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RESD

Renewable Energy and Sustainable Development (RESD) is a biannual international peer-reviewed journal which presents a global forum for dissemination of research articles, case studies and reviews focusing on all aspects of renewable energy and its role in sustainable development. The topics of focal interest to RESD include, but are not limited to, all aspects of wind energy, wave/tidal energy, solar energy, as well as energy from biomass and biofuel. The integration of renewable energy technologies in electrical power networks and smart grids is another topic of interest to RESD. Experimental, computational and theoretical studies are all welcomed to RESD.

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Overall process for publishing a paper will be taken approximately 4 months after initial submission. Reviewing process will take about 2 months, and then publishing process will not exceed 2 months.

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The Editor first evaluates all manuscripts. It is rare, but it is entirely feasible for an exceptional manuscript to be accepted at this stage. Those rejected at this stage are insufficiently original, have serious scientific flaws, have poor grammar or English language, or are outside the aims and scope of the journal. Those that meet the minimum criteria are passed on to at least 2 experts for review.

Authors of manuscripts rejected at this stage will normally be informed within 2 to 3 weeks of receipt.

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Reject

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Energy Efficiency and Renewable Energy: the key factors for a sustainable future

Wolfgang Streicher,
Dipl.-Ing. Dr. techn. (University professor)
Unit Energy Efficient Buildings,
Institute of Structural Engineering and Material Sciences;
University of Innsbruck, Austria
Email: wolfgang.streicher@uibk.ac.at

Climate change is the current biggest challenge for humans. Without mitigation and adaptation in climate change there will be billion of people migrating from one continent to others and within continents. This will probably cause military conflicts and large human suffering. The migration will take place from places where it becomes too hot and/or too dry to do agriculture and to feed the population and no other sources for trading are available into regions with more productive climate. In the last UN Climate Change Conferences, therefore several resolutions to keep the climate change within 1.5 to 2°C until 2050 have been taken. The resolution of COP21 in Paris to keep the temperature increase well below 2°C is signed already by 172 of 197 parties (http://unfccc.int/paris_agreement/items/9485.php).

One very important step to reach these goals is to develop new ideas and implement existing technologies for energy efficiency and renewable energies in a broad range. This will also bring down the costs for the energy system transformation. The limitation of renewable energies in regions with high population density will lead, on the on the one hand, to large energy distribution networks causing new economic and political dependencies between countries, and, on the other hand, to more efficient technologies and systems like energy efficient buildings (for hot and cold climates), energy efficient transportation systems like more public transportation, smaller and electric (or hydrogen) driven cars, and more efficient industrial processes.

Knowledge generation and distribution as done in the International Journal on Renewable Energy and Sustainable Development plays an important role for this further development.

About Professor Wolfgang Streicher

Wolfgang Streicher is university professor of Energy Efficient Buildings and Renewable Energies at Innsbruck University in Austria and currently ISES Europe president. He teaches Building Services Engineering, HVAC, Heat Pumps, Tube Hydraulics, Modelling, Thermodynamics, Energy and Ecology.

His current research focus is on (i) development of cost and energy efficient systems solutions for HVAC systems including renewables; (ii) energy demand of cities using GIS and bottom up approaches; (iii) hydraulics of complex tube networks; (iv) energy efficient systems for cities (v) solar thermal systems.

He works in these fields since more than 30 years and has published numerous papers in reviewed international journals and conferences. Moreover, he has coordinated and coordinates projects for Austrian institutions as well as the European Commission and the International Energy Agency.

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State-of-the-art Charging Solutions for Electric Transportation and Autonomous E-mobility

Siddhartha A. Singh, Deepak Ronanki, A. V. J. S. Praneeth, and Sheldon S. Williamson
Smart Transportation Electrification and Energy Research (STEER) Group Advanced Storage Systems and Electric Transportation (ASSET) Laboratory UOIT-Automotive Center of Excellence (UOIT-ACE) Department of Electrical, Computer, and Software Engineering Faculty of Engineering and Applied Science University of Ontario-Institute of Technology ACE-2025, 2000 Simcoe Street North Oshawa, ON L1H 7K4, Canada
Tel: +1/(905) 721-8668, ext. 5744 Fax: +1(905) 721-3178
sheldon.williamson@uoit.ca
http://www.engineering.uoit.ca/; http://ace.uoit.ca/

Abstract - As regards moving towards electrification of transportation, there is need to replace gas stations with Electric Vehicle (EV) charging stations at equally convenient locations and look at various energy storage methods onboard an electric vehicle. There are various charging methods which have been discussed in the literature. This paper discusses some new charging technology that can possibly have a tremendous impact on the future of energy storage in transportation electrification.

Keywords – electrification of transportation; Electric Vehicle; Ev; Electric; Vehicle charging station; energy storage; autonomous electric vehicle.

I. INTRODUCTION

Charging of an Electric vehicle can be universally classified into Plug-in Charging Technique and Wireless Charging Technique. Plug-in Charging can be further classified into AC charging and DC charging. Plug-in AC charging is achieved by connecting the AC grid to the onboard battery charging system through a connector. The on-board battery charging system consists of the onboard rectifier, the power factor correction stage and the DC-DC converter/charger as shown in Fig 1 using a block diagram. [1][2][3]

Fig.2, shows the typical architecture of an off-board Plug-in DC charging station. All the power conversion units are off-board the electric vehicle. The galvanic isolation for safety is achieved either through a bulky 60Hz isolation transformer between the AC grid and the rectifier or a High frequency (HF) isolation transformer at the DC-DC conversion stage. DC charging of an EV reduces the need of multiple power conversion units on-board as well as off-board the EV. The battery on-board the electric vehicle is directly charged by the off-board converters. [4][5] The Society of Automobile Engineers (SAE) has included DC level I and level II charging in the J1772 standard [6].

Wireless charging of Electric vehicle batteries can also be classified as an on-board charging technique. The power transfer is achieved by contactless plates, through capacitive power transfer (CPT), or contactless coils or magnetic cores, through Inductive Power Transfer (IPT). The overall structure of the power conversion system remains the same for both IPT and CPT as shown using a block diagram in Fig.2.

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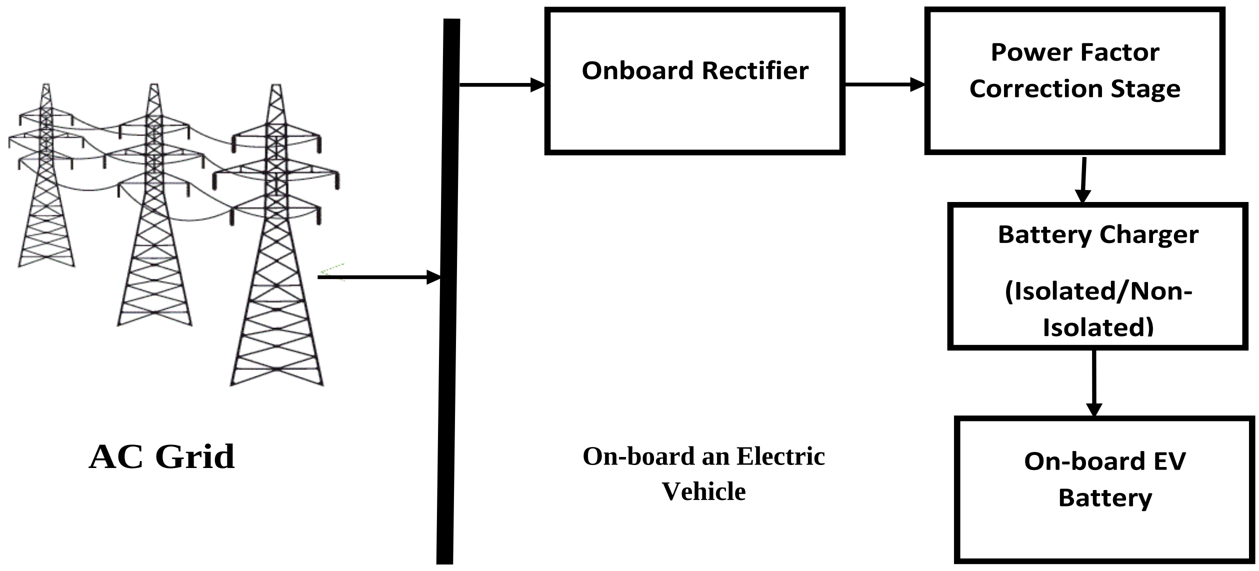

Fig.1. Block diagram of a typical on-board plug-in AC charging architecture

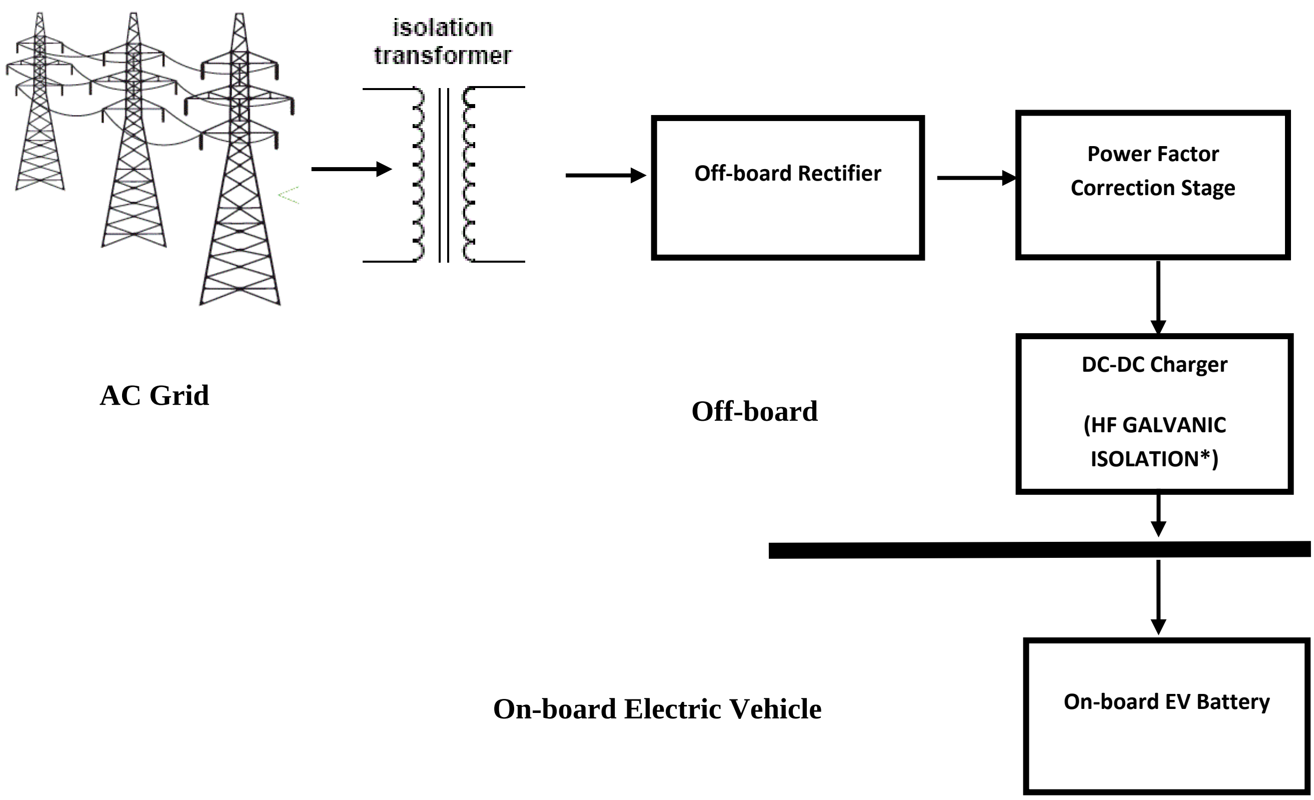

Fig.2. Block diagram of a typical off-board plug-in DC charging architecture

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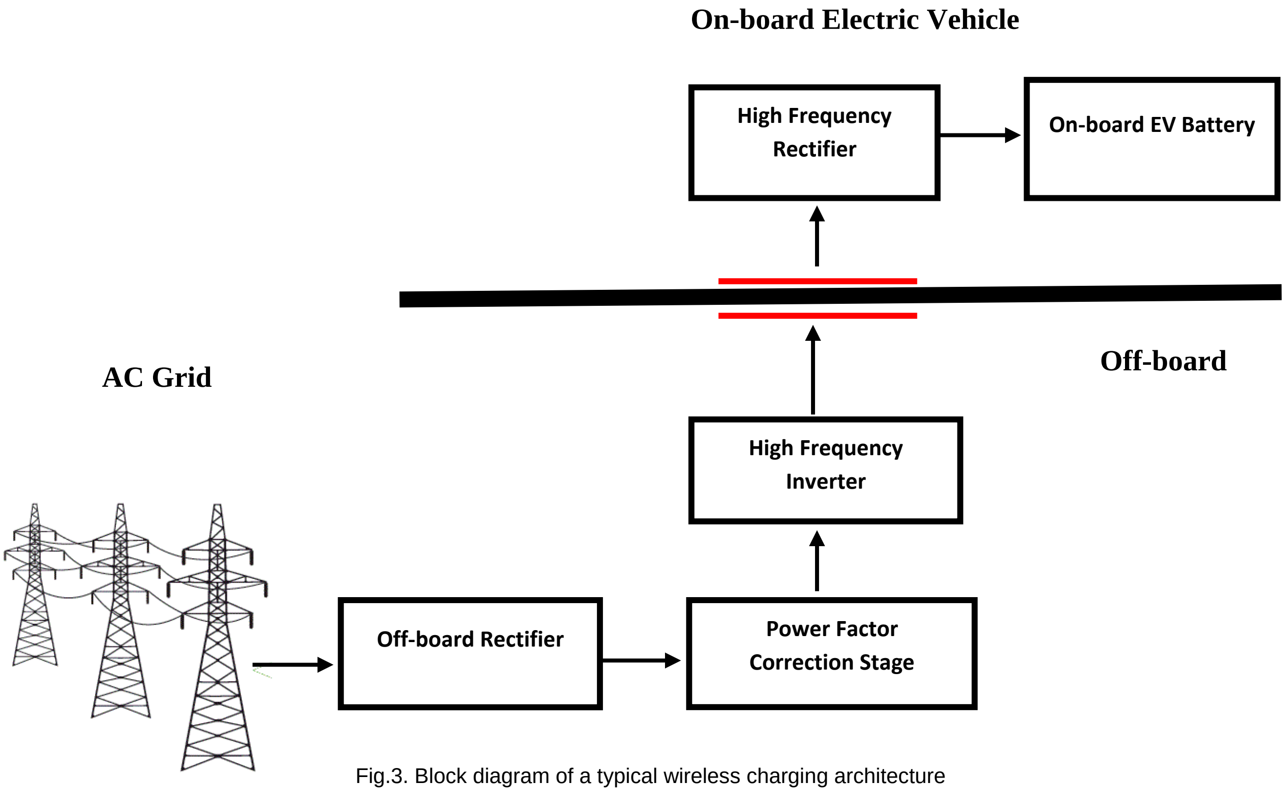

Fig.3. Block diagram of a typical wireless charging architecture

The lines marked in red can either be contactless plates or coils depending on the power transfer technique used. The AC grid provides the entire power required by the EV to charge the battery. The power factor correction stage and the primary of the high frequency transformer is moved off-board. The secondary of the high frequency transformer which is connected to the battery using a rectifier is present on-board the electric vehicle. [6]-[8]

The on-board chargers are with limited power and compact size which are suitable inside a vehicle. On the other hand, for off-board charging eliminates the need for power conversion units on-board the EV. The off-board charging involves redundant power electronic components with bulky size and the associated extra costs for installations. The use of renewable energy for charging of EVs has become a very important area of interest in recent times. During charging of EV using the plug-in off-board technique and even the WPT techniques, there is a huge dependency on the AC grid. Use of multiple power conversion stages contribute to the overall reduction in efficiency.

The use of a renewable energy source interconnected to the AC for energy storage has been used in the past for energy storage systems providing back up power as well as for charging of electric vehicles. As mentioned previously, EV charging systems require multiple stages and the number of stages increases further when interconnecting such charging infrastructure to the AC grid. Usually, residential or semi commercial solar photovoltaic arrays have a lower voltage available at the output of the array and require a boost stage to match the photovoltaic output voltage to the grid connected inverter.

Table 1. DC Charging Electrical Ratings (North America)

Charging Level	Battery Voltage Level (V)	Type of charger	Max. Continuous Current (A)
Level-I	200-450V	Off-Board	80A
Level-II	200-450V	Off-Board	200A
Level III (proposed)	200-450V	Off-Board	400A

For future electrified transportation, some of the key areas of interests are the development of technologies which are compact, highly efficient and less dependent on the AC grid.

In the following sections, new technologies have been discussed which are going to play important roles in the electrification of transportation as there is a trend to move towards a greener planet. In section III, a solar-grid interconnected single stage DC charger has been discussed for residential and semi-commercial applications providing level I and Level II charge (DC) for EVs, section IV discusses an onboard EV motor drive integrated energy storage system and section V, on-board EV charging has been discussed.

II. SOLAR-GRID INTERCONNECTED SINGLE STAGE DC CHARGING FOR RESIDENTIAL/SEMI-COMMERCIAL OFF-BOARD CHARGING

Z-source inverters were first proposed in [10]. They have a unique ability to buck or boost in a single stage through two inductors and two capacitors in a 'X' shaped connection. A modified Z-source inverter (M-ZSI) for DC charging, shown in Fig.4, was first proposed in [11][12]. Each of the impedance network capacitance in split into two capacitors, CHB.

Each of the two capacitors leg acts as a source to split primary isolated half bridge converter. The secondary of the high frequency transformer, T, is connected to the EV battery, for simplicity, using a battery internal resistance, rB and a battery voltage VB. The switch S5, is used instead of a diode to prevent unwanted turn on and off and maintain a constant current for bidirectional power flow. The diode bridge of the secondary side of the high frequency transformer, T, is replaced by an active bridge for bi-directional power flow operation.

The basic operation of this proposed topology is based on the power balance equation given by,
$P_{charge}=P_{PV} + P_{Grid}$

The various modes of operation are PV to GRID, PV+GRID to EV battery and EV battery to GRID. During the PV to Grid mode, the generated photovoltaic power is directly fed into the grid in the absence of an EV connected to the charger. In the PV + Grid to EV mode, the grid and the PV provide the required power for the battery. Any fluctuation in the PV power is compensated by the grid. The various power-efficiency curves for this topology is shown in figure 5.

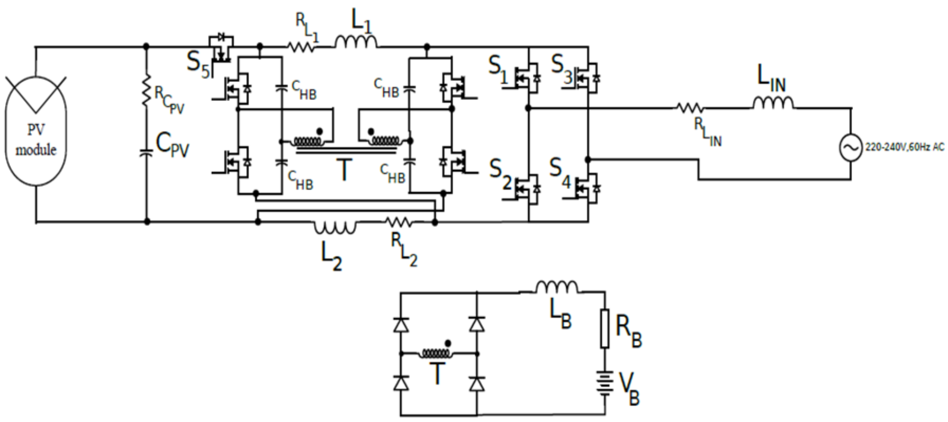

Fig.4. Proposed modified Z source converter based single stage topology

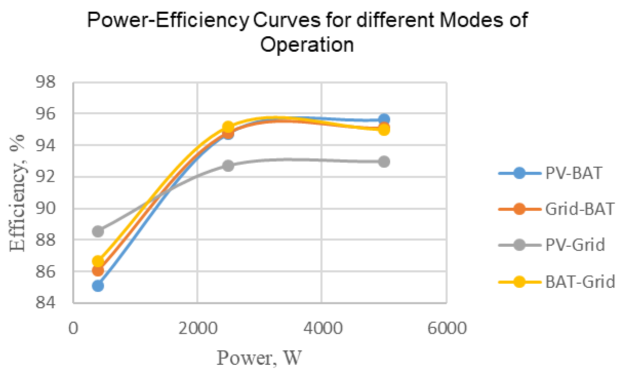

Fig.5. Efficiency curves for different modes of operation for a MZSI charger [11]

From the curves, it can be seen that the efficiency of the PV-BAT is the highest at 95.9%. For Grid to Battery or Battery to Grid (V2G) it is almost the same at 95%. The efficiency from PV to Grid is 93%. The advantages of the proposed topology are: Reliability, lesser number of power stages during different modes of operation.

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III. INTEGRATED MOTOR DRIVE AND ON-BOARD BATTERY CHARGERS

The on-board chargers have restriction of power due to their weight, space, cost constraints and isolation requirements [13]. To limit these constraints, integration of charging task in the electric traction system is a feasible solution as these operations are not simultaneous. The basic idea of an integrated charger is usage of motor windings as filter inductors or an isolated transformer and the inverter functions as a bi-directional AC–DC converter and these are considered as the integrated motor drive and battery chargers [14], [15]. This provides a major advantage that levels 2 and 3 have a high power bidirectional charger with unity power factor at low cost [16]. These chargers can be classified based on converter configuration, motor type and construction, number of motor phases and type of wheel drive. An integrated motor drive and battery charger system were commercially used in electric cars by AC Propulsion Inc. [17] based on an induction machine and General Motors Inc. [18], Ford company [19], Valeo Engine and Electrical Systems [20] use split winding AC motor topology without switch like a contactor [21]. These integrated chargers are already used in two wheelers [22], fork lift trucks [23] and cars [24]. A few advancements in motor topology modifications in order to operate as a three phase PFC coupled boost rectifier are split-phase induction motor [25], special double winding machine [26], split-phase permanent magnet synchronous motor [27], split-phase permanent magnet assisted synchronous reluctance motor [28], delta-star permanent magnet synchronous motor [29], split-phase switched reluctance motor [30] and multiphase machines [31], [32]. Few examples of using topologies without. without motor modifications are in four-wheel drive system [33] and integrated charger with switched reluctance motor (SRM) drive presented in [34] uses embedded components of motor and converters with voltage boosting feature and PFC charging and [35] multilevel converter fed SRM.

In this section, main focus is on Modular Multilevel Converter (MMC) which serves as an integrated converter for onboard fast charger and motor drive system. The MMC offers advantages such as modular realization, inherent redundancy, low total harmonic distortion, higher efficiency with standard devices, filter less configuration, no capacitors at DC bus, no filters at AC and DC side which are made to use in EVs [36], [37]. MMC can be realized as a i) power converter driving the motor ii) effective battery management system by submodule control iii) AC charging through arm inductances with sequence of operation of submodules. In addition, MMC provides fault tolerant capability, redundancy of modules and elimination of large DC link capacitors.

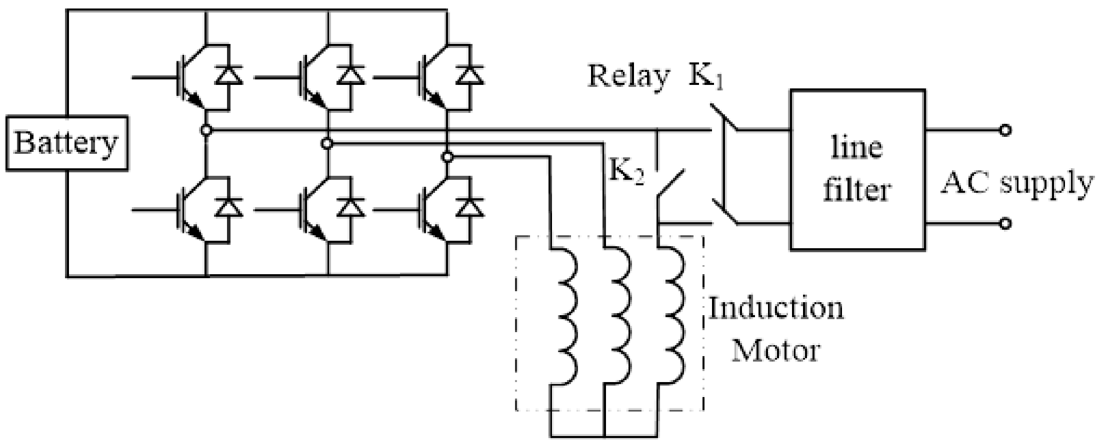

Fig.6. Schematic of a 3 phase motor drive.

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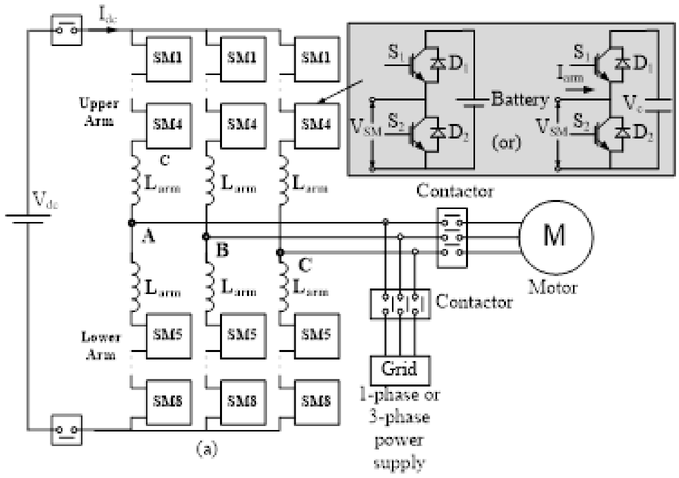

Fig.7. Schematic of a MMC based motor drive

However, these are associated with some problems and can be summarized as [38]-[41]: i) It requires a higher number of semiconductors, gate drivers and corresponding control equipment. ii) Energy stored in distributed capacitors is considerably higher than conventional inverters. iii) It also requires a higher number of sensors to monitor capacitor voltages and arm currents. The major issue with MMC is that it requires a capacitor balancing algorithm and circulating current suppression control as it contains a double frequency component, which increases the stress and losses in power switching devices [40], [41]. MMC with the use of wide gap power switching devices can be a future solution for integrated fast on board charger and motor drive system in autonomous vehicles with features of high reliability, efficiency and redundancy. This makes the easy and identical modules manufacturing, hierarchical redundancy capability and reduction in dimensions of the whole converter for automotive manufacturers at the cost of improved technology at submodule.

IV. ONBOARD-CHARGING

In all the autonomous and self-driven electric vehicles, energy in the battery can be refilled with battery chargers which must be highly efficient and reliable, with high power density, low cost, and low volume and weight. The charging time and battery life are linked to the characteristics of the battery charger. The most important criteria in selection of on-board battery charger for a vehicle is based on the available battery pack ratings (kWh) and limited weight to space ratio to maintain average charging time to a low value.

The power flow from the battery chargers can be unidirectional or bidirectional. In Unidirectional charging the power flow is from grid to the vehicle. So it limits hardware requirements and simplifies interconnection issues. In a bidirectional charging it allows charging from the grid and battery energy injection back to the grid (vehicle to grid).

Table 2. AC Charging Electrical Ratings (North America)

Charging Level	Voltage Level	Type of Charger	Interface Equipment	Power Level	Charging Time
Level-I	120 V ac(US) 230 V ac(EU)	On-Board	Type-I(J1772)	Upto-3.3KW	6-9hours
Level-II	240 V ac(US) 400 V ac(EU)	On-Board	Type-II connector	7.7-43KW	1-4 hours
Level-III	Single phase and 3 phase (proposed)	>20kW			

This is the latest trend in the charging systems with the automotive (CAR2HOME) to grid. It stabilizes the power with adequate power conversion when it is plugged to grid. The on-board charging through the renewable generations (Solar) helps to minimize the additional power stabilizing equipment in the vehicle. The concept of sun2car shown in Fig: 1 is one of the solutions for charging the vehicle through a PV used by Toyota and Nissan. Fig: 2 shows the Tesla's super charger, which provides a huge research scope in extracting the maximum energy from the sun and utilize it for charging the EV battery pack. There are various topologies involved in onboard charger for charging the electric vehicle [3] [41]. Most of the onboard chargers have the front-end topology as AC-DC power conversion to maintain the power quality in the system when the vehicle was connected to a grid supply for charging [42]. The converted DC will normally have a huge low frequency ripple which will affect the life of the battery especially the li-ion battery [43]. There should a two-stage power conversion required in a li-ion battery pack to reduce the low voltage ripple content and to make it easy to implement the charger control algorithms [44]. There are many topologies in PFC like interleaved, bridgeless, semi-bridgeless, which can improve the output ripple in capacitors and the heat management problems in the converter. In this paper, the researchers are interested in reducing the charge time of the vehicle with high power quality. There are different topologies in ac–dc converters with good power quality and less harmonics discussed in [45] - [46]. Proper selection of the PFC topology helps to minimize the low frequency ripple, the power quality, and the size of EMI filter and emissions.

Fig.8 Sun2Car concept

Fig. 9. Tesla Super Charger

To avoid the bulky capacitors at the PFC, [48] provides a solution for sinusoidal charging that can be implemented through using bidirectional converters. There are different stages in the battery charger, represented in the block diagram (Fig. 3). The main motivation is to compact the size of the charger and improve the efficiency at full load conditions. There are many contributions to improve the efficiency of the converters [45]-[47]. The resonant converters at the DC/DC side have the major role in deciding the efficiency of the whole charger with isolation transformer and wide control algorithms implementations for charging the battery packs [49].

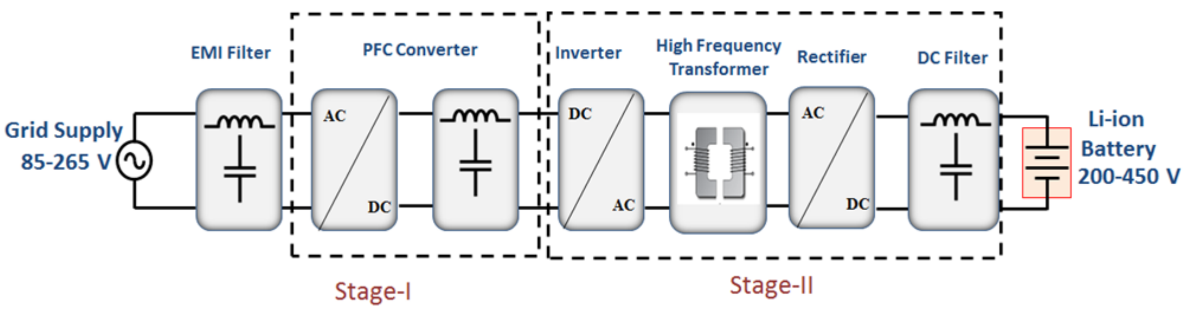

Fig. 10. Block diagram of on board charger stages

In the block diagram of Fig. 3, Stages II&I are the same for both conductive and inductive power chargers [49]. Stage II in the wireless charger is separated with a magnetic coil of specified air gap length and the corresponding compensations on primary and on secondary. The EMI filter shown in the charger is required to filter the common mode and differential mode noise, surge protector and harmonics suppressor. There are many challenges in using the resonant converters for the charging application to have a wide output voltage [51] - [52]. The overview of the paper is to design a charger with minimized size and weight, universal output voltage and faster rate of charge. An EV charger must ensure that the utility current is drawn with low distortion to minimize the power quality impact and at high power factor to maximize the real power available from a utility outlet. IEEE-1547, SAE-J2894, IEC1000-3-2, ECR-10(Rev.4), CISPR-25, and the U.S. National Electric Code (NEC) 690 standards limit the allowable harmonic and dc current injection into the grid, and EV chargers are usually designed to comply [53]-[59]. The overview of the stages is shown in Fig.4.

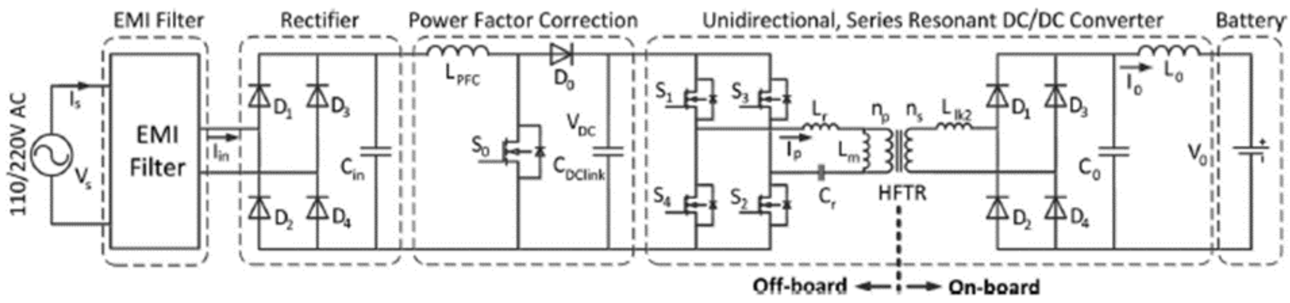

Fig.11. Overview of an isolated onboard charger [61]

The two-stage topology as shown in Fig.11 consists of only AC-DC power conversion. To avoid the additional DC-DC converter for the low voltage (LV) modules the integrated on-board with AC-DC for main Battery and DC-DC converter for auxiliary loads operated with LV supply (12/24 V) as proposed in [62]-[63].

V. CONCLUSIONS

This paper discusses some of the topologies in the area of energy storage for electric vehicles. Various charging technology for onboard electric vehicle battery was discussed. Some possible state of the art technologies have been presented in this paper. Using solar grid tied inverter/chargers can be used for charging at residential locations converting residential houses into a charging station. MMC technology is an attractive solution for onboard energy storage and AC onboard charging directly from the grid is a convenient way of charging directly from the AC supply. The various standards for charging are also presented for the discussed topologies.

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A Review of Using Supercritical CO_2 Brayton Cycle in Renewable Energy Applications

Wen-xiao Chu, Katrine Bennett, Jie Cheng and Yi-Tung Chen*
Department of Mechanical Engineering, University of Nevada, Las Vegas, NV 89154, USA
*Corresponding author: Tel: +1 (702)895-1202
*yitung.chen@unlv.edu

Abstract **-** Supercritical carbon dioxide (sCO_2), which is an environmentally friendly working fluid, has very good thermal physical properties. Many researchers have studied the heat transfer mechanism and the enhanced heat transfer method of the supercritical CO_2 Brayton cycle (sCO_2-BC). The sCO_2-BC has many applications including the next generation of Fast Cooling Reactor (FCR), solar power system, extraction process and heat pump system. The sCO_2-BC provides high efficiency and high compactness, which is important because system miniaturization is vital to these developing technologies. The present paper reviews the recent references on the research progress of the sCO_2-BC system. Furthermore, it discusses the analysis of key components such as the compressor, turbine and heat exchanger, which differ from the devices used in the conventional steam Rankine cycle due to the special thermal properties of sCO_2. Finally, the researchers propose some recommendations towards the development of sCO_2-BC system for future work.

Keywords **-** Supercritical CO_2 Brayton cycle; Compressor; Turbine; Heat exchanger

I. INTRODUCTION

Carbon emissions are increasing rapidly due to the increasing rate of energy consumption by human beings. The utilizations of renewable energy conversion systems, like nuclear and solar energies, are imperative to slow or stop the environment pollution and destruction caused by carbon emissions. Carbon dioxide (CO_2), which is an environmentally friendly working fluid, has excellent thermal properties when used in a supercritical state. Supercritical CO_2 (sCO_2) is capable of performing expansion working with a lower pressure residence when compared with steam. For this reason, Feher [1] proposed using sCO_2 as a working fluid in the Brayton cycle in 1967. The sCO_2 Brayton cycle (sCO_2-BC) is an attractive working fluid for nuclear reactor systems [2-4], solar power systems [5-7] and other renewable systems [8-11], because of its high overall efficiency due to special thermal properties [12]. The density of sCO_2 is of the same order of magnitude as water. However, the sCO_2 viscosity is similar to that of air. Fig. 1 illustrates the overall cycle efficiency of the sCO_2-BC evaluated from the turbine inlet temperature in the reactor system compared with other thermal cycles [3]. The sCO_2-BC has a much higher efficiency, than other cycles, when the turbine inlet temperature is over 550ºC. It is possible for the overall efficiency of the sCO_2-BC to exceed 50%. The cycle efficiency of the sCO_2-BC with the turbine inlet temperature of 550ºC is expected to be compared with the helium cycle at 750ºC, which means that the cost of materials can significantly be decreased. Thus, the sCO_2-BC has great potential for industrial applications [2].

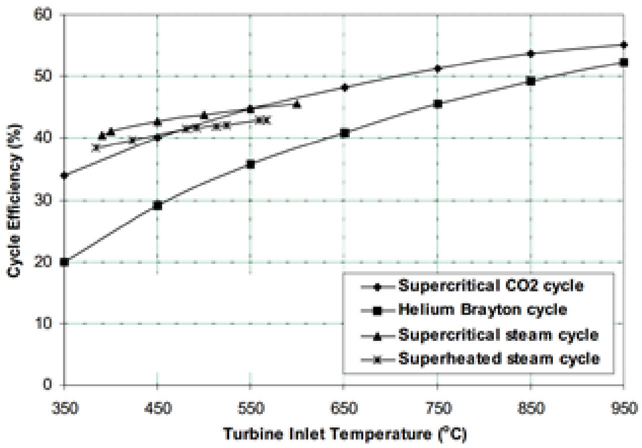

Fig .1. Comparison of power cycle options [3]

Due to the excellent thermal properties of sCO_2, the sCO_2-BC requires significant fewer turbine stages than a cycle using helium or steam under the same thermal power level. Additionally, the operating pressure of sCO_2-BC is always higher than 10 MPa, which allows the compressor, turbine and heat exchanger to be more compact [13]. On the other hand, it is crucial to design and optimize such components for a long-term operation under high temperature and high-pressure conditions. Therefore, the safety, stability and reliability of the operating components in the system should be considered and studied comprehensively [14,15].

In this paper, the performance evaluation, system optimization and economic analysis studies of sCO_2-BC systems from the last five years are reviewed. Other studies of related key components, such as the compressor, turbine and heat exchanger, are introduced briefly. Then, some recommendations are proposed based on the latest studies.

II. STUDIES ON THE SCO_2-BC SYSTEM

The original thermo-dynamic process of sCO_2-BC is shown in Fig. 2, with only some basic components illustrated. In order to improve the overall efficiency of sCO_2-BC, some more complex system compositions are developed. Wang et al. [16] summarize the six typical layouts of sCO_2-BC. These include the simple recuperation cycle, recompression cycle, precompression cycle, intercooling cycle, partial-cooling cycle and split expansion cycle. The derivative relationships between these six typical layouts of sCO_2-BC are shown in Fig. 3. It can be seen that the systems are gradually improved as the necessary components are added into the original cycle to overcome the deficiencies.

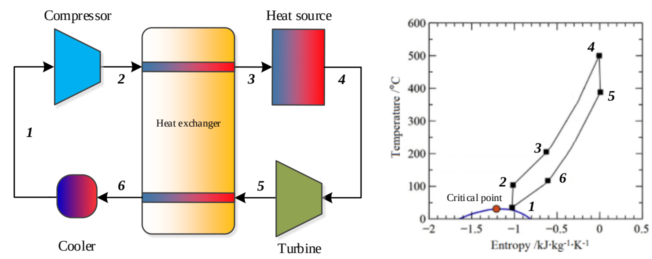

Fig .2. Original supercritical CO_2 Brayton cycle (sCO_2-BC)

The sCO_2-BC can be used in the very high temperature reactor (VHTR) and the fast cooled reactor, which are proposed by the U.S. Department of Energy's Next Generation Nuclear Plant (NGNP) [17]. The simplified design and compact size of the sCO_2-BC may reduce the installation, maintenance and operation cost [7]. Dostal et al. [2-4] created the preliminary design for the compressor, turbine and heat exchanger of the sCO_2-BC in a 600 MW reactor system including detailed volume and the cost estimation. Furthermore, three typical direct cycle designs were further investigated, in which the plant layout and the control scheme design were also included.

With the growing interest in renewable energy, the sCO_2-BC applicability in the field of solar energy is investigated. The sCO_2-BC configurations were explored and optimized for use in a concentrating solar power (CSP) application combined with a dry cooling process, which might achieve the efficiency with 50% or greater [5]. Ortega et al. [6] analyzed the sCO_2-BC in a solar receiver with the power of 0.3-0.5 MW using MATLAB, which can predict the thermal performance of the receiving equipment coupling with the radiation mechanisms. Moreover, it was proposed that the transient nature of the solar resource is the biggest challenge in the CSP system. Nami et al. [14] proposed a standard for evaluating the compressor, turbine, recuperator and cooler considering the factors of energy, economic and environment. Iverson et al. [18] studied the behavior of sCO_2-BC in response to a fluctuating thermal input. The investigation was similar to short-term transient environments and the results showed good agreement with experimental data. Padilla et al. [19] conducted a multi-objective optimization of the compressor, turbine and recuperator on the thermal performance of the sCO_2-BC. It was determined that the more compact characteristics of designing a compressor and turbine operating with the supercritical fluid must be overcome in order to successfully bring the technology to the market. These challenges include the fact that all the components should be designed with a more compact structure because of the miniaturization characteristics of sCO_2-BC. Recent studies focused on optimizing the design of the key components, like the compressor, turbine and heat exchanger, which is described next.

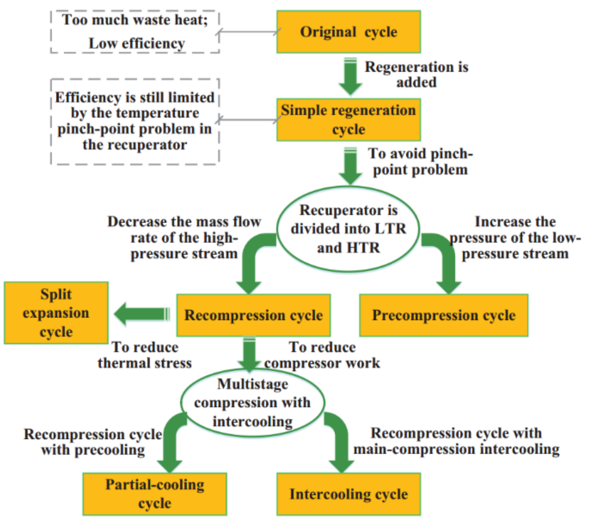

Fig .3. Schematic of derivative relationships of six typical sCO_2-BC [16]

III. STUDIES OF SCO_2-BC COMPONENTS

1. Supercritical CO_2 Compressor and Turbine

The compressor increases the working fluid pressure from a low to a very high pressure, which can be seen in the Temperature-Entropy (T-S) diagram shown in Fig. 2. Cardemil et al. [20] recognized that CO_2 has better comprehensive performance when operated at supercritical conditions. The effect of the compressor on the overall efficiency of the sCO_2-BC was studied by Dyreby [21]. The results indicated that the overall efficiency could be improved by increasing the compressor inlet pressure. However, it was found that the increase of compressor outlet pressure never affects the thermal efficiency. Ibsaine [22] presented a new compressor design concept, which was especially suited for sCO_2 heat pump applications. The compressor consists of an integrated thermal system that consists of a thermal compressor and a conventional vapor compression heat pump. The computational model was verified by comparison with experimental measurements from the thermal compressor prototype. In Ibsaine's study, the impacts of the size of dead spaces and leaks between the displacer and the cylinder wall were studied parametrically. Pecnik [23] investigated a high-speed centrifugal compressor operating with sCO_2 and compared the results with data from tests in the Sandia sCO_2 compression loop facility. Then, Lettieri et al. [24] studied a multistage compressor operating with supercritical CO_2 by CFD method. The thermal properties of supercritical CO_2 was calculated with the National Institute of Standards and Technology real gas model [25]. In order to improve the stage efficiency, a vaned diffuser was analyzed instead of the standard vaneless diffuser in order to decrease the meridional velocity and widen the gas path. Rinaldi el al. [26] calculated the compressor map for three different rotational speeds (45 krpm, 50 krpm and 55 krpm) and the methodology and results were validated against experimental data from the Sandia National Laboratory. The comprehensive assessment of sCO_2 real gas effects is important for evaluating the performance of compressor considering the high variability of thermal properties of sCO_2. Baltadjiev [27] investigated the centrifugal compressors at different thermodynamic conditions relative to the pseudo-critical point of CO_2. The results indicated that it has a reduction of 9% in the choke margin of the stage due to the thermal properties variations and the condensation was not a concern at the investigated operating conditions.

The turbine is the component used for power generation, and as such, it can directly indicate the system efficiency. The sCO_2 turbine is far smaller than the steam turbine due to its low pressure-ratio. Furthermore, the sCO_2 turbine is much simpler than the steam one because it does not need to allow for phase change and moisture separation. Kato et al. [28] found that the sCO_2 gas turbine reactor system, with a partial pre-cooling cycle, attained the excellent cycle efficiency of 45.8% at the temperature of 650ºC. Chen [29] proposed the centrifugal prototype turbine using the sCO_2-BC and analyzed the performance with experimental and numerical methods. The shape and size of the nozzle of the supercritical CO_2 turbine was optimized and it was found that choked flow did not occur when the diameter of the nozzle was larger than 0.7 mm. Additionally; the turbine output torques and the electric power generation can be improved with the increase of the nozzle inner diameter. The achievable thermal cycle efficiencies of the steam turbine cycle, helium turbine cycle and sCO_2 turbine cycle were studied and compared by Ishiyama [30]. These efficiencies were found to be 40%, 34% and 42%, respectively, when the heat source temperature is 480ºC. Furthermore, the volume of a sCO_2 turbine was estimated to be only half that of a steam turbine generating the same power.

2. Supercritical CO_2 Heat Exchanger

In the sCO_2-BC, the recuperator and cooler, which play important roles in maintaining safe operations, always have significant impacts on the efficiency of the whole system. The shell-and-tube heat exchanger (STHE), which has been used for nearly a hundred years and has a mature manufacturing process, is now in wide use in the high pressure and high temperature systems [31]. However, the application of the STHE is limited by its required large volume and high cost when systems require compactness and miniaturization. In recent decades, the HEATRIC Company has developed a new type of printed circuit heat exchanger (PCHE) [32]. This new PCHE meets compactness requirements and can reliably operate for long term in extreme temperature and pressure conditions. The PCHE has performed excellently when used in the SCO_2-BC system.

Mylavarapu et al. [33-36] at Ohio State University investigated the PCHE in the high temperature helium facility (HTHF) with experimental and numerical methods. The straight fins of Alloy 617 plates were fabricated by photochemical etching and assembled by diffusion bonding. The experimental test data could be used to determine the design operating conditions for the PCHE in the HTHF. Ma et al. [37] also analyzed the thermal and hydraulic performance of a PCHE with zigzag fins. It was found that the flow could not be fully-developed at the high temperature due to the significant variation of the thermal physical properties of sCO_2. Tsuzuki et al. [38-40] developed a new PCHE with S-shaped fins. They validated numerically that the PCHE with S-shape fins had the same heat transfer performance as the zigzag PCHE but with the benefit of one-fifth of the pressure drop. With continued focus on fin structures, the heat transfer performance of a PCHE with airfoil shaped fins was proposed and analyzed by Kim et al. [41]. It can be seen that the PCHE with airfoil shaped fin can obtain the same heat transfer performance as the zigzag channel PCHE with only 1/12 the pressure drop. This is due to the streamlined fin shape and the increase of heat transfer area. Furthermore, Xu et al. [42] analyzed the airfoil fin structure parametrically and proposed that it was necessary to reduce the flow resistance along the flow direction in order to improve the comprehensive thermal hydraulic performance of the PCHE.

IV. CONCLUSIONS

The sCO_2-BC is an efficient thermodynamic cycle due to the excellent thermal properties of the sCO_2, which have significantly improved the systems overall performance when compared with other conventional cycles. Researchers have studied the sCO_2-BC system extensively, including performance evaluation and component optimization.

- The sCO_2-BC has very high overall efficiency, possibly above 50%. The sCO_2-BC may be used in the next generation reactor systems and solar power systems, which can significantly reduce the system volume.

- It is a challenge to design the compressor and turbine with sCO_2 working fluid for stable system operation. The sCO_2 compressor and turbine are far smaller than conventional ones due to the low pressure ratio, which can definitely contribute to the system miniaturization.

- The PCHE is a compact heat exchanger with a volume of 85% that of a comparable STHE. Complex fin structures for the PCHE have been developed; ranging from continuous zigzag shape to discontinuous airfoil shape, which aim to improve the comprehensive performance.

According to the investigation review above, some recommendations for future work of the sCO_2-BC system are proposed. Firstly, the material problem is now becoming the focus, due to system operating temperatures and pressures exceeding 700^{o}C and 20 MPa, respectively. Secondly, the behavior and the performance of the compressor and turbine operating close to the critical point, should be tested and evaluated due to the high variability of sCO_2 thermal properties. Finally, the dynamic analysis of the entire system should be studied with transient analysis in cases of great fluctuation, to ensure the system should operate near the stability point very well.

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

Prof. Dr. Mohamed Medhat Dorra[1], Assoc. Prof. Dr. Hend El-Sayed Farouh[2] and Eng. Lubna A. Amer[3]
Department of Electrical Power and Machines Engineering, Tanta University, Tanta, Egypt
[1]Professor of Architecture, Faculty of Engineering, Cairo University, Giza, Egypt.
[2]Associate Prof. of Sustainable Architecture & Urban Development, Housing & Building National Research Center, Giza, Egypt
[3]PhD candidate, Faculty of Engineering, Cairo University, Giza, Egypt
hfarouh@imc-egypt.org, lamer@mdd-architects.com

***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].

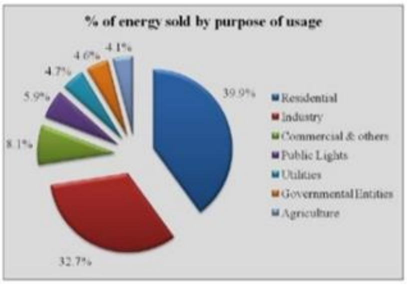

Fig .1. Egyptian electricity consumption- The most consuming areas are the residential ones. The Egyptian Electricity Holding Company Annual Report 2009/2010. Egyptian Electricity Holding Company, Cairo, Egypt, 2010.

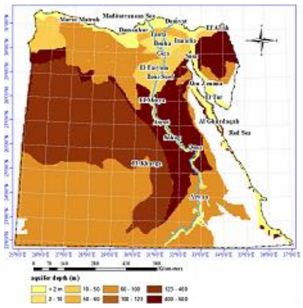

Fig .2. Classification of aquifer depth in Egypt. M. Salim, Selection of Groundwater Sites in Egypt. Journal of Advanced Research, 2012

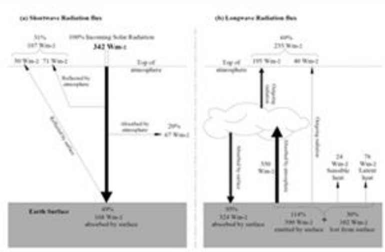

Fig .3. Earth's energy budget diagram showing the short-wave (a) and long-wave (b) energy fluxes. Banks, David. An Introduction to Thermogeology: Ground Source: Heating and Cooling. Wiley-Blackwell, 2012.

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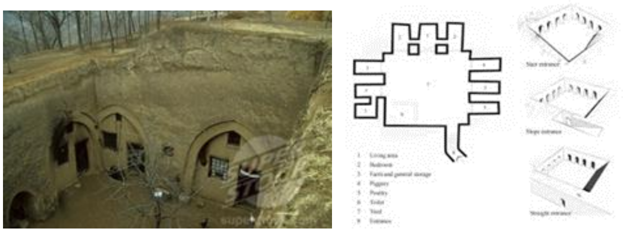
(b) Aerial view of a typical Matmata earth shelter dwelling.



(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].

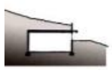
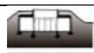
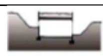
On the Hillside	Bermed	Underground	Relation to Surface
			Openings
			Chamber
			Atrium
			Elevational
			Penetrational

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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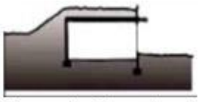
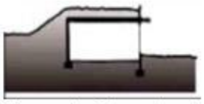
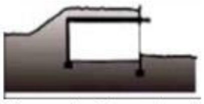
Table 1 . Some Worldwide Earth Sheltered Housing Units

	Project	Ecology House Marstons Milss, Massachusetts, USA,1972.
	Architect	John E. Barnard Jr.
	Climate	Hemiboreal
	Type	 Underground - Atrium
	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	 Bermed - Elevational
	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	 Bermed - Elevational
	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	 Bermed - Elevational
	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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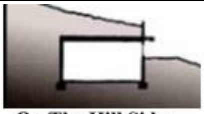
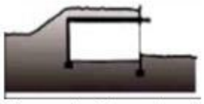
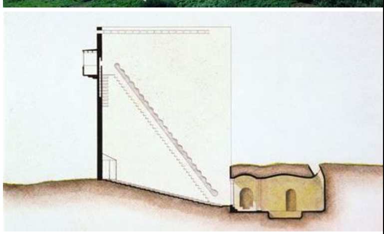
	Project	Underground-home. Located in the Swiss village of Vals.
	Architect	SeARCH and Christian Muller Architects
	Climate	Tundra
	Type	 On The Hill Side
	Notes	The introduction of a central patio into the steep incline creates a large façade with considerable potential for window openings.
	Project	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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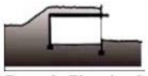
	Project	Earth House Republic of Korea, 2009.
	Architect	Byoungsoo Cho, Yangpyeong-gun, Gyeonggi-do
	Climate	Hot Summer Continental
	Type	 Underground - Elevational
	Notes	Used a geothermal cooling system with a radiant floor heating system under the rammed clay, concrete floor.
	Project	Woodland Home 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.

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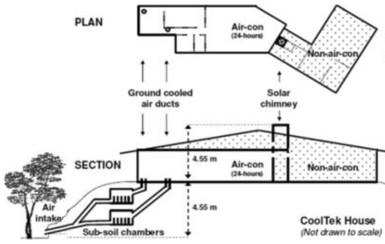
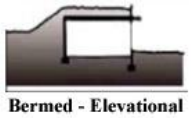
	Project	CoolTek House in Malacca, Malaysia.
	Climate	Hot Humid
	Type	
	Notes	The original concept was to have the heat passively ventilated out by solar chimney and draw in the cooled air from ground cooled duct.
	Project	UK's first earth-sheltered social housing scheme at Honingham (Harrall, J., 2007).
	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]

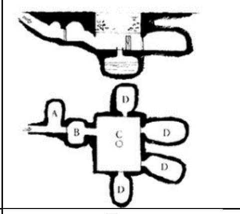
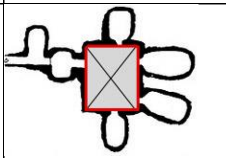
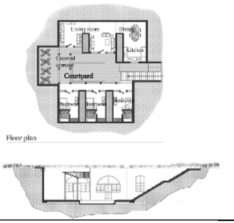
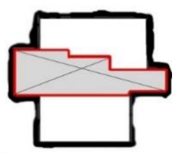
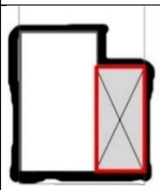
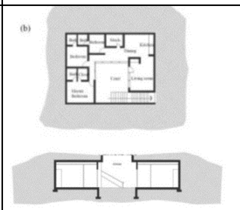
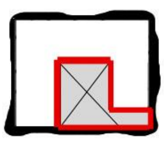
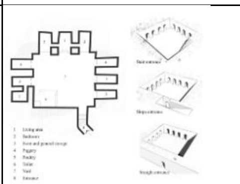
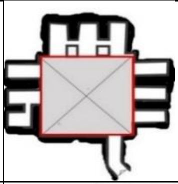
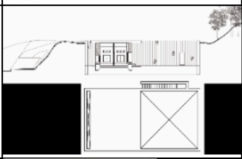
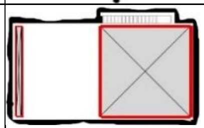
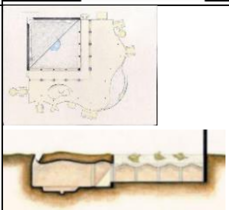
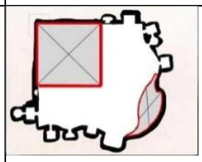
A local material	Socially accepted
A bio-degradable material	Flexible production scale
An adapted material: Produced locally	Cost efficiency
A transferable technology	Energy efficiency and eco friendliness: The energy consumption in a m3 can be from 5 to 15 times less than a m^3 of fired bricks. The 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	

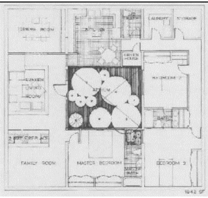
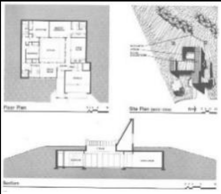
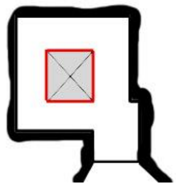
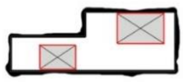
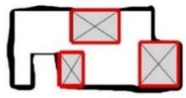
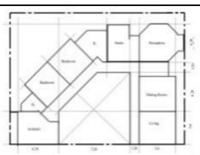
K. Underground courtyard houses [Constructing case studies]

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	

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.

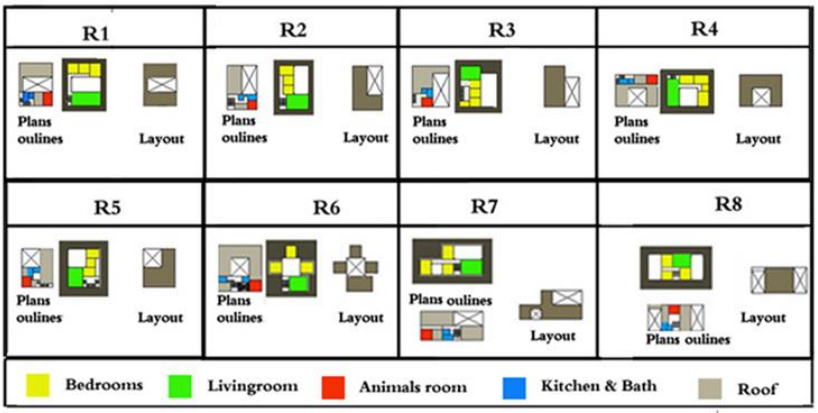


Fig. 6. Deduced eight types of courtyard houses which represent the case studies
Source: Researchers.

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

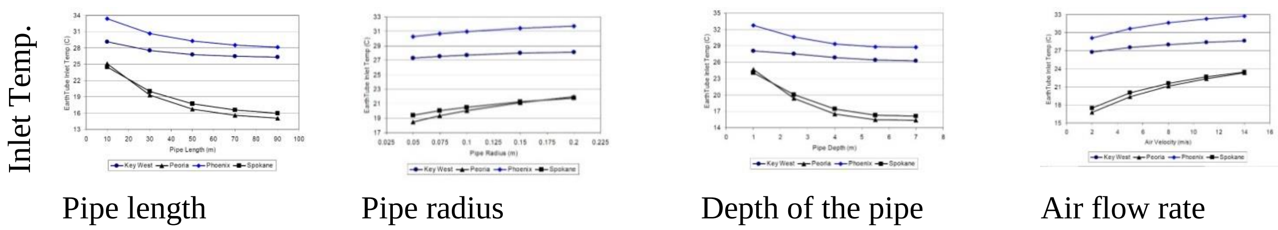


Fig. 7. Factors that affect Earth Pipe Cooling performance [28]

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.

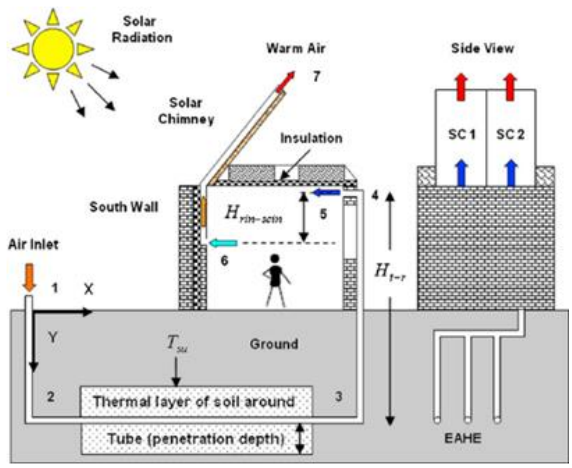


Fig. 8: Schematic diagram of integrated earth to air heat exchanger and solar chimney (Maerefat, M., Poshtiri, A., 2010)

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 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".

http://dx.doi.org/10.21622/RESD.2018.04.1.021

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

http://dx.doi.org/10.21622/RESD.2018.04.1.021

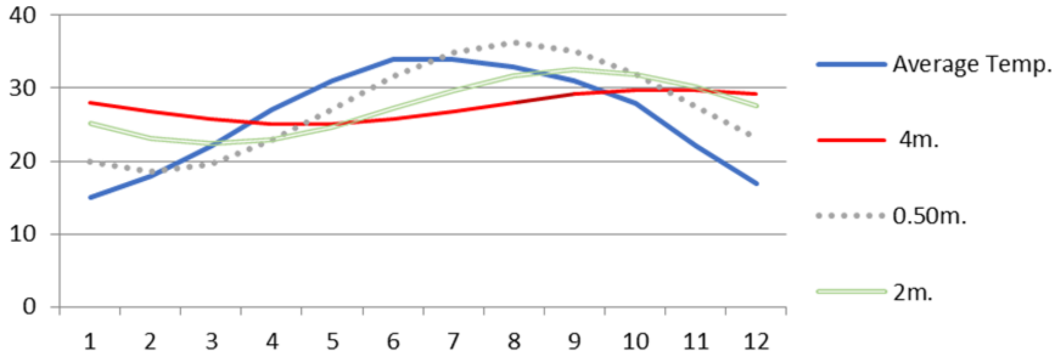


Fig.10. Average monthly temp. compared to calculated soil temp.in Aswan
Source : Researchers

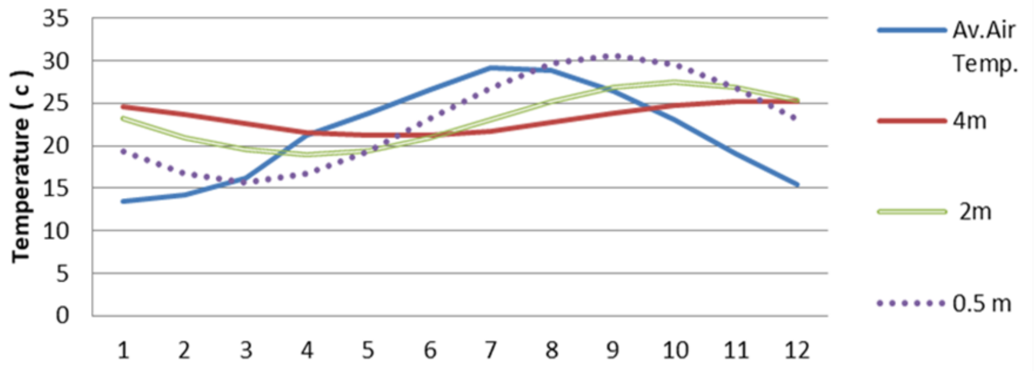


Fig. 11: Average monthly temp. compared to calculated soil temp.in Ismailia
Source : Researchers

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).

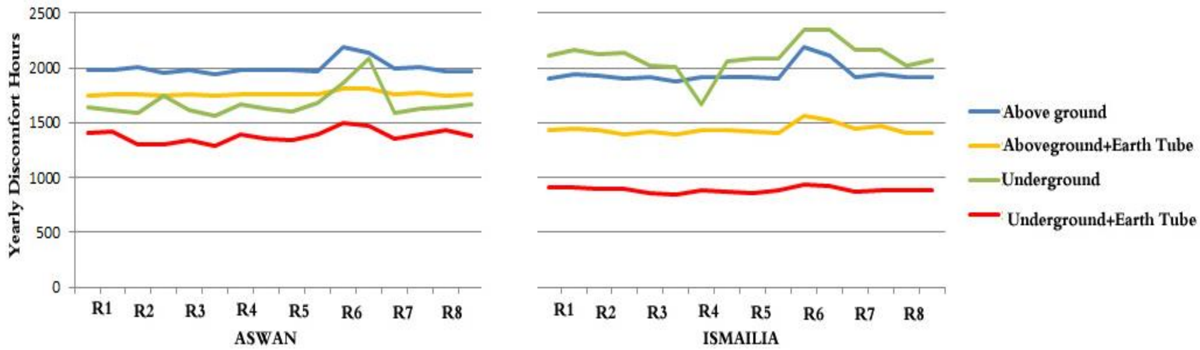


Fig. 12. Yearly discomfort hours [Measured for the four plans(arrangements): (O-A-B-C)] Source: Researchers

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.

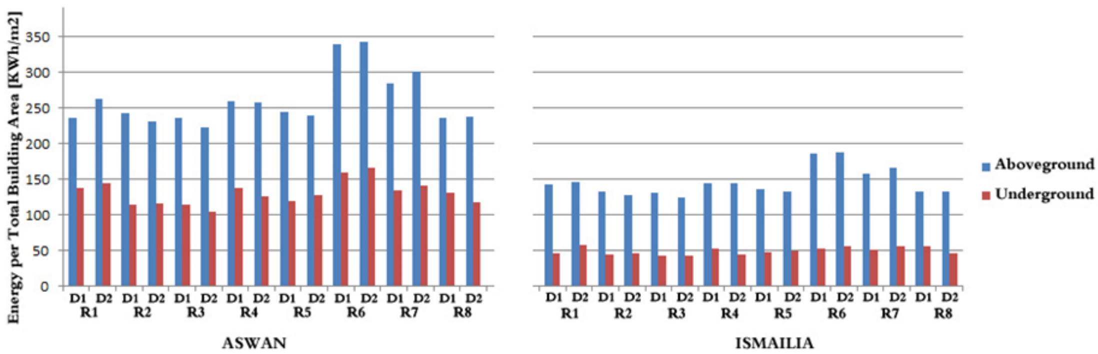


Fig. 13. Energy consumption to reach thermal comfort [Measured for the two plans: [P (O- B)]. Source: Researchers

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.

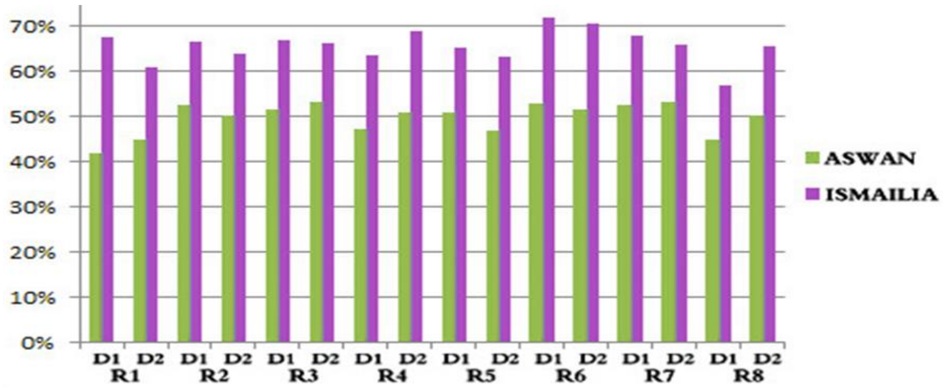


Fig. 14: % Decrease in energy consumption (% Difference between plan PO& PB) for the two directions of the eight types. Source: Researchers

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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Generating Electricity Using Geothermal Energy in Iran

Armin Ramezani, Mohammad Vahedi Torshizi, Arash Attari and Farhad Tabarsa
Department of Bio-System Mechanical Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran.
mohammadvahedi4130@gmail.com,
armin.Ramzani@yahoo.com, arashattari1995@gmail.com,
farhadtabarsa75@gmail.com

***Abstract* -** Given that fossil fuels will end one day and that these types of fuels produce a lot of pollution, each country should look for new ways to generate energy that is needed for its people in proportion to its energy resources. Given that Iran is geographically located in an appropriate region of the earth, it has a great potential for using renewable energy. In this study, sources and uses of Iranians' geothermal energy have been studied, all of which indicate that Iran has a very good potential for electricity production using geothermal energy. According to the information gathered, Iran has one geothermal energy plant in Meshkin shahr city and this plant power with a capacity of 100 megawatts is an active power plant in Iran. Also, the potential of geothermal power generation was verified in Khoy located in Azarbaijan Gharbi province, Sabalan Ardebil province, Sahand in Azarbaijan Sharghi and Damavand in Tehran province Examination verified that around 8.8% of total land in Iran is capable of geothermal energy production.

***Keywords* -** Iran, Geothermal Energy, fossil fuels, renewable energy.

I. INTRODUCTION

Iran (Islamic Republic of Iran) is located in the West Asia, surrounded by Caspian Sea, Azerbaijan, Turkmenistan, Armenia, Pakistan, Afghanistan, Iraq, Persian Gulf, Oman Gulf and Turkey [1]. Total area of this country is 1.65 million km2, and its population is about 80 million people including 49.6% females and 50.6% males. Iran has a warm and dry climate by long summers and short, cold winters[2] [3]. The same climate and the four seasons have led to a special look at using renewable energy in sustainable development in different fields. Statistics showed that Iran has the fourth largest crude oil reserves, the second largest natural gas reserves in the world [4], and a very high potential in renewable energy sectors, such as solar, wind, geothermal, etc. which can be used exclusively in any of the cities in Iran [5].

On the one hand, energy plays a significant role in the economic and social activities of the humans and the country and the growth of energy and its use and productivity will also lead to the welfare of people. Hence, over the past years, great attention has been paid to energy production in a variety of ways [6]. On the other hand, fossil fuels have been used extensively in the past two decades and fossil resources are limited and one day they will end. So any country should know the energy available in it and also lookto create new ways to produce energy[7]. Also Iran has a lot of fossil resources, which could be easily used for many years, but the point to consider is, how long can these fuels be used? Figure 1 shows the use of renewable energy in seven countries, which is the largest amount of wind power use for china and the largest use of solar energy in Germany [8].

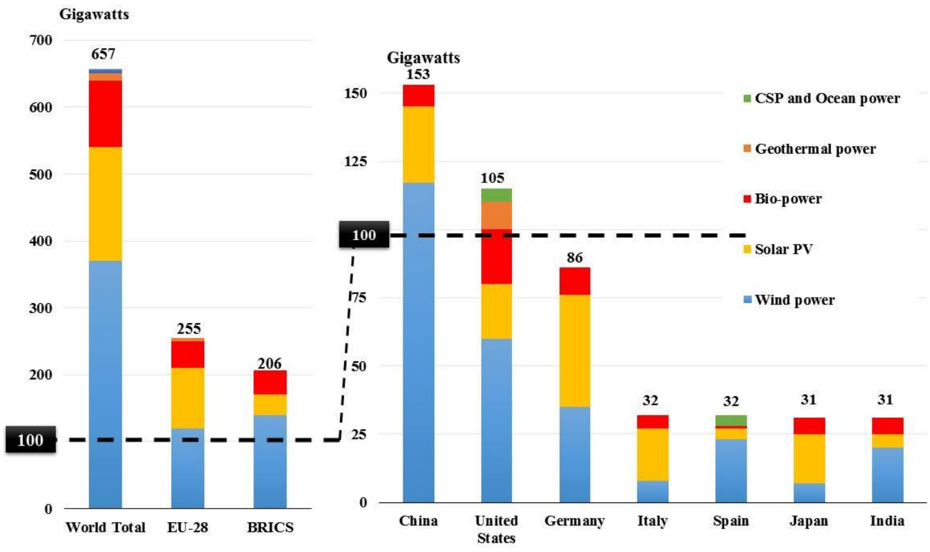

Fig.1. Renewable power capacities in the word, eu-28, brics, and top seven countries

In recent years, the consumption of fossil fuels in Iran and the world has multiplied [9]. In addition, the rising cost of fossil fuels and their damaging environmental impacts, such as pollution, rising ground temperatures, and ozone depletion, have increased the desire to use renewable energies [10][11].

The large oil and gas producers Iran is the world´s 7th largest emitters of CO_2 from Fossil Fuels. The diagrams below show the per capita CO_2 emissions from Fossil Fuels (without bunkers) and cement, annually since 2000. The green bars show the free emission level – the exceedance is the basis for calculating the national Climate Debt. Iran was responsible for 1.9% of global emissions in 2015.

Also Iran has the highest share of 36.15 % of greenhouse gas emissions in the Middle East, and next to Iran are Saudi Arabia and United Arab emirates which are also ranked 24.29% and 14.9%, respectively. The use of energy carriers, with the production of pollutant and greenhouse gases in the conversion process and causing more warming of ground and climates in the destruction of the ozone layer, put the environment seriously in the face of the threat [12] [13]. Figure 2 shows the contribution of different sectors to greenhouse gas emissions [14].

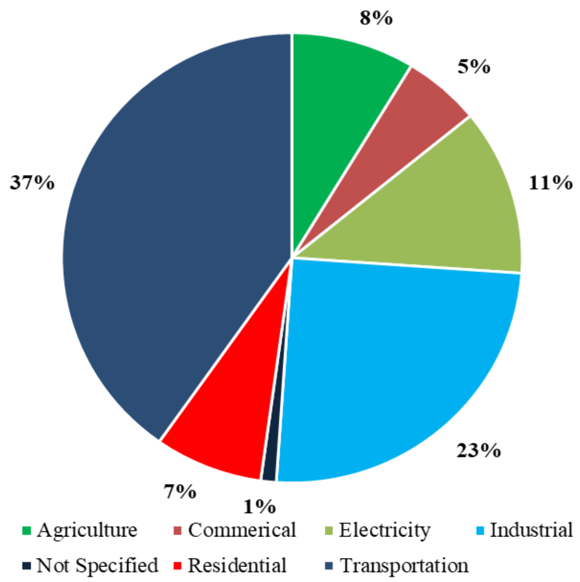

Fig. 2. Green House Gas Emissions by Sector

Today, the challenge of energy policies is to reduce fossil fuel production and environmental costs. Since the expansion of access to energy (heat, light, etc.) is very important in developing countries [15] and various political and other measures have been taken to reduce energy consumption, renewable energy is introduced to solve this problem and high productivity of renewable energy and the transfer of clean technologies are considered in different countries,. Given the fact that in the last century there has been a significant growth of energy consumption in the world, meeting the energy needs of humans has been considered as well as the major role fossil fuels play in supplying this energy [16] [17].

Also Iran has abundant resources in fossil fuels. Proven oil reserves include gas liquids of more than 137 billion barrels, accounting for 11 percent of the world's resources while natural gas resources are more than 26.7 trillion cubic meters or 15% of the world's total resources [18]. Figure 3 shows the production of fossil fuels for Iran [19] .

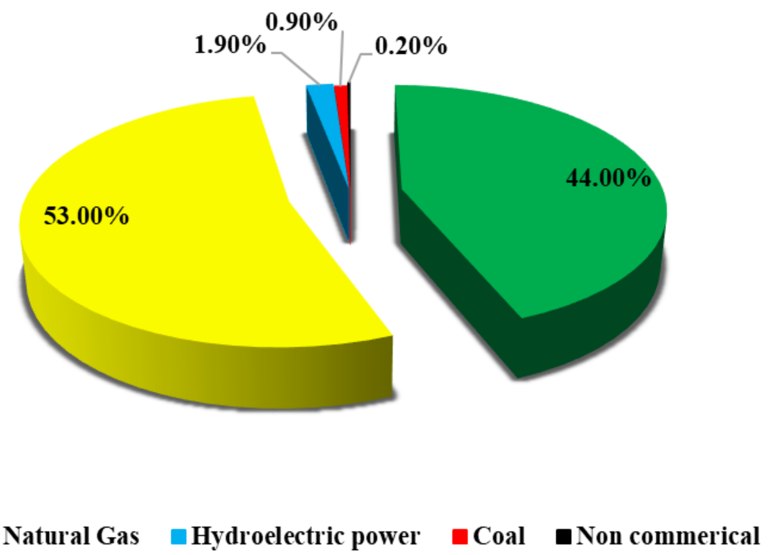

Fig. 3. Production of fossil fuels in Iran

It is a well-known fact that Iran's economy is a mixed economy where the government companies own oil and the other large companies agriculture and investment services. Given the diversity of the Iranian economy, Iran's economy is still heavily dependent on oil exports. At present, oil exports account for 80% of total exports which accounts for nearly 50 percent of the government's budget and is 23 percent of the gross domestic product. With growing demand for energy, increased environmental pollution, and depleting energy sources, human society today faces multiple challenges of transition towards sustainable development and poverty eradication [20] .In 2005, 2713.4 million tons of carbon dioxide emissions from burning of combustible fuels have been released in the world. The 1671.7 million tons equivalent to greenhouse gas (CO_2) emissions in the Middle East region have been released and 1,238.1 million tons of this gas were due to the burning of combustible fuels [21].

the total new global investments in renewable energy increased from $40 billion in 2004 to $244 billion in 2012 [22]. According to the International Energy Agency, utilization of renewable energy will triple between 2008 and 2035. Also, it is anticipated that the share in renewable electricity production in the middle eastern regions, the heart of the world's fossil fuel reserve, will amount to 16% in 2035 [6].

Table 1. Lists of Power Plants with Fossil Fuels in Different Parts of the Country

Power plants with capacity of 1 MW And less		Power plants with a capacity of more than 1 MW		Province name	Rating
Capacity (MW)	Number	Capacity (MW)	Number		
662.2	110	43.1	8	Khorasan razavi	1
-----	-----	16.85	5	Kohkeloye va boyer ahmad	2
317	21	14.46	4	Esfehan	3
-----	-----	102.52	4	Zanjan	4
32.84	5	9.843	6	Tehran	5
100	1	19.61	5	Markazi	6
-----	-----	11.2	3	Kerman	7
66	2	13.975	4	Fars	8
-----	-----	18.66	3	Khuzestan	9
-----	-----	53.78	2	Gilan	10
169	18	-----	-----	Kerman	11
160	4	4	1	Yazd	12
-----	-----	3.96	4	Azarbayjan sharghi	13
155	12	-----	-----	Khorasan jonobi	14
1.2	1	1	1	Mazandaran	15
-----	-----	10	1	Kermanshah	16
-----	-----	6	1	Azarbayjan gharbi	17
-----	-----	10	1	Kordestan	18
-----	-----	5	1	Chaharmah bakhtiyari	19
-----	-----	2.8	1	Hamedan	20
50	7	-----	-----	Ghazvin	21
15	3	-----	-----	Semnan	22
-----	-----	1.6	2	Lorestan	23
-----	-----	0.66	1	Sistan va balochestan	24
2.5	1	-----	-----	Boohsher	25
5	1	-----	-----	Hormozgan	26

Geothermal energy is one of the renewable energy resources witnessing increasing interest. It can supply energy demand in two different forms. It could be used indirectly for geothermal power generation or be utilized directly for heating purposes such as greenhouses, district heating, fish farming and others [23].

82 countries around the world have reported installing direct use of geothermal applications. Some of these countries have a long history in the research and development of direct geothermal energy use. Amongst these countries are: the US, Iceland, and New Zealand. In the case of the US, the direct utilization of geothermal energy includes heating of swimming pools and spas, aquaculture and greenhouses, district heating, industrial applications and ground-source heat pumps. The largest application is ground-source heat pumps accounting for 88% of the annual energy use. In summary, when considering direct-use without geothermal heat pumps, the distribution of annual energy use is as follows: 34% for fish farming, 28% for bathing and swimming, 15% of individual space heating, 9% for greenhouse heating, 9% for district heating, and the rest is for agricultural drying, industrial process heating, cooling, and snow melting. The current installed capacity and annual energy use for district heating is 81.55 MW/th and 839.6 TJ/yr [23] [24].

Iran has a high geothermal energy potential. The country geothermal gradient range varies from 2°C/100m in the Zagros belt to 13°C/100m around the Damavand volcano in the north. Most geothermal energy studies in Iran have focused on electricity production, while, research on the direct use of geothermal energy have received less attention [25] [26].

The result indicated that 8.8% of land area in Iran has geothermal potential with 18 promising high-temperature geothermal fields. These eighteen prospected areas have been recommended for detailed geological, geochemical and geophysical investigations. The most investigated field in Iran is the Sabalan geothermal prospect. Sabalan lies in the Moeil valley on the western slopes of Mt. Sabalan, approximately 16 km southeast of the Meshkin-Shahr city. Eleven wells including 7 productions, 1 reinjection, and 3 monitoring wells have been drilled in Sabalan, which is recognized as a potential for geothermal power generation [27].

II. GEOTHERMAL ENERGY

1. What is Geothermal Energy?

Geothermal energy is one of renewable energy sources. Geothermal is a Greek term and is composed of two words; geo which means earth and thermal which means heating. Geothermal energy is the energy available in the depths of the earth. It is created from solar energy that has been stored inside the earth for thousands of years [7]. Also, the collapse or decay of radioactive uranium, thorium and potassium in earth originated in a long depth mainly in areas prone to earthquakes, volcanic young and tectonic plates of earth focused. The earth's heat is driven from parts of the earth in a variety of ways, including volcanic eruptions - water springs, ocean springs and golfers, due to the reduced density of the earth and the conductivity [28] .Geothermal energy, unlike other renewable energies, is not limited to season, time, and conditions and cannot be exploited without interruption. Also, the cost of electricity in geothermal power plants is compatible with other conventional fossil fuels and it is even cheaper than other types of renewable energy [29]. Figure 4 shows a schematic of a geothermal power plant [30].

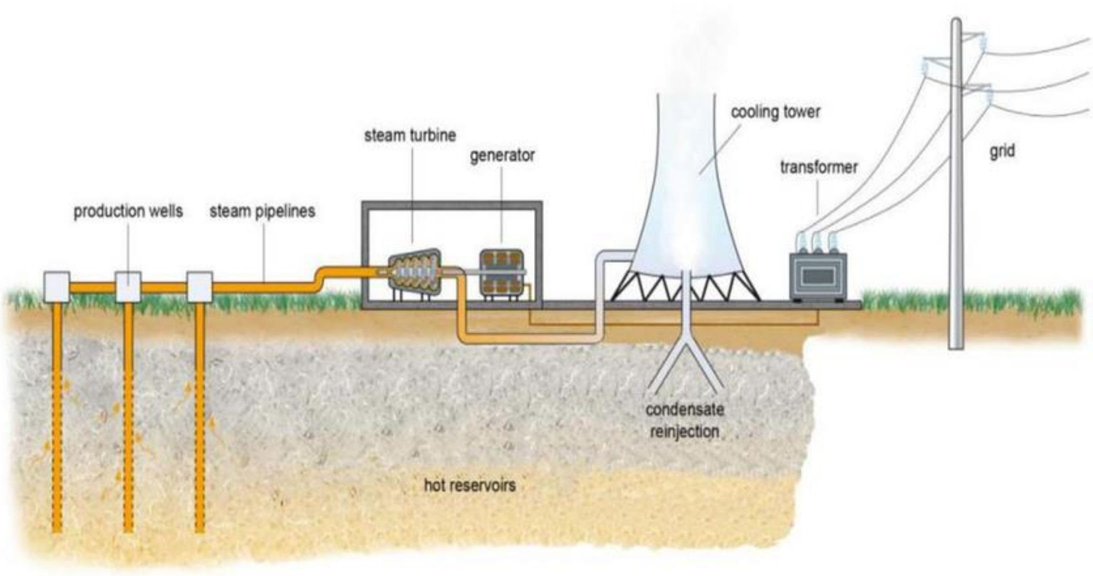

Fig. 4. Schematic of a geothermal power plant

Figure 5 shows the geothermal energy dispersion in the world indicating that the United States, Mexico and North America have more energy production [30].

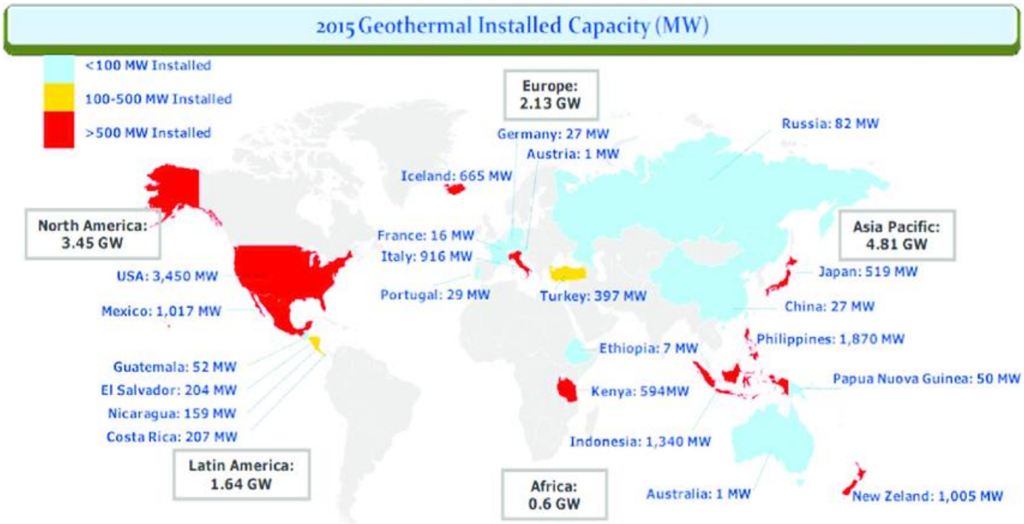

Fig. 5. Worldwide geothermal based electric power generation

2. Environmental Benefits

One of the most important advantages of using geothermal heat pumps is the reduction of environmental degradation effects given that heating systems work with fossil fuels and this kind of fuel is one of the main factors in the production of environmental pollutants. Replacing a variety of new energies instead of fossil fuel systems can significantly reduce greenhouse gas emissions and pollutants [31] [32].

Figure 6 shows the amount of Co_2 production for thermal power plants with fossil fuels and renewable fuels [30]. It can be seen that geothermal power plants have a very low CO_2 production rate compared to that of fossil fuels power plants, and the binary cycle produces very little Co_2 [33] .

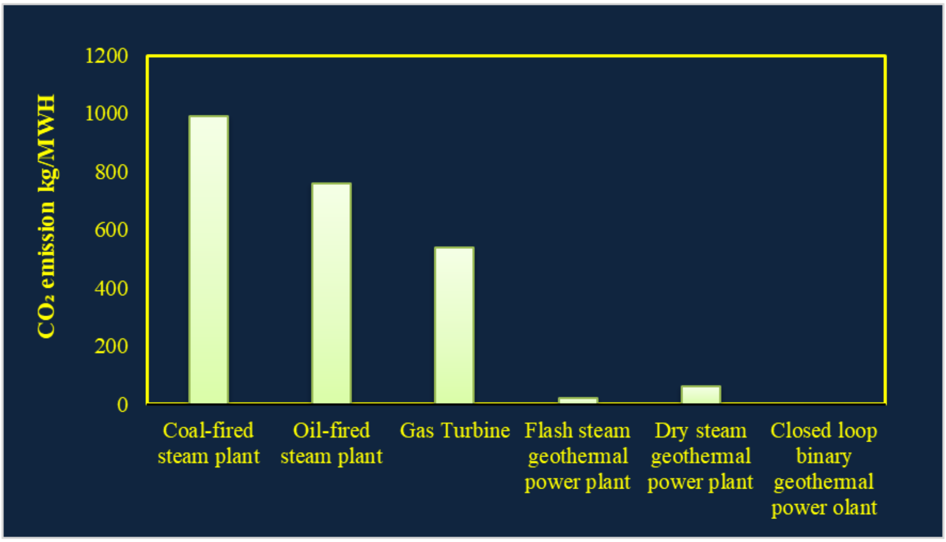

Fig. 6. CO2 emissions from various power plants

Also Figure 7 shows the geothermal energy use in different sectors from 1995 to 2015.

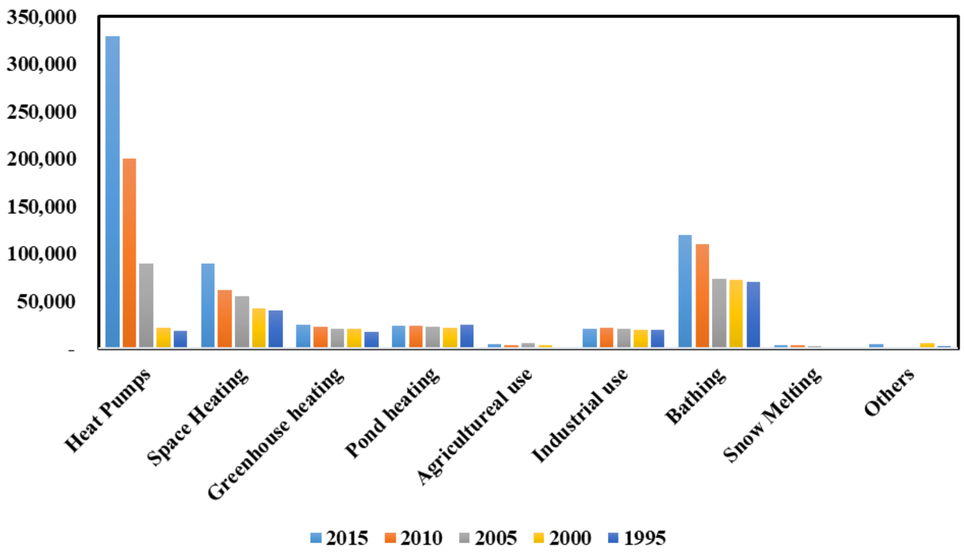

Fig. 7. Amount of geothermal energy used in different sectors from 1995 to 2015

In Figure 8, the amount of electricity generated by geothermal energy in the ten countries has been investigated and it has been proved that United States is the highest in using this energy [34]

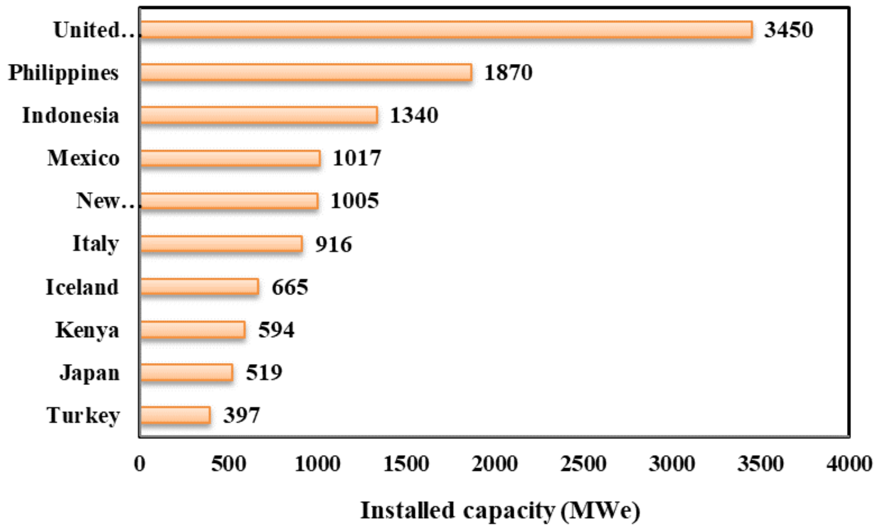

Fig. 8. Geothermal energy capacity in ten countries

3. Geothermal Energy Capacities and History in Iran

In Iran, since 1975, extensive studies have been initiated in order to identify the geothermal energy source potential of the Ministry of Energy in cooperation with ENEL Consulting Engineers in the north and northwest regions of Iran in an area of 260,000 square kilometers. The result of this research revealed that Sabalan, Damavand, Khoy, Mako and Sahand areas, with an area of more than 31,000 square kilometers, are suitable for further studies and geothermal energy utilization. In this regard, the exploration program, including geological, geophysical and geochemical studies, was planned. In the year 1982, with the completion of preliminary exploratory studies in each of the areas mentioned, the areas susceptible are more precisely identified and as a result, in the Sabalan area: Meshkin shahr, Sarein and Busheli areas, in the Damavand area of the district: Neunal, in the Maku- Khoy regions: Black and Dasht and in the Sahand area, five smaller regions were selected to focus on the activities of the exploratory phase. After a relatively long interruption and with the aim of reactivating the plan, existing reports were revisited by UNDP experts in 1991 and the Meshkin Shahr geothermal region was introduced as the first priority for further exploratory studies [35].

Following the mentioned studies, exploration, injection and descriptive drilling projects were defined in order to identify more potential in the Sarein area of Meshkin Shahr in 2002 that drilling operations are the first geothermal wells in the same year began. The first phase of this project was completed in 2004. In total, three exploratory wells and two injection well bars were drilled at this stage and two-loop test of three exploratory wells was successfully carried out, which was the most important achievement of this phase of the project to acquire the know-how in geothermal wells. The second phase of the project began in 2005. In Figure 9, areas with geothermal energy are shown.

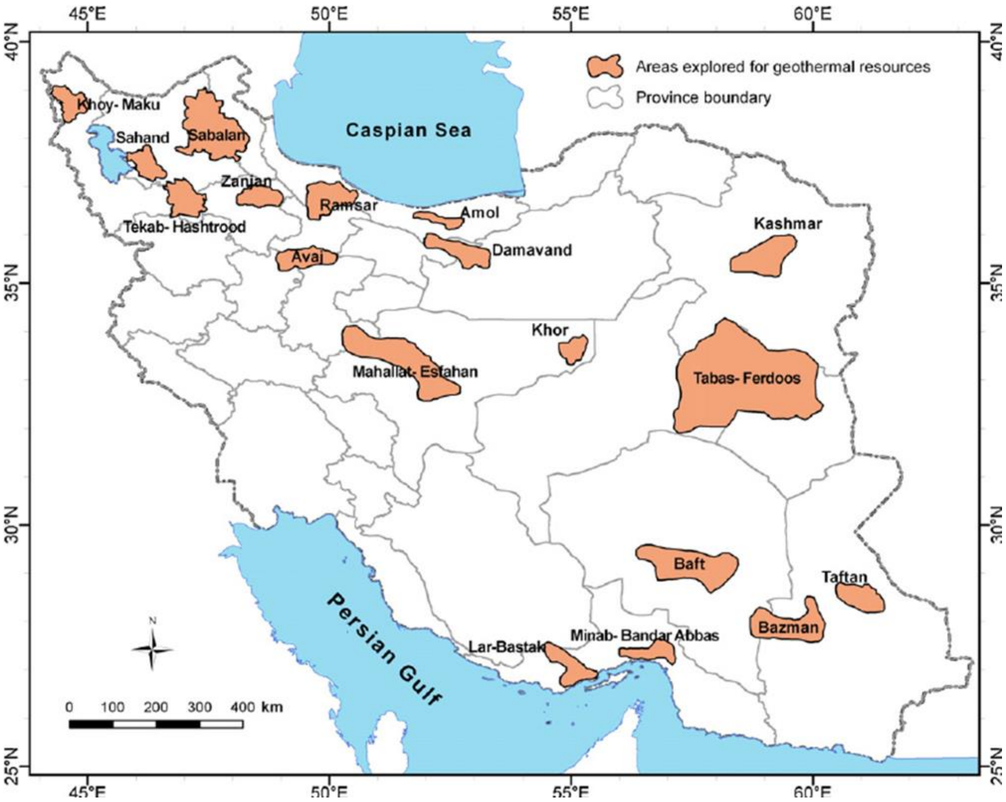

Fig. 9. Geothermal potential areas in Iran

In the project for the development of the geothermal field and the construction of Meshkin Shahr Power Plant, the drilling of wells, the operation of wells during the test period and the manufacture of test equipment in the country have been completely indigenous and were done by local experts.

Also, in the field of using geothermal heat pumps, t so far, the technology of installing earth coils has been completely and 100% native in Iran n. [36] Figure 10 shows the distribution of geothermal energy in Iran, according to the figure, it can be stated that geothermal energy can be used in three parts of the northwest, center of Iran and south of Iran. Of course, in the northwest of Iran due to the presence of volcanoes and in the center of Iran due to the presence of the desert, and in southern Iran, the use of this energy can be very useful due to the Persian Gulf Sea.

Fig. 10. Distribution of geothermal potential in different regions of Iran for review

4. Iran Geothermal Power Plant

A. *Meshkin Shahr - brief history*

The Meshkin Shahr geothermal prospect lies in the Moil valley on the western slopes of Mt. Sabalan, approximately 16 km SE of Meshkin Shahr City. Mt. Sabalan was previously explored for geothermal resources in 1974, with geological, geochemical, and geophysical surveys being undertaken. Renewed interest in the area resulted in further geophysical, geochemical and geological surveys being carried out in 1998. These studies have resulted in the identification of a number of prospects associated with Mt. Sabalan. The present study has been undertaken to find out what information is needed to establish baseline environmental conditions involving surveys of geology and land, weather conditions, noise conditions, ecology and socio-economic conditions [36].

B. *Meshkin Shahr Power Plant*

Meshkin Shahr Power Plant (Ardabil province, near Meshkin Shahr city) is one of Iran's geothermal plants with a production capacity of 55 MW. In this power plant, the water is injected through the pipe and by 250 to 500 degrees Celsius, the water is turned into steam, then the steam comes to the surface and the steam turbine circulates [37]. Based on studies by the Office of the New Energy Organization of Iran, the Meshkin Shahr area is the best point for using the geothermal energy capacity in the country. So that the main purpose of this office is to build and operate a 100 MW nominal power plant in the area. According to studies, Sabalan's domains in Meshkin Shahr have the capacity to build up to 400 megawatts of power plants [38]. According to the studies of the power plant of the Energy Office, the first exploration well of Meshkin Shahr was erected vertically in 2002 with a depth of 3,200 meters and a temperature of 250 degrees Celsius. The second exploratory well was drilled in 2004 to a depth of 3,177 meters with a 140-degree cavity at the end of the well, and then the third exploratory well at a depth of 2,695 meters and a temperature of 211 degrees Celsius was drilled. The 17 wells forecast for this plant, so far, 11 wells have been drilled and three wells have successfully passed the steam outlet test stage [39]. Table 2 shows the characteristics of this power plant.

Table 2. Geothermal Power Station at Meshkin Shahr

Power plant specifications	
Founding date	1377
Type of power plant	geothermal
The number of geothermal wells	17
Deep geothermal wells	More than 2, 000 meters
Condition	active
The owner	New Energy Organization of Iran (SANA)
Maximum power	400 Mw
power	100 Mw

C. *Sabalan geothermal power plant*

Northern slopes of Sabalan hosts many hot springs (seven in the Mouil Valle near Meshkin Shahr, one further west at Yel Sou, and three aligned along majo NE trending structure near Ghotur-Suii). The temperatures of these thermal springs range from 21°C to 82°C. Chemically they fall into different types including neutral, Cl-SO4 and acid SO4. Giggenbach [40] (1992) analyzed the hot springs waters and found relatively low Na-K-Mg temperatures of about 150°C. Mt. Sabalan lies on the South Caspian plate, which underthrusts the Eurasian plate to the north. It is in turn under thrust by Iranian plate, which produces compression in a northwest direction. This is complicated by a dextral rotational movement caused by northward under thrusting of the nearby Arabian plate beneath the Iranian plate. There is no Benioff-Wadati zone to indicate any present day subduction.

Mt. Sabalan is a Quaternary volcanic complex that rises to a height of 4811 m, some 3800 m above the Ahar Chai valley to the north. Volcanism within the Sabalan caldera has formed three major volcanic peaks which rise to elevations of around 4700 m[41] .

Analysis of the single–flash geothermal power plant was conducted using energy and exergy concepts for Sabalan, Iran. Reservoir fluid enthalpy and mass flow rate are 1000 kJ/kg and 500 kg/s respectively. EES software was used to model the plant. Optimization was done to maximize the net power output of the plant. Optimum pressure value for separation is 5.5 bar. With these optimum pressure values the net power output of the plant is calculated to be 36594 KW_e. Pumps and compressor will use 843 KW_e and 3350 KW_e, respectively. Table 2 illustrates important parameters at major stages of power plant at optimal pressure. The overall first and second law efficiencies of the power plant are 7.32% and 32.73%, respectively. The reference conditions for exergy analysis are 15ºC and atmospheric pressure. Figure 11 shows exergy destruction at different stages of the plant. 1.38% of the total exergy destruction is due to transmission from the reservoir to wellhead. 1.09% of the exergy is destroyed at the separation step. 4.91% is lost at the steam expansion unit. 23.35% are destroyed in the condenser. 13.19% and 41.44% are the waste brine from condensing steam and separator, respectively. Finally, the remainder is 32.73%, which is the fraction of the initial exergy that the plant turns to power [42] .

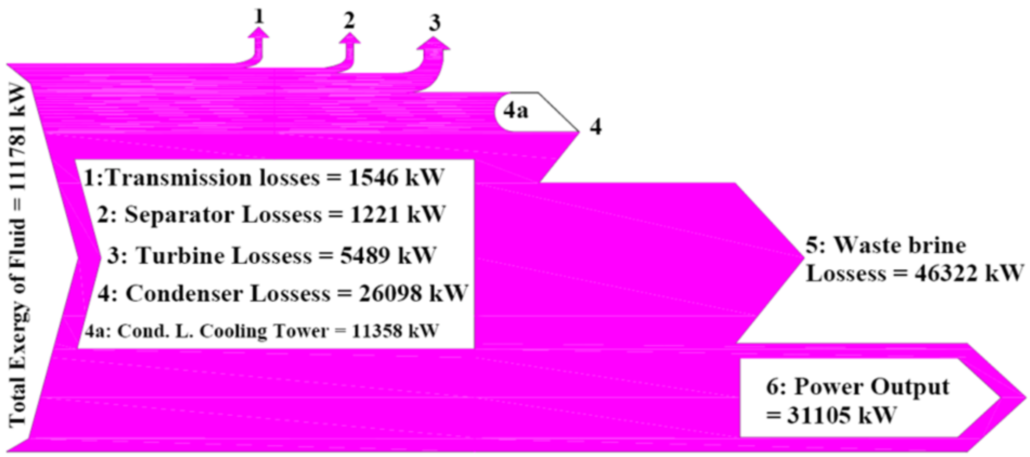

Fig. 11. Grassman presentation of the overall exergy flow

5. Resources and Geothermal Maps in Iran

The position of Iran in the tectonic boundaries shows the enormous power of the country's framework [43]. The continental plate of Saudi Arabia and the Indian Ocean plate have, on the other hand, caused major deformations in Iran and Zagros region Wrinkle is the evidence of the huge surface of these forces. Being placed in a volcanic belt has made Iran's geopolitical area very active and high potential of geothermal energy and the presence of volcanic activity and abundant hot water sources are evidence of this claim. There is eothermal energy potential in the country, according to studies conducted in more than 10 areas that have been identified based on tectonic activity, hot springs, surface emergencies and other geological evidence. According to studies conducted in 1377, these areas are as follows: District of Sabalan, Meshkin Shahr, Sarein and Busheli - Damavand Region, Nandul Area - Maku Region, Black Area of Fountain - Khoy Region, Dorsal Region - Sahand Region - Taftan District, Bessman - Nayband Region - Birjand Area, Ferdos - Takab Region, Hashtrood - Region Khor, Bayabanak - Isfahan District, Localities - Ramsar District - Bandar Abbas Region, Minab - Boushehr District, Kazeroon and Lar Bastak Area.

According to the world classifications, Iran is in the group of countries with potential reserves for the production of heat from geothermal energy using cyclic evaporation and binaries (for a period of 30 years) and the ability to generate electricity from geothermal energy with a capacity of more than 200 megawatts.

Table 3 shows the geothermal energy potential (kJ) in the Iranian provinces, which is the highest value for West Azarbaijan.

Table 3. Geothermal Energy Potentiometric Estimation (KJ) in Iranian Provinces

thermal energy(KJ)	Number of possible geothermal areas	The approximate number of hot springs	province name	R
58×10^{16}	7	15	Azarbayjan sharghi	1
74×10^{16}	10	41	Azarbayjan gharbi	2
44.4×10^{16}	6	50	Ardebil	3
29.6×10^{16}	4	6	Esfehan	4
7.4×10^{16}	1	2	Ilam	5
22.2×10^{16}	3	3	Bosher	6
--------	--------	--------	Tehran	7
7.4×10^{16}	1	1	Chaharmahl va bakhtiyari	8
7.4×10^{16}	1	1	Khorasan jonobi	9
22.2×10^{16}	3	3	Khorasan razavi	10
22.2×10^{16}	3	3	Khorasan shomali	11
--------	--------	--------	Khuzestan	12
22.2×10^{16}	3	3	Zanjan	13
7.4×10^{16}	1	1	Semnan	14
37×10^{16}	5	10	Sistan va balochestan	15
22.2×10^{16}	3	3	Fars	16
29.6×10^{16}	4	4	Ghazvin	17
--------	--------	--------	Ghom	18
--------	--------	--------	Kordestan	19
59.2×10^{16}	8	9	Kerman	20
14.8×10^{16}	2	2	Kermanshah	21
7.4×10^{16}	1	1	Kohkeloye va boyer ahmad	22
7.4×10^{16}	1	1	Golestan	23
14.8×10^{16}	2	2	Gilan	24
14.8×10^{16}	2	2	Lorestan	25
37×10^{16}	5	5	Mazandaran	26
7.4×10^{16}	1	6	Markazi	27
103.6×10^{16}	14	16	Hormozgan	28
--------	--------	--------	Hamedan	29
7.4×10^{16}	1	1	Yazd	30
--------	--------	--------	Alborz	31
1.087×10^{19}	**147**	**191**	**Total**	

III. SUMMARY AND CONCLUSIONS

Iran has more than 200 fossil fuel power plants which produce about 26,000 megawatts of electricity. According to the results, geothermal energy can generate about 100 megawatts of electricity. Also, with the introduction of different regions of Iran and using these energies, electricity production can be increased. Given that fossil fuel consumption in Iran is very high, Pollution in Iran is higher than the global level. However, with the use of geothermal energy, these contaminations can be reduced. Also, surveys on geothermal energy in 18 regions of Iran have suggested the largest areas of Tabas, Mahallat and Sabalan for the use of geothermal energy.

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