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# FEASIBILITY STUDY OF A LOW CARBON HOUSE IN TABRIZ, IRAN

**Abstract**
The reduction of $CO_2$ emissions is essential in the building sector as it contributes highly to carbon emissions. In 2014, approximately 22% of the total $CO_2$ emissions in Iran came from residential buildings, commercial buildings, and public services (1). Therefore, designing and constructing low carbon energy efficient buildings should benefit significantly in the reduction of $CO_2$ emission by targeting a 12% reduction in greenhouse gas emissions by 2030 (2). This report investigates technical and economic aspects of using passive and active solar thermal methods for a low carbon-emitting house in Tabriz city, Iran. The house is designed and developed using reduced embodied carbon materials, which improved the energy efficiency of the building with the use of materials such as natural wood for wall structure, window frames and doors, and natural cellulose for insulation (3). A 3D model of the house developed to demonstrate the real dimensions of the building. The passive cooling using natural air ventilation is considered and tested with the aid of CFD software to determine the final average temperature of the house, which found to be 23.4°C based on an outside temperature of 30°C. The house designed to have 15 photovoltaics panels and three evacuated tube collectors that generated a total 69.1% annual fraction of the self-consumption electricity, and a total 57.7% annual fraction of energy provided by the solar thermal system. The active system saved $CO_2$ emissions by 7,553 kg in a year. The annual heating of the house found to be 19.62 kWh/m$^2$, whereas the total primary energy demand calculated as 47.19 kWh/m$^2$. The Levelised cost of energy (LCOE) for the PV system calculated at 3.43 p/kWh lower than the current rate of electricity. The LCOE of the thermal system found to be 23.42 p/kWh higher than the current rate of domestic natural gas subsidised by the state. The total profit of the entire active system calculated to be £20,479.60 with a payback time of 11 years.

**Keywords:** Sustainable House, Passive Cooling, Solar Power, Tabriz-Iran

## 1. Introduction
With Iran ranking the fourth largest oil reserve and the second largest natural gas supplier in the world, it is not surprising that oil and petroleum products account for the largest fraction of greenhouse gas emissions. Hence, the Iranian government was required to reduce by 12% its greenhouse gas (GHG) emissions by 2030 (2). This reduction in $CO_2$ emissions must be implemented in the building sector as it contributes highly to carbon emissions. A house needs to meet certain criteria to be considered a passive house such as the space heating energy demand (must not exceed 15 kWh/m$^2$of net living space per year), the renewable primary energy demand (must not exceed 60 kWh/m$^2$ of treated floor area per year), thermal comfort (for all living areas all year round with not more than 10 % of the hours in a given year being over 25°C) and airtightness (a maximum of 0.6 air changes per hour at 50 Pascal pressure) (4). These requirements were implemented in this project alongside an active design for the proposed house to meet the energy demand. The main aim of this project is feasibility study to design and develop a low carbon emission building in Tabriz, Iran, by using low embodied energy materials and to see if this house is financially viable to build or not. This project is therefore, separated into three parts as its objectives. The objectives were as follows: 1- To design a house by considering a passive natural cooling system 2- Design and analysis of the active system to meet the maximum energy demands for the house and 3- Financial analysis of the active system.

## 2. Passive design of the house
A 3D model of the house using architectural software was designed and low em-bodied carbon materials were used in order to reduce carbon footprint.

### 2.1 Construction materials
#### 2.1.1 Wall structure
The different varieties of the construction materials used in Iranian buildings such as stones, wood and gypsum are based on the seismological conditions, climate, and local availability. Natural stones like granite, shell rock and marbles are used as load bearing and decoration for external walls. Timbers such as pine are usually used for ceilings and wall framing, especially in seismically active areas. Therefore, a highly insulated wall with low carbon materials is required to work in extreme cli-mates like Tabriz (13). A breakdown of designed wall structure is shown in table- 1. The U-value for this wall is found to be 0.153 W/m2K which meets the passive house design standards.

| **Exterior Side** | | |
|---|---|---|
| Material | Thermal Conductivity(λ) W/m °K | Thickness(l) mm |
| Wall cladding (granite stone) | 1.76 | 30-40 |
| 0.5 inch Gypsum sheathing | 0.65 | 12.7 |
| 4.75 inch cellulose Insulation | 0.038 | 121 |
| 0.5 inch Ply wood | 0.106 | 12.7 |
| 4.75 inch cellulose Insulation | 0.038 | 121 |
| 0.5 inch Gypsum board | 0.65 | 12.7 |
| **Interior Side** | | |
| Total | | 315.1 |

Tab. 1 - Double Stud Wall Structure

#### 2.1.2 Windows
Natural wood such as timber has a high structural quality and is used in building sector worldwide. The amount of operational energy, its low carbon footprint, and the significant environmental benefit of timber over concrete and steel makes timber a sensible choice as a building material in doors, wall structure and window frames in the house (5). The windows are triple glazed, 44 mm with argon filling with U-value of 0.6 W/m$^2$K as supplied the window manufacture (14).

#### 2.1.3 Floor
Concrete's strength, great thermal mass and energy efficiency can provide environmental benefits that offset the energy needed during the manufacturing process. The amount of carbon in concrete can be affected by the different designs and specifications required during the manufacturing process (16). A low energy reinforced concrete slab which is made from low energy concrete, low energy reinforcing steel and other non-structural elements such as floor finish, paints and renderings, has been used in the flooring of the house (15).

### 2,2 Insulation
Plenty of natural and low embodied energy insulation materials are available on the market- such as cellulose, wood fiber, wool, hemp, hempcrete, straw and cane. Their performance and other properties such as ease of insulation, shrinkage and compaction, protection against moisture, affordability and availability are very important when choosing the right low embodied energy insulation material. Cellulose insulation is made from recycled shredded newspapers. It is resistant to mould, insects, vermin and fire. Thermal conductivity of cellulose in walls is 0.038- 0.040 W/mK with an embodied energy of 0.45 MJ/kg

and a thermal resistance of 2.6 $Km^2/W$ at 100 mm thickness. Cellulose, therefore, is an ideal insulation material in walls (6).

### 2.3 The house Orientation

A building's correct orientation is important in order to increase its energy efficiency and reduce its negative impacts on the environment. The orientation of the house, from south to east, means it receives the maximum amount of solar radiation which increases the energy efficiency of the building (7). Also, based on the sun's movement, in the northern hemisphere, large triple glazed windows are placed on the south side of the building to face the sun and receive the maximum solar radiation in order to light and heat the building during the winter, as shown in the figure 1(8).

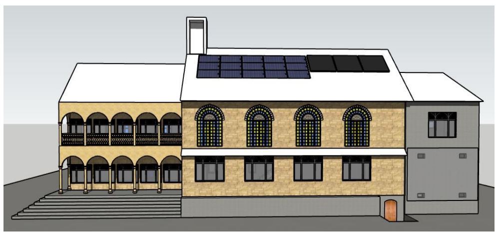

Fig. 1 - The South-side of the Proposed House

The main heat gain will be solar gain through windows. Designed shading and surrounding landscapes in the south side of the house, double roofs with space between for air circulation, can help to reduce the cooling load of the building (10).

### 2.4 Passive Cooling Design Using Pool-House and Solar Chimney

Space cooling has become a very important consideration for a building in an excessively warm climate such as Iran's. pool-houses have been used in traditional Iranian buildings, which are located in the basements of two story buildings, in order to employ the cooling property of the soil. The central pond of the pool-house and the entering air flow from the northern side are used to create more effective cooling by promoting evaporation of the water which then transfers cooled air into the rooms above, the same as a passive cooling system, as shown in the figure 3 (9).
A solar chimney, as seen in the figure 4, is a simple way to improve natural ventila-tion in buildings by encouraging the convection of air upwards. The glass on a solar chimney- as a solar absorber- allows the heat to be transferred into the air in the chamber of the solar chimney, by convection. The heated air expands and rises. The created upward airflow sucks the air into the inlet located on the north side of the house, after which the warm air then flows into the ground. The ground acts as a heat sink so that warm air dissipates the heat and the cooled air flows into the house. Due to the airtightness of the house, the airflow is increased by the forced convection of air into the solar chimney (11).

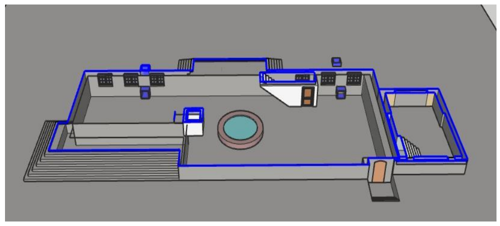

Fig. 3 - The Pool House in the Basement of the proposed house

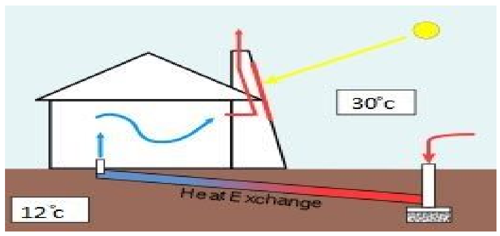


Fig. 4 - A Solar chimney (12)

### 2.5 CFD Simulation for the Designed Passive Cooling System

CFD simulation used to visualise the airflow in the designed cooling system in order to determine the average air temperature throughout the house. Simulation was set during summer days in Tabriz with the inlet mass flow rate of air being 0.472 kg/s. Simulations for three different scenario of airflow were tested. The final design was a top-down cooling strategy - 'house with cooling+ upstairs vents+ top down cooling'- that takes the cool air directly from the basement to the first floor, as shown in the figure 5.a.

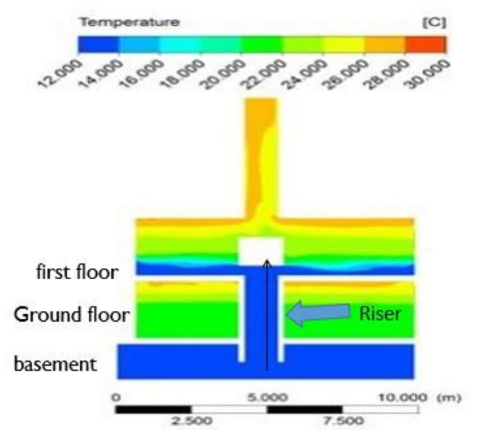


Fig. 5.a - A Top-down Cooling Design by CFD Simulation

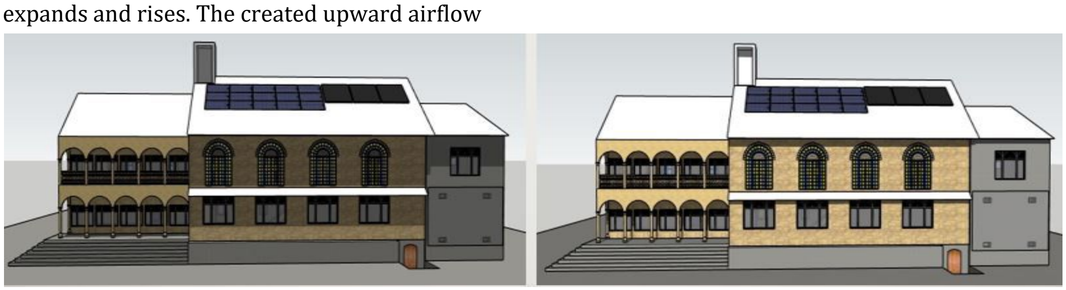

Fig. 2 – The south –side of the proposed house in the midday of 15th Aug (with windows shading) and 15th of Jan (sun covers all over windows)

The cool air will then spread throughout the first floor and descend to the ground floor, as seen in figure 5.b. This approach equalised the temperatures across the house resulting in a uniform cooling.

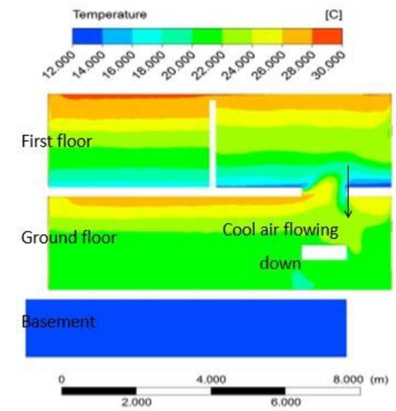


Fig. 5.b - A Top-down Cooling Design by CFD Simulation

The final average indoor air temperature found to be 23.4°C where the outside temperature was set at 30°C, as seen in the figure 6.

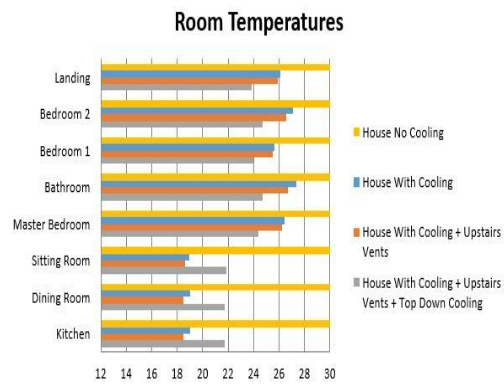


Fig. 6 - Room temperatures Results by CFD Simulation

### 4. The Active Design of the House

The active system was designed based on the size of the house, the electrical en-ergy demands and the heating and hot water demands of the family. The house was designed to have 15 solar PV panels with the total nominal power of 4,050 W and three evacuated tube collectors. A heat pump with a heat recovery ventilation was also considered to provide additional heat and ensure a high indoor air quality.
Polysun software was used to analysis the annual operation of this active system.

### 4.1 The Results by Polysun Software

The total annual electricity production was found to be 6,524.8kWh with 69.1% self-consumption fraction, as seen in the figure 7 and 8. The total annual solar fraction of thermal energy was 57.7% with 9,069.9 kWh field yield, as shown in the figure 9.
An annual space heating of 19.62$kWh/m^2$ was calculated which is slightly higher than the standard requirement for space heating energy demand. Total annual domestic energy demand was found to be 47.19 $kWh/m^2$, this is much lower than the minimum standard requirement of the renewable primary energy demand.

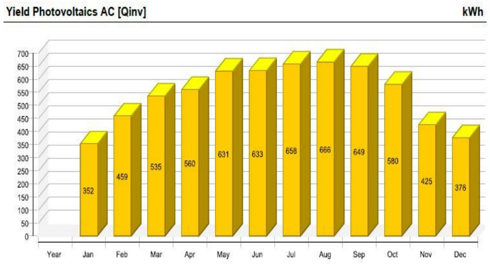

Fig. 7 - The System Photovoltaic Yield

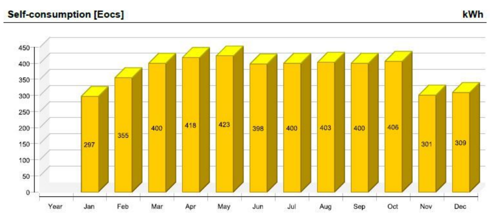

Fig. 8 - Total Self- Consumption Electricity

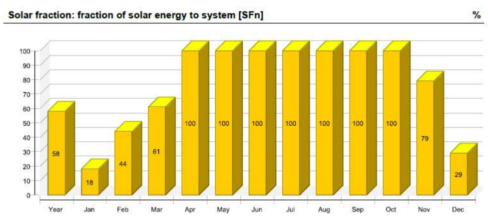

Fig. 9 - The Solar Thermal Energy to the System

An annual space heating of 19.62kWh/m$^2$ was calculated which is slightly higher than the standard requirement for space heating energy demand. Total annual domestic energy demand was found to be 47.19 kWh/m$^2$, this is much lower than the minimum standard requirement of the renewable primary energy demand.

**5. Financial Analysis**
In order to determine the feasibility of the proposed active system, it is essential to analysis the system by focusing on the income statement, balance sheet, and cash flow statement.

**5.1. Subsidies**
**5.1.1. PV System**
There is only a Feed-in-Tariff (FIT) for exported electricity into the grid which is 8,000 IRRS/kWh, equal to £0.15/kWh, by Iran's Ministry of Energy (18). The total ex-port FIT in year1 was calculated as £302.40 which is reduced in the consecutive years due to 68% degradation of the solar panels. The Power Purchase Agreement (PPA) contract is also guaranteed over a 20-year term by Iran's Ministry of Energy, therefore the exported electricity will have no more benefit by the beginning of year 21 (18).

**5.1.2. Thermal System**
There are no financial incentives with regards to the amount of energy generated by a solar thermal system and heat pump.

**5.2. Payback Payment**
**5.2.1. PV System**
The National Development Fund of Iran loans 75% of the CAPEX with a maximum 5 years return and an 8% interest rate. The annual inflation rate is about 12% (17). The Payback period for the PV system, with £1,697.85 CAPEX was calculated as shown in the table 2.

| Loan/£ | Fixed Pay-ment/£ | Variable Payment/£ | Payback Payment /£ |
|---|---|---|---|
| 1,273.39 | 254.68 | 101.87 | **356.55** |
| 1,018.71 | 254.68 | 81.50 | **336.18** |
| 764.03 | 254.68 | 61.12 | **315.80** |
| 509.35 | 254.68 | 40.75 | **295.43** |
| 254.67 | 254.68 | 20.37 | **275.05** |

Tab. 2 - Payback Payment for the PV System

**5.2.2. Thermal System**
The Payback period for the thermal system, with £14,070 CAPEX was calculated and shown in the table 3.

| Loan/£ | Fixed Pay-ment/£ | Variable Pay-ment/£ | Payback Payment /£ |
|---|---|---|---|
| 10,552.50 | 2110.50 | 844.20 | **2,954.70** |
| 8,442.00 | 2110.50 | 675.36 | **2,785.86** |
| 6,331.50 | 2110.50 | 506.52 | **2,617.02** |
| 4,221.00 | 2110.50 | 337.68 | **2,448.18** |
| 2,110.50 | 2110.50 | 168.84 | **2,279.34** |

Tab. 3 - Payback Payment for the Solar Thermal System

**5.3. Profit**
**5.3.1. PV System**
The total profit of the PV system at the end of year 25 was found to be £7,634.95. The PV system could be paid back in the 4th year by looking at its revenues and costs.

**5.3.2. Thermal System**
Total profit of the thermal system at the end of year 25 was calculated as £12,844.65. The capital cost of a thermal sys-tem is very high, and there is no Renewable Heat Incentive (RHI) for solar thermal systems in Iran, so the thermal system cannot breakeven in early years. However, the proposed thermal system is subsidising PV system that on its own does not make good profit.

**5.3.3. The Entire Active System**
The total profit of the active system at the end of year 25 was calculated as £20,479 that can be paid back by the end of year 11.

**5.4. Levelised Cost** of **Energy (LCOE)**
The average total expense of building and running a power generating system over its life time, divided by the total energy output of the system over that lifetime, is called the Levelised Cost of the Energy (LCOE) of the system (19).

$$LEC = \frac{I + \sum_{n=0}^{N} \frac{AO}{(1+d)^n}}{\sum_{n=1}^{N} \frac{Qn}{(1+d)^n}}$$

where:

LEC= Levelised Energy Cost, I= Capital investment, AO= Annual operations & maintenance cost in the year n, d= Discount rate, Qn= Energy generation in the year n, n= Life of the system

**5.4.1. PV System**
The LCOE of the PV system was found to be 3.43 p/kWh that is lower than the current electricity cost of 4 p/kWh. Therefore, the PV system is economically feasible. Its cost can be paid back in the 4$^{th}$ year.

**5.4.2. Thermal System**
The LCOE of the thermal system was found to be 23.42 p/kWh which is higher than the current cost of domestic natural gas. Generally, the price of energy is very low in Iran. However, the price of energy is rising dramatically due to increased population demand, a weak economy and other contributing political issues. The new cost of energy will, therefore, be levelized with the cost of thermal energy in the coming years.

**6. Conclusion**
The proposed house was designed using low embodied energy materials in order to reduce $CO_2$ emissions. The active system was able to achieve a 57.7% solar fraction from the thermal system and a 69.1% electricity self-consumption fraction from the PV system. The total annual $CO_2$ saving from the active system was found to be 7,553 kg making a good contribution towards GHG reduction. Due to the energy output of the active system and the use of insulation, the total energy used for the domestic appliances was found to be 47.19kWh/m$^2$that is lower than the standard requirement of 60kWh/m$^2$. An annual space heating demand of 19.62kWh/m$^2$ was calculated that is somewhat higher than the minimum requirement of 15kWh/m$^2$but is much lower than heating demands of a new builds. As a result of the passive cooling design of the house, a final average indoor air temperature of 23.4°C was achieved based on a reference outside temperature of 30°C. The LCOE of the PV system was found to be 3.43 p/kWh which is lower than the current cost of electricity. It is therefore economically feasible. The LCOE of the thermal system was calculated at 23.42 p/kWh which is higher than the current subsidised cost of domestic natural gas. However, cost of energy is dramatically going up in Iran due to increasing energy demands, a weak economy and other political issues making solar thermal LCOE more feasible in the coming years given the environmental and public health benefits. It is important to bear in mind that the proposed thermal system is subsidising the PV system as this alone does not make a good enough profit. Also, this thermal system is improving the air quality by reducing 1,806 kg of $CO_2$ emissions. The active system had a total capital cost of £15,767.85 and after all the financial calculations, the total profit was found to be £20,479. The active system capital cost is paid back in the 11$^{th}$ year.

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