used for simulation **ENER-WIN [15]**. ENER-WIN is categorized in the following steps, as shown in Fig. 14.

a. First run the program and select the building type as a residential building from the interface window.
b. Select the city for the weather data generation taken Asyut city Egypt as a case study.
c. Draw the building geometry for the ground floor plane.

d. Draw the building geometry for the first floor plane.
e. Define each zone in the plane through the zone processing window.
f. Define each zone description by defining each zone envelope materials cataloging and user profile cataloging; it can be taken as in table 1. The building envelope materials used in this prototype is used as the building material available in the market with low price and used by the contractor in the location of the taken new Asyut city Egypt which used as a case study.
g. Energy summations as Execute the simulation with selected HVAC systems or evaluating passively heated and cooled buildings (no HVAC).
h. System simulations and saving the output results.

Table 1: Building description printed from the run

*** PROJECT: Project Name LOCATION: Asyut (ES), EGYPT
PLAN: Preliminary TYPE: Residential Weather Year: 2013 Date of Run:

MATERIAL DESCRIPTIONS CATALOG:

MATL ID	NAME	U-FACTOR	SOLAR ABSORPTIVITY	TIME LAG	DECREMENT FACTOR
1	insulation wood frame w/ wd siding	.454	0.30	1.0	0.0
2	Brick veneer, insulation stud wall	.454	0.75	3.0	0.0
8	Roof w/ 6"(15 cm) fiber insulation dark color	.284	0.8	2.0	0.0
9	Heavy wt conc. roof w/ rigid insulation	.397	0.8	3.0	0.0
14	Slab-on-grade, un insulated	.568	0.0	3.0	0.0
15	Slab-on-grade, insulated	.284	0.0	4.0	0.0

WINDOW DESCRIPTIONS CATALOG:

WINDOW ID	NAME	U-FACTOR	SOLAR HT. GN. COEF.	EMISSIVITY	DAYLIGHT TRANS.
1	1/4" (6mm) clear plate	6.416	0.83	0.84	0.87

The orientation of buildings would be determined partly by the sun and partly by the wind. The best orientation of this prototype for the annual energy performance using the conventional systems without any passive cooling techniques is northwest as shown in Fig.13., though we have run the programme for this prototype in this orientation direction to decrease the energy usage for this prototype using the passive cooling techniques.

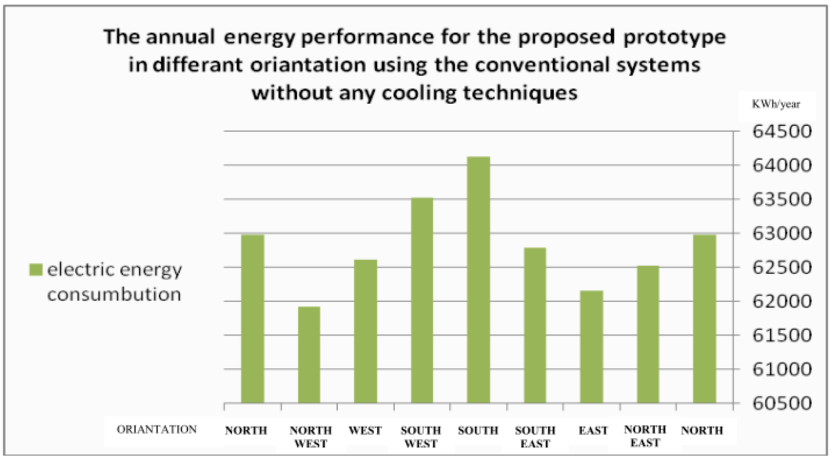

Figure 13: The annual energy performance for the proposed prototype in different orientation using the conventional systems without any cooling techniques

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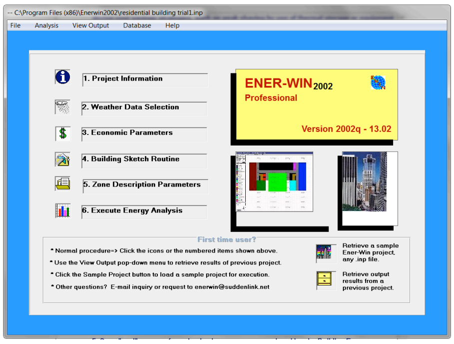
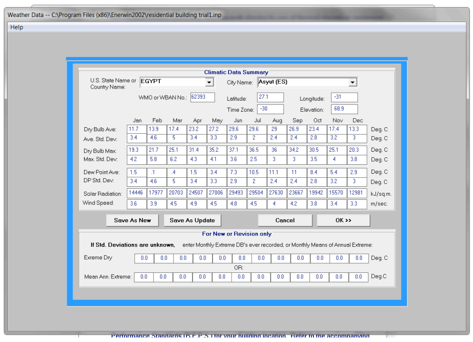
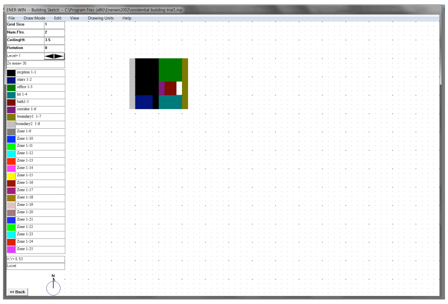


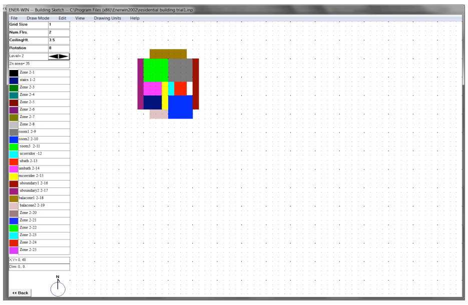
a.ENER-WIN Software interface



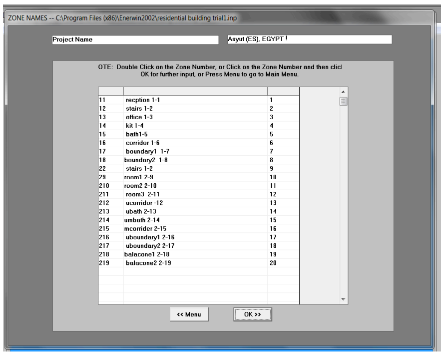
b. weather data generation



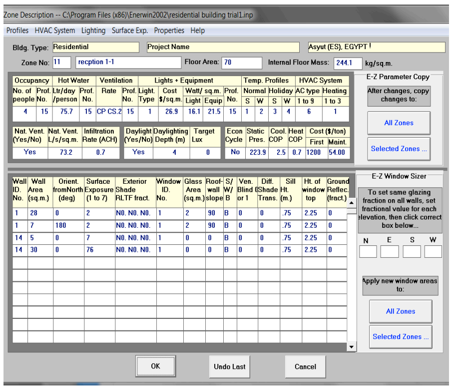
c. Building geometry processing for ground floor



d. Building geometry processing for first floor

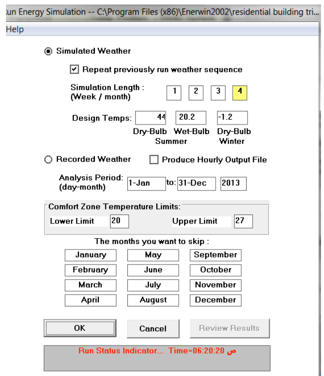


e. Zone processing



f. Zone description

g. Execute the simulation with HVAC or passive



h. Load calculations and system simulations

Figure 14: ENER-WIN Software for building energy analyses.

Using ENER-WIN Software for building temperature and relative humidity analyses, the obtained results by using the active energy HVAC system can be described in The hourly deference between the outdoor temperatures, and the indoor temperature for reception area with use of passive system (without HVAC) in the cold season (December, January & February) are shown in Fig. 15. Also The hourly deference between of the outdoor relative humidity and indoor relative humidity for the most important indoor zones as reception area with use of passive system (without HVAC) in the cold season (December, January & February) shown in Fig.16.

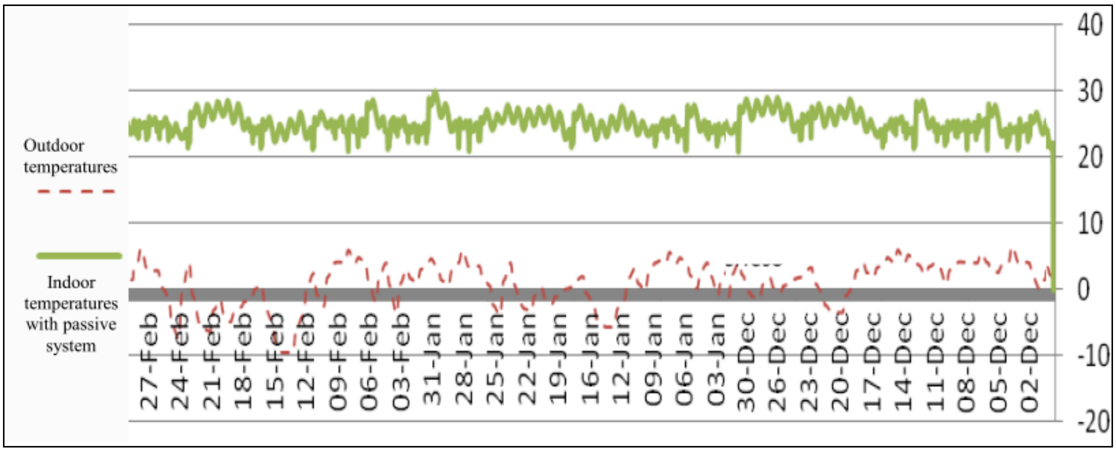


Figure 15: The hourly deference between the outdoor temperatures, and the indoor temperature for reception area with use of passive system (without HVAC) in the cold season (December, January & February)

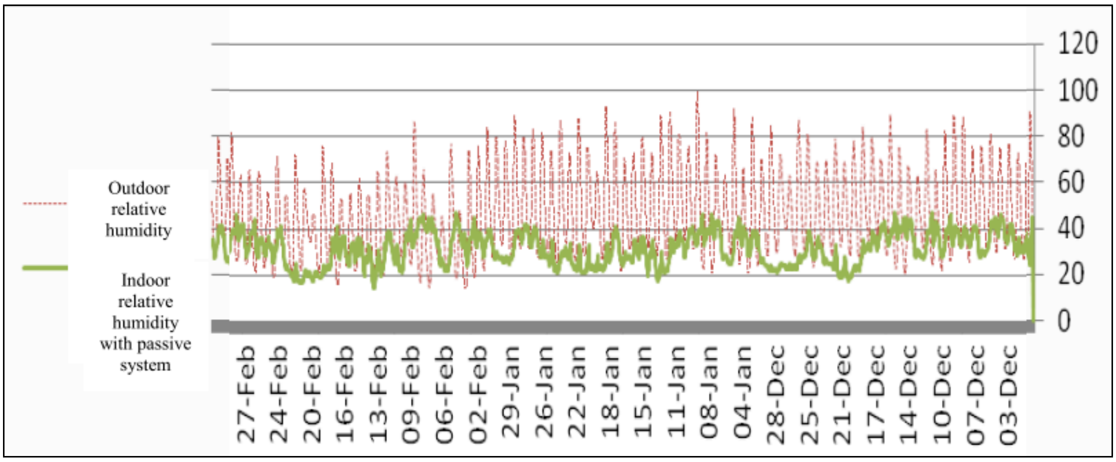


Figure 16: The hourly deference between of the outdoor relative humidity and indoor relative humidity for the most important indoor zones as reception area with use of passive system (without HVAC) in the cold season (December, January & February)

The hourly deference between the outdoor temperatures, and the indoor temperature for reception area with use of passive system (without HVAC) in the hot season (June, July & august) are shown in Figs. 17. Also The hourly deference between of the outdoor relative humidity and indoor relative humidity for the most important indoor zones as reception area with use of passive system (without HVAC) in the hot season (June, July & august) shown in Figs.18.

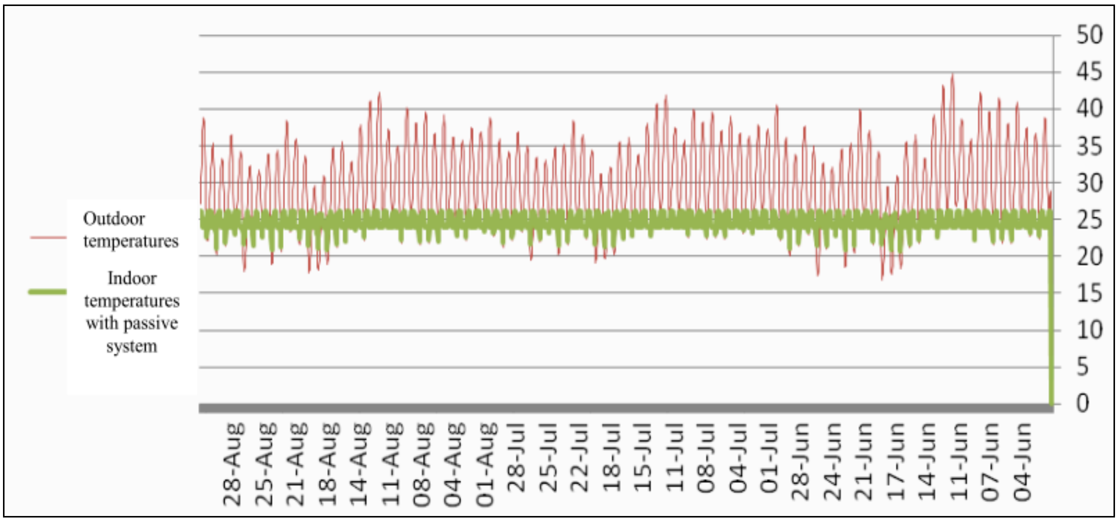


Figure 17: The hourly deference between the outdoor temperatures, and the indoor temperature for reception area with use of passive system (without HVAC) in the hot season (June, July & august).

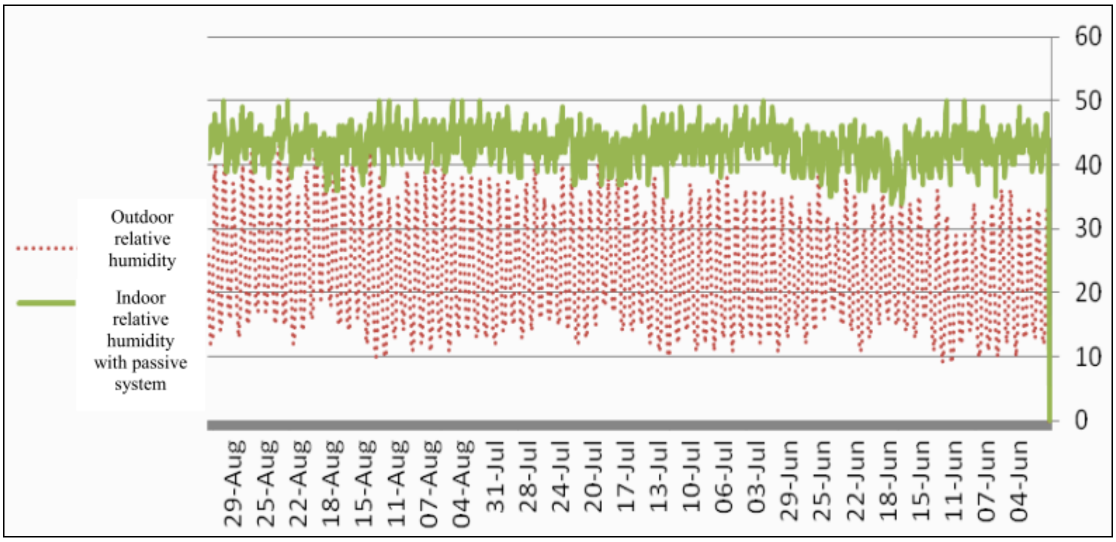


Figure 18: The hourly deference between of the outdoor relative humidity and indoor relative humidity for the most important indoor zones as reception area with use of passive system (without HVAC) in the hot season (June, July & august).

The obtained results by using ENER-WIN Software for building energy analyses using the active energy HVAC system are shown in Figs. 19, 20 & 21. From these figures clearly seen that the total electric energy consumed was 40283.5 KWh/year with peak electric energy demand = 167.5 KWh/year, also required peak heating power is 11.185 kw at 14 Feb. at 7 am, while the peak cooling power is 18.28 kw at 11 Jun. at 6 pm. As illustrated in Fig.19, the maximum need of electric energy occurs in July, corresponding to the maximum cooling load in the same month, whoever this load could be reduced by using passive cooling technology such as underground earth cooling system which will lead to minimize the consumption of electric energy required for the cooling.

The maximum use of space heating energy occurs in Jan, as shown in Fig. 19, to overcome this load can be done by using a passive heating technology as P V/ thermal hybrid solar collectors to decrease both the electric energy needed and heating load . Therefore, the electric energy consumption can be decreased in the cooling energy demand in the hot season (June, July & august), and heating energy demand in the cold season (December, January & February) through using the renewable energy resources on the site with appropriate efficient technologies.

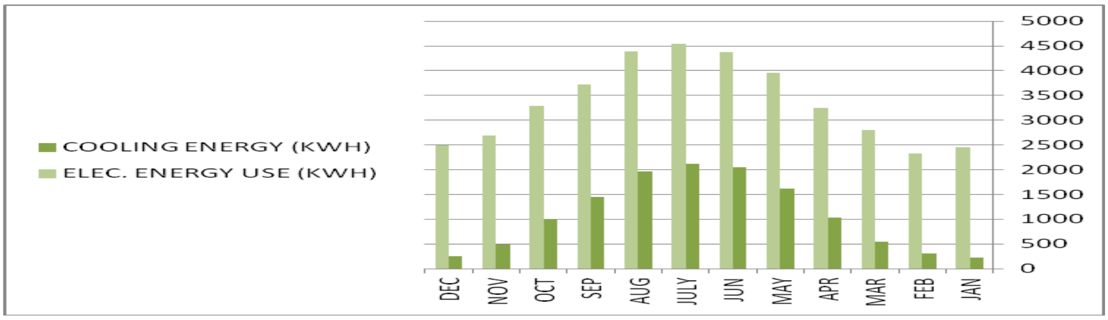


Figure 19: Monthly electric energy and Monthly Cooling energy consumed by the active energy system.

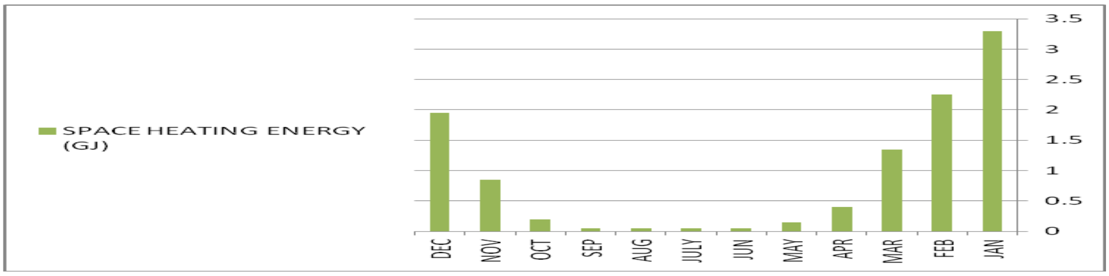


Figure 20: Monthly space heating energy consumed by the active energy system.

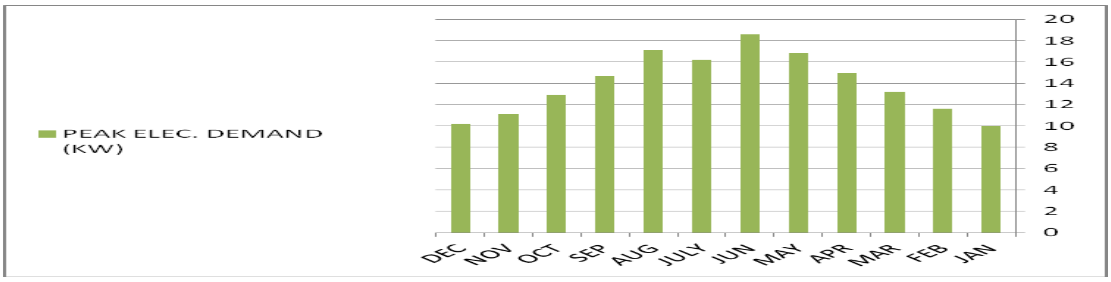


Figure 21: Monthly peak electric energy demand by the active energy system.

Also the results show that using the smart passive energy techniques, show that the total electric energy consumption is 32509 KWh/year. Correspondence to total peak electric energy demand = 120.3 KWh/year, as shown in Figs.22 & 23.

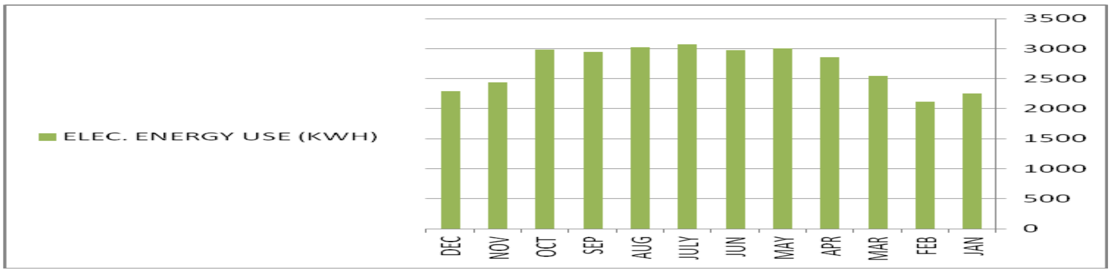


Figure 22: Monthly electric energy consumed by the passive energy system.

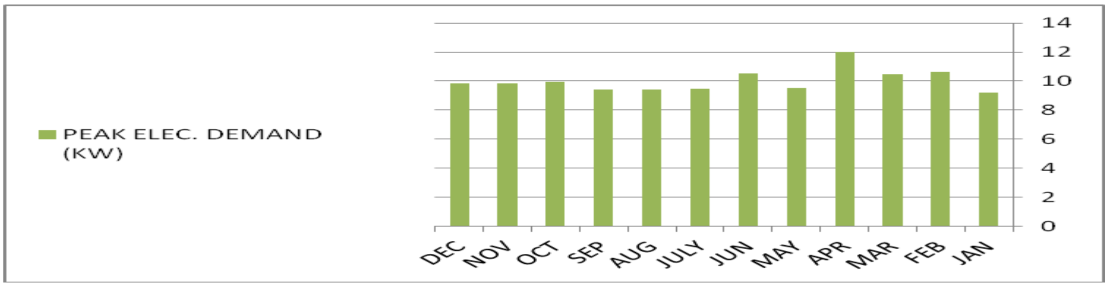


Figure 23: Monthly peak electric energy demand by the passive energy system.

4. Conclusions.

This study presents a wind catcher earth air tunnel system as a tool for passive cooling for a suggested renewable energy efficient home for new cites in Egypt. The proposed design for an energy efficient smart home with renewable energy utilizations in Egyptian desert new cities as compared with conventional design homes can be can be consider as a key for Egypt future in the habitation of people in new towns.

This proposed prototype home is designed for a single-family detached house with area of 240 m2 in two floors; each floor has 120 m2, which the efficient renewable energy technologies planned to provide such home by electricity, heat and supply of cold air need in summer times as following:

Electric and Heat supply: This by using hybrid photovoltaic thermal solar collectors as a source for both electric power and solar thermal energies.While the PV module generates electrical power, in combined with a small-scale vertical axis wind turbines, as a source for electric power. For output heat generated use, a heat exchanger is used to heat water in a storage tank for the use of domestic hot water, home heating in winter and optional solar driven cooling systems in summer.

Cold Air Supply: This by using a combined four cross opening wind catcher with earth air tunnels as a source for fresh cold air supply, assisted by a horizontal and vertical solar shimmy collector for sucking the hot air from the home to be exhausted.

The use of wind catcher earth air tunnel system as a tool for passive cooling could help to reach the thermal comfort conditions inside the prototype house in summer hot seasons, also in winter cold seasons. The results obtained from building energy analyses using the active energy HVAC system, the total electric energy consumed was 40283.5 KWh/year with peak electric energy demand = 167.5 KWh/year, also required peak heating power is 11.185 kw at 14 Feb. at 7 am, while the peak cooling power is 18.28 kw at 11 Jun. at 6 pm. However, using the smart passive energy techniques, show that the total electric energy consumption is 32509 KWh/year.

Correspondence to total peak electric energy demand = 120.3 KWh/year. This means that the prototype house could be efficient and save about 20% of the home energy bill.

In case of the renewable resources are not sufficient or exceed the needs, the suggested house is equipped by both multiplexer for both renewable power resources and grid power as well as a smart meter for the house energy management. This type of power combination will result in reducing the consumer electrical bill and better manage the peak loads by the electrical utilities.

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