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A Multi-Scenario Zero-Energy Building Techno-Economic Case Study Analysis for a Renovation of a Residential Building

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ABSTRACT

According to the previous pieces of research, the building sector consumes about 40 % of total yield energy and produce one-third of GHG pollution emission. This point shows the significant potential in two aspects of energy optimization and pollution reduction in this field. The purpose of this research as a case study is to construct a residential building and develop the paths for reaching a zero-energy building, considering GHG emissions in the climate of Tehran, Iran. In thirty scenarios of this study, solar panels, solar water heaters, ground source heat pumps, and combined heat and power generators were selected to provide the required power and energy in the building. All three passive, single active, and hybrid active scenarios were defined and analyzed with respect to technical and economic factors. In all of the defined scenarios, the conditions are two-folded: (a) considering the effect of national profits, fuel saving, and pollution reduction and (b) without considering them so that the results would become more realistic. In the end, three different types of conclusions were made with respect to macro-engineering, energy, and economic perspectives. Statistical conclusions based on a questionnaire filled by 50 people and the perspective of achieving NZEB definition are presented.

1. INTRODUCTION

Due to an increase in energy prices in the world during 1970 to 1980 in most parts of the world, engineers felt the need to find a way for reducing energy consumption at homes and optimizing energy usage; however, at that time, building houses with zero-energy consumption was just in the theoretical realm of studies [1, 2]. With the emergence of energy and pollution crises, zero-energy buildings started to receive more attraction from the governments; for instance in the United States, a law was passed in 2007 in support of the construction of buildings with zero-energy consumption and assigned a specified time limit for transforming half of the commercial buildings by 2040 to ZEB in the first step and, then, transforming all commercial buildings by 2050 in the United States [3, 4]. Likewise, in Europe in 2010, it was decided to apply a zero-energy approach to buildings with public utilities and the ones belonging to the authorities from 2018 and, then, from 2020 onwards to all new buildings [3, 5, 6].

Some researchers have investigated the effect of climate conditions on the use of zero-energy buildings in Saudi Arabia. The study notes that the household sector consumes 52 % of the total network power [7, 8]. In Iran, in 1991, the approval of Chapter 19 by the cabinet was a significant step towards energy-saving in buildings, and its implementation became mandatory for public buildings from 2005. According to published statistics, Iran ranked 11th among the highest consumption countries regarding energy consumption, whereas the countries whose ranks are higher than Iran are considered as developed countries. On the other hand, Iran's share of solar radiation is higher than many other countries' share. However, despite the proper conditions for producing clean energy from renewable energy sources, Iran's share regarding energy production from these sources in the year 2014 was only 6.6 % of the world's share.

For a better understanding of energy crisis in Iran, in 2017, there were about 200 hours of energy shortage accounting for approximately 3000 MW. This amount of energy can be produced by a power plant 1.5 times larger than Shahid Rajaie power plant. Moreover, according to world statistics in 2014, Iran ranks 8th in terms of carbon dioxide production in the world [9]. Given these statistics, the efforts to optimizing and reducing fossil fuel consumption, building energy-efficient buildings, using devices with high-energy consumption and renewable energy sources for energy production seem essential. Residential buildings are a crucial component of energy consumption, and about 30-40 % of energy is consumed in developed countries.

Besides the alarming significance of the energy crisis, emission reduction in reaction to global warming is an important issue, and the buildings are major contributors to this propensity, accounting for more than 36 % of EU's greenhouse gas emissions. Therefore, there is an excellent potential for reducing emission in the construction sector [10, 11].

In Iran, the share of residential buildings in energy consumption is about 40 % of total energy production. Today, fossil sources are rapidly eroding away, opening the door for the "energy crisis". Further to this, the effects of the excessive use of fossil fuels and greenhouse gas emissions, especially CO_2, have damaged the ozone layer. In Iran, residential buildings account for 25 % of total greenhouse gas emissions. This share of energy consumption is equivalent to consuming 432.4 million barrels of crude oil and 85 % of the energy generated from natural gas and electricity. Therefore, it is

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necessary to optimize the design conditions of buildings in terms of energy efficiency [9].

Different definitions and concepts have been proposed for zero-energy buildings. For example, the definition proposed by Torsely et al. under the theory proposed by the US Department of Energy states that “a zero-energy building is a commercial or residential building whose consumption of energy is minimized by optimizing energy supply devices and the required energy can be produced by renewable energy sources. Throughout the studies, it was found that the realization of the real meaning of zero energy is not possible in many cases; thus, a new concept as zero-energy buildings was defined [12]. The approach to reducing energy consumption in buildings is the subject of review in buildings with net energy consumption of zero. In this discussion, high-energy buildings are investigated, whose basis is the idea that, during one year, the building has an energy balance of zero and its net energy consumption is zero. Hence, even if, in some cases, the amount of energy required by residents is received from the network, the amount of energy generated through energy sources should be such that the level of production and consumption is approximately equal due to sending and receiving energy [13, 14]. In this regard, an effort is made to use appropriate methods to optimize and reduce the consumption of buildings by considering the previous methods first. Efforts made are in fact aiming to achieve zero heating in the form of solar buildings. One of the first examples of these buildings is MIT Solar House, built in 1939. The energy supply system in this building has a large solar collector and a large tank for storing heat energy. Bliss Home, built in 1955, has solar collectors and rock storage. Some examples from the 1970s include the Gorsgard home in Denmark and the Saskatchewan's home. These buildings have been designed and constructed based on proper insulation to reach the goal of building zero-energy buildings. Design methods and the principles used to build Saskatchewan home today are the design and construction of passive houses or buildings with zero-energy consumption. These early examples have helped the design and enhancement of the standards for this type of building. The standards for building houses with optimal energy consumption include the use of optimal insulation of building components, proper seaming of all surfaces, and the heat recovery systems of ventilated air in the building [15-17].

Bahadorinjad et al. dealt with designing a zero-energy building in Tehran by considering all essential principles in designing an optimal building, such as heater and greenhouse, to provide natural heating and wind catchers to ensure the required cooling of the building and photovoltaic panels to supply the required electricity in the building [18].In the building studied in this project, solar energy was considered as the primary source of energy for warming up water, electricity, and natural heating of the building.

In this paper, a case study is conducted to reconstruct a residential building and turn it into a zero-energy building concerning GHG emission in the climate of Iran and the climatic conditions of Tehran. The building is first analyzed in energy consumption and, then, the optimization strategies and their impact are examined. The next step examines the different scenarios of each source of energy in the respective systems, including PV, Geothermal, SWH, and CHP. Finally, three conclusions will be made based on the macro and general perspectives using AHP and the standard of the system's compliance with the zero-energy concept.

2. MATERIAL AND METHODS

The first step in obtaining necessary information on the fuel consumption and energy of the building is to review and collect information on electricity and gas bills for the past three years. In the second step, the amount of energy needed and the effect of optimization with insulation were calculated to carry out energy analysis on the difference between mediocre and good insulation materials. Furthermore, different scenarios were examined in terms of energy production, initial capital, and so on in different conditions; finally, conclusions are drawn based on the obtained results.

2.1. Analysis of climatic conditions

The building has a longitude of 51.38 degrees and a latitude of 35.78; it is a two-story (duplex) house with a total area of 500 square meters. Moreover, its height from the sea level is 1580 meters. The internal temperature of all spaces, such as rooms, living room, and kitchen, is 21.6 degrees Celsius, according to human comfort conditions. The analysis and study of the climatic conditions of the area considered is the most critical step in designing an optimal building for energy consumption. In the first step, the weather conditions in Tehran were examined according to the weather information extracted from the results of local weather stations.

2.2. Energy analysis of the building

Data from electric bills of the last three years were collected and analyzed, producing a monthly usage average shown below.

Because the number of inhabitants in this case study is less than usual, an adjustment factor for energy consumption is considerd. Based on the extrapolating energy demands, the monthly energy usage of the building is equal to 253 kWh (with an adjustment factor of 2); after converting it to Kw, it will be 0.34 kW and is 85 W for each square meter. It is mentioned that the average yearly energy usage of the building is equal to 3036 kWh (Table 1 and Figure 1).

Table 1. Electric bills average usage.

Average monthly consumption	Consumption at a mid-price	Consumption at a high price	Consumption at a low price
126.9kW	161.2kW	38.7kW	54.5kW

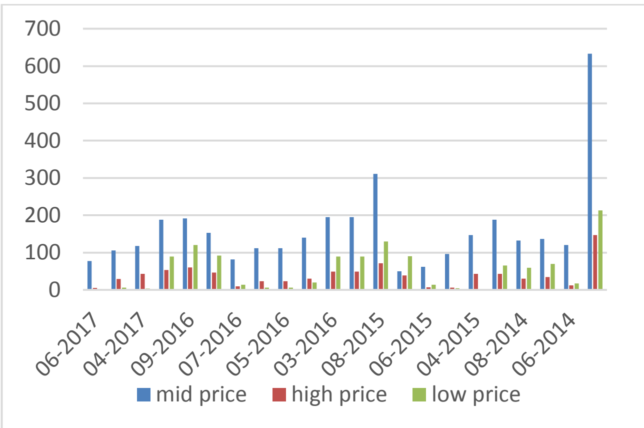

Figure 1. Monthly consumption-kW/date.

In the next step, data of gas bills of the last three years were collected and analyzed, leading to a monthly usage average as found in Table 2 and Figure 2.

Table 2. Gas monthly usage average.

Total consumption	days	Daily average consumption
21817 m^3	1085	20.1
Gas cost per year		
Space heating	DHW	
190$	140$	

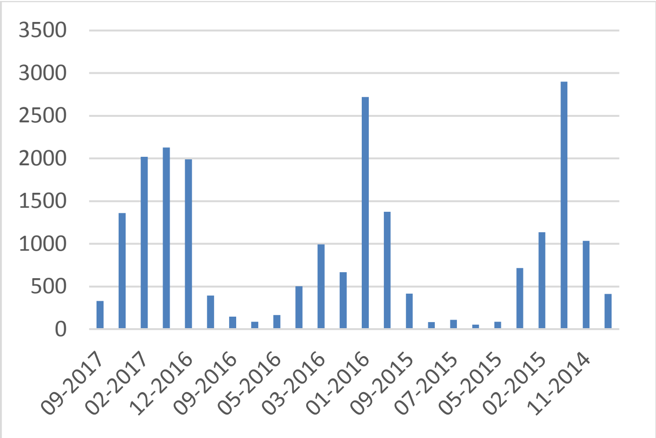

Figure 2. Gas consumption - m^3/date.

From the result above, the daily gas usage is equal to 20 m^3, and the cost of monthly gas usage is approximately 25$.

Table 3. DHW demand.

No.	Facility	Total gpm	Quantity
1	Washstand	5*2=10	5
2	Bathtub	1*20=20	1
3	Shower	3*30=90	3
4	Kitchen sink	2*10=20	2
5	Dishwasher	1*15=15	1
6	Washing machine	2*15=30	2
Total		185	
Total with a demand factor		185*0.3=55 gpm	
Total DHW needed		55*1.25=68.75 gallon	

From Table 3, details, and assuming two hours for max daily usage, the total amount of DHW is equal to 500 liters [19, 20].

2.3. Photovoltaic panels

2.3.1. Power per unit area (W/m²)

The average of power per unit area in daily consumption (*Ps*) in W/m^2 can be obtained through Equation (1) by dividing Pmpp with the PV panel occupied area, in which the maximum power point (*Pmpp*) for the specific location was extracted as reported by weather information that was imparted in the previous section. This data can be found in the manufacturer's data sheet [21, 22].

$$P_s = \frac{P_{mpp(location)}}{Area_{PV}} \quad (1)$$

2.3.2. Real energy conversion efficiency

With the usage of the daily average of power generated (P_s), the efficiency of PV panel real energy conversion (η_{REAL}) is computed. In Equation 8, standard irradiation (E_{STC}) obtained from the local solar climate database such as SATBA[2] or energy affairs [9]. The real energy conversion efficiency (η_{REAL}) is described in Equation "9" and differs from the standard conversion efficiency (η_{STC}).

$$\eta_{real} = \frac{P_s}{E_{STC}} \quad (2)$$

$$\eta_{STC} = \frac{P_{mpp(STC)/PVarea}}{E_{STC}} \quad (3)$$

2.3.3. Potential generation of electrical energy

By multiplying P_s by the daily average of hours with sunlight (insolation), the possible generation of electrical energy can be achieved. The Hr_{day} can be drawn out from the climate database. The potential energy is computed by the following equation [21]:

$$\eta_{real} = \frac{P_s}{E_{STC}} \quad (4)$$

2.4. Solar water heater

2.4.1. Storage volume

The storage for solar water heating (V_{st}) is calculated through Equation "5", in which B is the total population, O is the occupation, DHW is the hot water demand per person on medium demand, HWD is the hot water demand of kitchen, and the '1.2' is the coefficient of hot water demand of kitchen.

$$V_{st} = [(B \times O \times DHW) + HWD_k] \times 1.2 \quad (5)$$

2.4.2. Energy demand

The energy demand is computed by the following equation, in which Q_s is the total heat capacity of the storage tank (kWh), m is the volume of the storage tank (m^3), C_p is the heat capacity of water (1.16 kWh/m³K), and ΔT is the temperature difference between hot water temperature and cold water temperature (K).

$$Q_s = m \times C_p \times \Delta T \quad (6)$$

2.4.3. Solar radiation

Solar radiation (S_R) is defined as the average monthly and yearly values of global solar radiation on a horizontal surface in kWh/m² extracted from climate database for a specific location.

2.4.4. Collector yield and collector array

For Collector Yield (C_Y), η_k is the efficiency of the collector, and η_{sys} is the efficiency of the system that can be achieved by manufacturer data sheet [23, 24].

$$C_y = S_R \times \eta_k \times \eta_{sys} \quad (7)$$

$$C_A = \frac{Q_s}{C_Y} \quad (8)$$

2.5. Ground source heat pump

GSHP has been computed by the following equation [25]:

2 Renewable Energy and Energy Efficiency Organization of Iran

$$T_{geo\ out} = T_{ground} - \left(T_{ground} - T_{geo\ in}\right)\exp\left(-\frac{(UA)_{geo}}{\dot{m}_{geo}C_{p\ geo}}\right) \quad (9)$$

2.6. Economic knowledge

2.6.1. Cost estimates

The investment return rate is based on a simple payback method and the overall LCC in this analysis is expressed as the sum of Life Cycle Cost, Capital costs, profitability, maintenance, Greenhouse gas emissions, and national profit, which can be shown in Equation 10.

$$LCC = CAPEX + OPEX + ENVEX \quad (10)$$

2.6.2. Net present value (NPV)

The NPV of future cash flows can be found from Equation 11 [26].

$$NPV = \sum_{i=0}^{n} c_i (1+r)^{-i} \quad (11)$$

2.7. AHP

2.7.1. Statistical knowledge

The Analytic Hierarchy Process can be defined as a general theory of measurement. The purpose is to derive ratio scales from both discrete and continuous paired comparisons. These comparisons may be taken from actual measurements or from a significant scale, reflecting the relative strength of preferences and feelings". It has an appropriate application in the field of group decision-making and is used in various decision situations.

To analyze the decision of choosing the best system by the analytic hierarchy process, the following steps must be taken:

1. Develop the ratings for each decision alternative.
2. Establish the weights for the criteria by.
   a. creating a pairwise comparison matrix for each criterion.
   b. normalizing the resulting matrix.
   c. averaging the values in each row in order to get the corresponding rating.
   d. calculating and checking the consistency ratio.
3. Compute the weighted average rating for each decision alternative and, then, choose the one with the highest score.

The method uses the following structure: problem modeling, weights valuation, weights aggregation, and sensitivity analysis. The judgment is a relative value or a quotient a/b of two quantities "a" and "b" having the same units. The results of paired comparisons for n attributes are organized into positive reciprocal n x n matrix as follows:

$$S_{ij} = \begin{bmatrix} 1 & S_{12} & \cdots & S_{1n} \\ \frac{1}{S_{12}} & 1 & \cdots & S_{2n} \\ \vdots & \cdots & \ddots & \vdots \\ \frac{1}{S_{1n}} & \frac{1}{S_{2n}} & \cdots & 1 \end{bmatrix}$$

Figure 3. positive reciprocal n x n matrix S.

2.7.2. Weighting by pair-wise comparison

A method for weighting and comparing several criteria to achieve our goals is used; in other words, the importance of criteria is compared pairwise with respect to the desired goal to derive their weights as shown in Table 4.

Table 4. AHP index values.

Definition	Index	Definition	Index
Equally important	1	Equally important	1/1
Equally or slightly more important	2	Equally or slightly less important	1/2
Slightly more important	3	Slightly less important	1/3
Slightly too much more important	4	Slightly too way less important	1/4
Much more important	5	Way less important	1/5
Much too far more important	6	Way too far less important	1/6
Far more important	7	Far less important	1/7
Far more important to extremely more important	8	Far less important to extremely less important	1/8
Extremely more important	9	Extremely less important	1/9

Index values are in the range of 1 to 9. For example, if criterion A is essential as criterion B, this pair receives an index of 1. If A is much more important than B, the index is 9. All gradations are possible in between. For a "less important" relationship, the fractions 1/1 to 1/9 can be used.

The evaluation requires a certain level of matrix consistency that can be assessed by consistency index CI as follows: firstly, λ_{max} (the highest eigenvalue of the matrix) has to be calculated as follows:

$$\lambda_{max} = \sum_{j=1}^{m} \frac{(S.V)_j}{m.V_j} \quad (12)$$

where *m* represents the number of independent rows of the matrix, S represents the pair-wise comparison matrix, and *v* means the matrix eigenvector. Then, the consistency index *(CI)* can be calculated by Equation 13 [27]:

$$CI = \frac{\lambda_{max} - m}{m - 1} \quad (13)$$

2.8. GHG emission

2.8.1. Electricity reductions (kilowatt-hours)

The GHG emission per kWh is determined by the following Equation 14 [28]:

1,640.7 lbs CO_2/MWh × (4.536 × 10-4 metric tons/lb) × 0.001 MWh/kWh = 7.44 × 10-4 tons CO_2/kWh (14)

2.8.2. Gallons of gasoline consumed

To obtain the number of grams of CO_2 emitted per gallon of gasoline combusted, Equation 15 is used [29].

8,887 grams of CO_2/gallon of gasoline = 8.887 × 10-3 metric tons CO_2/gallon of gasoline (15)

3. THEORY/CALCULATION

3.1. Passive systems

This building is of villa type with a gable roof and has a low grade on insulators and sealant (Table 5). Due to the thermal calculation, the effects of insulators and sealant are studied in two different scenarios, which are using the whole sealant equipment and using just double glazed windows and door sealant.

Table 5. Components assumption before optimization.

NO.	Components	Specifications
1	Windows	Skylight, 0 %-5 % of roof, U-4.8, SHGC-0.6, single glaze
2	Roof	Earthen gable roof
3	Outer walls	Cement and break
4	Inner walls	Break and plaster
5	Floor	Cement, Stone and wooden parquet

Table 6. Components assumption after optimization.

NO.	Components	Specifications
1	Windows	U-1.6, SHGC-0.32, double glazed
2	Roof	Earthen gable roof + Rockwool
3	Outer walls	Cement and break + Extruded polystyrene (XPS)
4	Inner walls	Break and plaster + Expanded polystyrene (EPS)
5	Floor	Cement, Stone, and wooden parquet + Expanded polystyrene (EPS)

At the end of the process and implementation of all suggestions using "Design Builder" software, the energy efficiency of the building can be optimized up to 20 %, and details can be found in Table 7.

Table 7. Passive efficiency solutions

Passive efficiency solutions	Percentage of energy reduction		
	Cooling	Heating	Total
Insulation of external wall	10.6	22.9	11.1
Insulation of internal walls and uncontrolled space	1.9	3.9	1.8
Insulation of roof	1.12	2.3	1.1
Insulation of floor	0.6	1.2	0.5
Window glazing and door sealant	6.9	8.3	5.1

Table 8. Result of two passive scenarios.

Case studies	Unit	1st scenario: using whole equipment	2nd scenario: using just double glazed windows and door sealant
		Amount	
Amount of gas consumption reduction of the building	Nm^3 year [3]	1460	435
Total energy savings	%	19.5	5.5
Building cost savings	$/year	75	22
National cost savings	$/year	112	35
Emission reduction	Kg	2800	950
Profit from emission reduction	$	70	20
Return of capitals (ROC) without national profit	Year	42	36
Return of capitals (ROC) with national profit	Year	16	9.4

Building cost saving is based on the actual energy demands of the building analyzed before, and fuel consumption is based on domestic price; in addition, for the National cost savings, fuel consumption is based on international price, which is 2.2 $ per 1000 ft^3 [30].

3 Normal cubic meter

3.2. Active systems (probe individually)

3.2.1. Photovoltaic panels

The weather conditions, pollution, and Shading Losses affected were impressed by adjacent buildings and the energy generation was calculated by Equations 1 to 4.

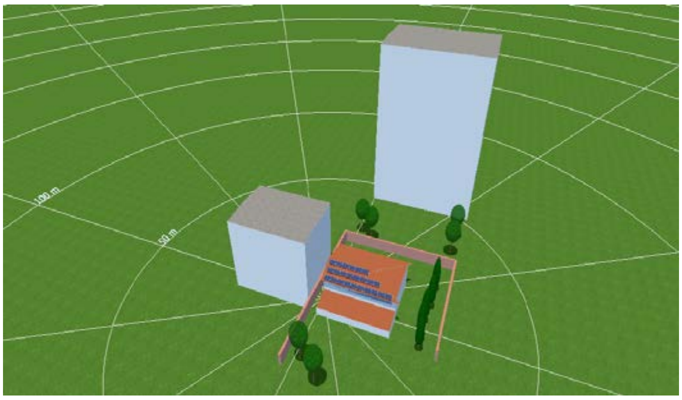

Figure 4. Environment and surrounding buildings of the studied project.

Table 9. PV's technical analysis.

PV generator output	4.8kWp
Area in use	40.2m²
Number of PV modules	24*200W
Number and power of inverters	3*1500W
Total investment costs	7500$
Annual maintenance costs	100$
Income from the feed-in grid	775$
Emission reduction (GHG)	3930kg
Amount of gas saving	2000m³
National cost savings	150$
Emission reduction profit	60$

For an economic and technical analysis of PV panels, two scenarios are defined: one is selling all the generated power and then buying it from the grid; the other is consuming the required energy for daily usage and, then, selling the surplus to the grid. The local specific export rate is about 1.2$ per kWh, and the inflation rate is assumed 5 % (Tables 9 and 10) [31].

Table 10. PV's economic analysis.

Result with national and GHG profit	
The rate of return (ROR)	11 %
Return of Capitals (ROC)	7 year
Result without national GHG profit	
The rate of return (ROR)	8 %
Return of Capitals (ROC)	8.7

3.2.2. Solar water heater

Due to our previous assumption, daily need for DHW is about 500 litter, and daily average heating energy is approximately 30kW. In this system, there are two scenarios as well (Tables 11 and 12): one is supplying DHW and part of the heating load (Figure 4), and the other is only supplying DHW (Figure 5). It is mentioned that the exisiting boiler is assumed as the backup system unit.

Table 11. SWH's technical analysis.

	1st scenario	2nd scenario
Collector type	**Standard flat plate**	**Standard flat plate**
Volume	2.25 m^3	0.75 m^3
Area in use	30 m^2	9 m^2
Total investment costs	4800$	1800$
Total solar fraction	15 %	15 %
Supplying DHW	100 %	100 %
Supplying heating load	30 %	-
The energy delivered by collectors	60985 kWh	18285 kWh
Emission reduction (GHG)	8772 kg	975 kg
Amount of gas saving	4511 m^3	206 1 m^3
Profit from gas saving	195$	138$
National cost savings	320$	80$
Emission reduction profit	130$	30$

Table 12. SWH's economic analysis.

	1st scenario	2nd scenario
Result with national and GHG profit		
Rate of return (ROR)	9 %	10 %
Return of Capitals (ROC)	7.4 year	7.1 year
Result without national GHG profit		
Rate of return (ROR)	-7 %	2 %
Return of Capitals (ROC)	27.5 year	12.8 year

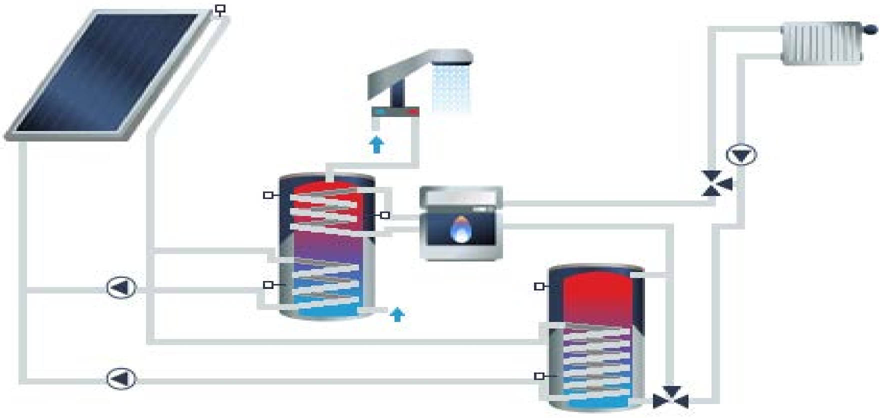

Figure 5. SWH's first scenario schematic.

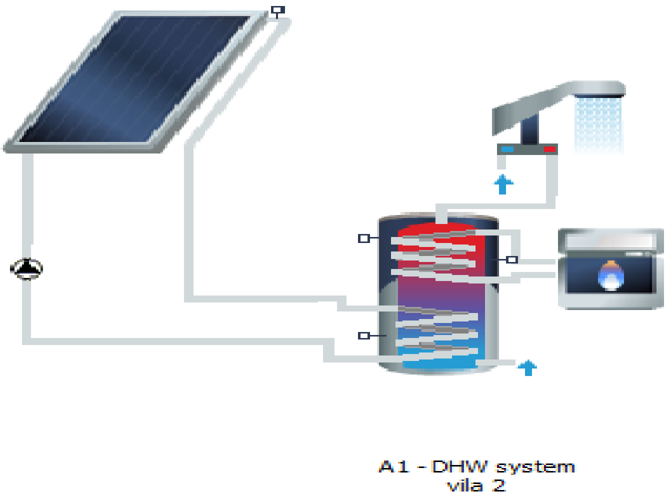

Figure 6. SWH's second scenario schematic.

3.2.3. Ground source heat pumps (GSHPs)

For this system concerning our limitation of the ground area, the situation that is defined is supplying part of DWH and part of the heating load. Due to the operating and excavation costs, the reasonable type for using GSHP is a horizontal closed loop, and the technical and economic results are found in Tables 13 and 14.

3.2.4. Combined heat and power (CHP)

The system for this building is chosen with respect to comfort, power needed, and space available, which is 33kW Tedom CHP unit. According to the bills, the monthly price of electricity for such a building is 0.006$ per kWh, and the natural gas price is about 0.04$ per cubic meter. In addition, for CHP units, feed-in tariff (energy selling to the grid) is 0.0028$ per kWh, and the natural gas price is 0.0022$ per cubic meter (Table 15). Two scenarios are defined: one is selling all the generated power and, then, buying it from the grid; the other is consuming the required energy for daily usage and, then, selling the surplus to the grid (Table 16).

Table 13. GSHP's technical analysis.

Area in use	200m^2
Depth	2m
Soil type	Sand, dry
Supplying DHW	70 %
Supplying heating load	28 %
Heating load	8309kWh
DWH	4850kWh
Emission reduction (GHG)	6200kg
Amount of gas saving	4000m^3
Profit from gas saving	175$
National cost savings	300$
Emission reduction profit	95$
Equipment cost	4250$
Excavation cost[4]	1000$

Table 14. GSHP's economic analysis.

Results with national and GHG profit	
The rate of return (ROR)	9 %
Return of Capitals (ROC)	8 year
Results without national GHG profit	
The rate of return (ROR)	-4 %
Return of Capitals (ROC)	23 year

Table 15. CHP's technical analysis.

Electric power	38kW
Heating power	65kW
Capital cost	20500$
CHP unit yearly gas usage	75000m^3
Cost of CHP unit yearly gas usage for 1st scenario	free[5]
Cost of CHP unit yearly gas usage for 2nd scenario	1690$
Minimum yearly electric power generation	247000kWh
Engine efficiency	35 %
Electric efficiency	33 %
Heating efficiency	54 %
Total efficiency	87 %
Fuel consumption	12 m^3/hr
Amount of gas saving[6]	7500m^3
Profit from gas saving	338$
Amount of electric power saving[7]	22000kWh
Profit from the electric power saving	35$
Income from selling all generated power	6775$
Income from selling the surplus of generated power	6175$
Maintenance cost	1250$
Amount of gas saving compared to the same energy unit that was generated via local boilers	67500m^3
Saving’s profit	7865$
Emission reduction (GHG) In macro perspective[8]	150 ton
Emission reduction profit	2250$
Note: According to EPA[9], to achieve 30 unit of electricity and 45 unit of steam in CHP system, 100 unit of fuel is needed; for a typical system of energy generation (power plant and boiler) with respect to T&D[10] factor that is usually between 5.8 % and 7.3 % to achieve the same amount of energy, 147 unit of fuel is needed.	

4 Based on the local price
5 Due to government support for districted generation (DG)
6 Yearly amount of gas that will not be used via boiler
7 Yearly amount of electricity that will not be generated via power plants
8 Comparison of total emission for the same amounts of energy produced
9 United States Environmental Protection Agency
10 Transmission and Distribution Losses

Table 16. CHP's economic analysis.

	1st scenario: Selling all the generated power and, then, buying it from the grid	2nd scenario: Consumption of the required energy for daily usage and, then, selling the surplus to the grid
Result with national and GHG profit		
The rate of return (ROR)	82 %	69 %
Return of Capitals (ROC)	1.2 year	1.4 year
Result without national GHG profit		
The rate of return (ROR)	32 %	21 %
Return of Capitals (ROC)	3 year	4.4 year

3.3. Active systems (probe hybrid)

In this section, the mentioned systems in hybrid form were compared, evaluated, and analyzed. Since solar heating systems and geothermal pumps cannot generate electricity by themselves, hybrid systems are required.

3.3.1. Photovoltaic planes and solar water heating systems

From the previous sections, the best scenario for PV planes is selling all the generated power (Figures 7 and 8) and, then, buying it from the grid. For the solar water system, there are two scenarios: (Tables 17 and 18): one is supplying DHW and most of the heating load; the other is supplying DHW and part of the heating load (Figure 6).

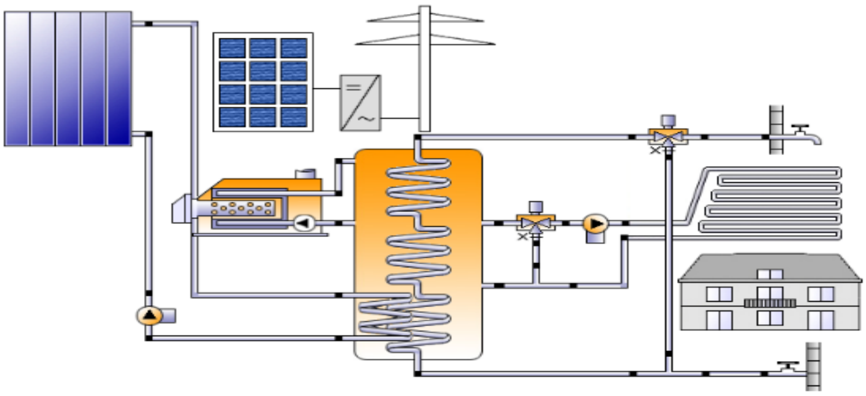

Figure 7. PV and SWH's schematic.

Table 17. PV and SWH's technical analysis.

	Supplying DHW and the main segment of the heating load	Supplying DHW and part of the heating load
Area of solar water (SW) heating panels	27	9
Area of PV panels	36	36
Solar fraction total	49 %	49 %
Amount of SW modules	9	3
SW annual field yield	15242 kWh	6242 kWh
Supplying heating load/ DHW	80 % / 100 %	25 % / 100 %
Amount of PV modules	20	20
Power of PV modules	20*200W=4 kW	20*200W=4 kW
PV annual field yield	6337 kWh	6337 kWh
Amount of gas saving	4575m^3	1500m^3
Income from feed-in the grid	775$	775$
Saving's profit	180$	55$
National cost savings	330$	110$$
Emission reduction (GHG)	6561kg	5061kg
Emission reduction profit	100$	75$

Table 18. PV and SWH's economic analysis.

	Supplying DHW and the main segment of the heating load	Supplying DHW and part of the heating load
Result with national and GHG profit		
The rate of return (ROR)	5 %	4 %
Return of Capitals (ROC)	10.7 year	11 year
Result without national GHG profit		
The rate of return (ROR)	-2 %	0 %
Return of Capitals (ROC)	18 year	15 year

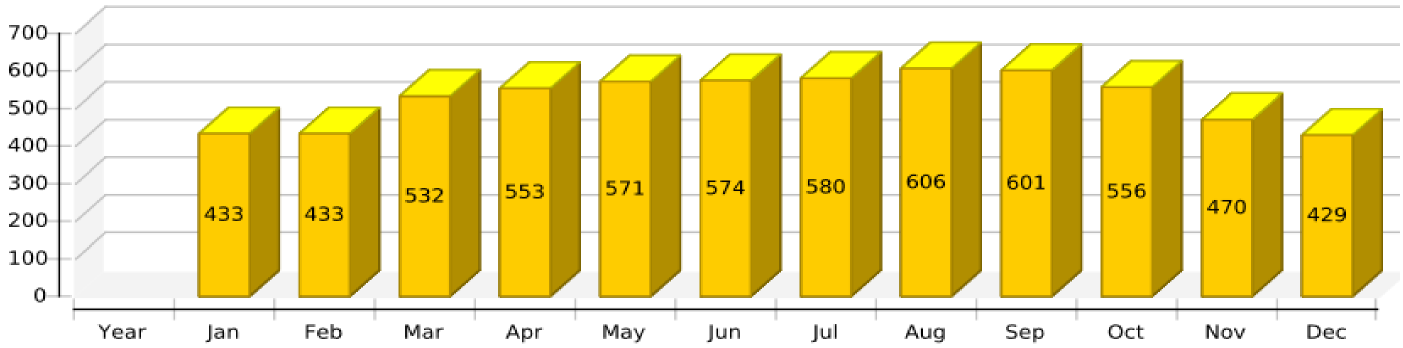

Figure 8. Yield Photovoltaics AC (kWh/date).

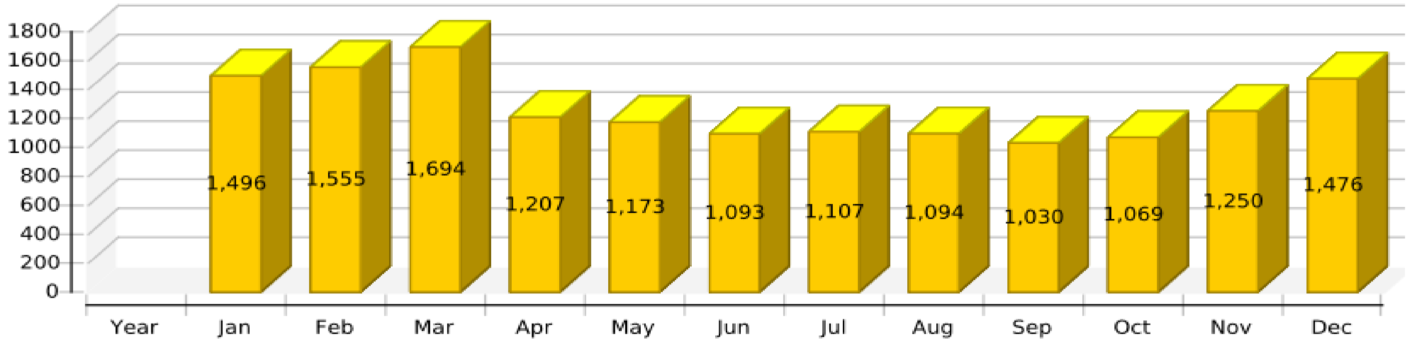

Figure 9. Solar thermal energy to the SWH system (kWh/date).

3.3.2. Photovoltaic panels and geothermal

Due to the previous section, the scenarios for PV panels are the same; moreover, the configurations of GSHP are the same as well (Figure 9), and technical and economic results can be found in Tables 19 and 20.

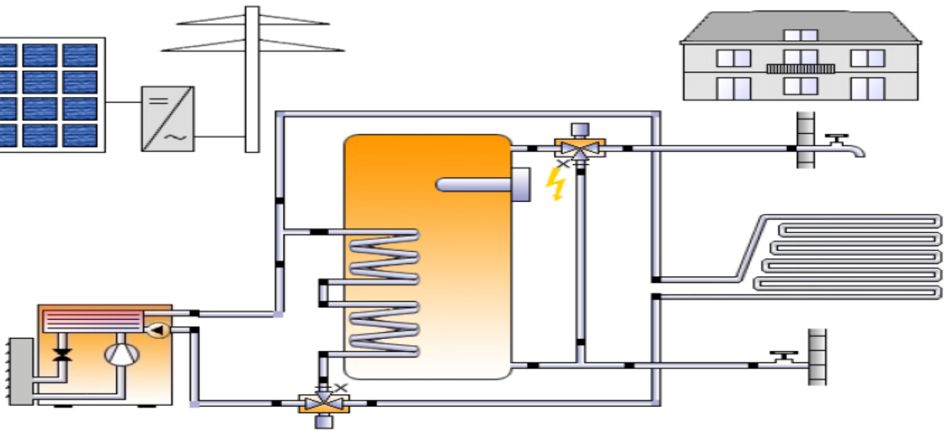

Figure 10. PV and GSHP's schematic.

Table 19. PV and GSHP's technical analysis.

Seasonal performance factor for air-to-water heat pump	3.1
Heat pump yearly energy harvest	16242 kWh
Supplying heating load/ DHW	45 % / 80 %
Amount of PV modules	24
Power of PV modules	24*200=4.8 kW
PV annual field yield	7604 kWh
Amount of gas saving	6275 m^3
Income from the feed-in grid	775$
Saving's profit	400$
National cost savings	175$
Emission reduction (GHG)	9561 kg
Emission reduction profit	142$
Maintenance cost	65$

Table 20. PV and GSHP's economic analysis.

Results with national and GHG profit	
The rate of return (ROR)	11 %
Return of Capitals (ROC)	7.1 year
Results without national GHG profit	
The rate of return (ROR)	3 %
Return of Capitals (ROC)	11.6 year

3.3.3. Geothermal heat pump with solar water heater

This system is solely made for checking the independence of the building considering DWH and heating load (Figure 10), and it cannot satisfy the concept of zero-energy building, because it cannot generate electricity. In addition, the previous sections containing two scenarios were analyzed (Tables 21 and 22).

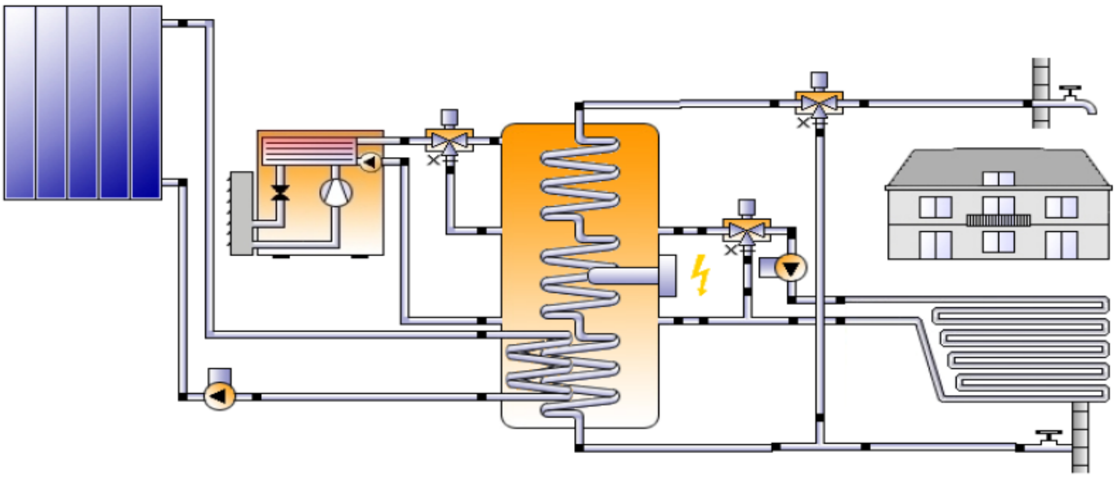

Figure 11. GSHP and SWH's schematic.

Table 21. GSHP and SWH's technical analysis.

	Fully supply heating load and DWH	Supply part of the heating load and DHW
Total gross area	$27m^2$	$9m^2$
Amount of SW modules	9	3
Solar fraction total	49 %	49 %
Heat pump yearly energy harvest	16242kWh	16242kWh
Solar water heater yearly energy harvest	15350kWh	7242kWh
Supplying heating load/ DHW	100 % / 100 %	35 % / 100 %
Amount of gas saving	6200 kg	4000 m^3
Saving's profit	245$	140$
National cost savings	495$	350$
Emission reduction (GHG)	12160kg	7860kg
Emission reduction profit	180$	117$
Maintenance cost	20$	10$
CC of CWH	5000$	1750$
CC of GSHP	5100$	5100$

Table 22. GSHP and SWH's economic analysis.

	Fully supply heating load and DWH	Supply part of the heating load and DHW
Result with national and GHG profit		
The rate of return (ROR)	2 %	2 %
Return of Capitals (ROC)	13 year	13 year
Result without national GHG profit		
The rate of return (ROR)	-14 %	-12 %
Return of Capitals (ROC)	51 year	48 year

3.3.4. Photovoltaic panels, solar water heating system, and geothermal heat pump

As mentioned before, the best scenario for PV planes is selling all the generated power and, then, buying it from the grid (Figure 11). For the solar water system, there are two scenarios: one is supplying DHW and most of the heating load, and the other is supplying DHW and part of the heating load (Tables 23 and 24).

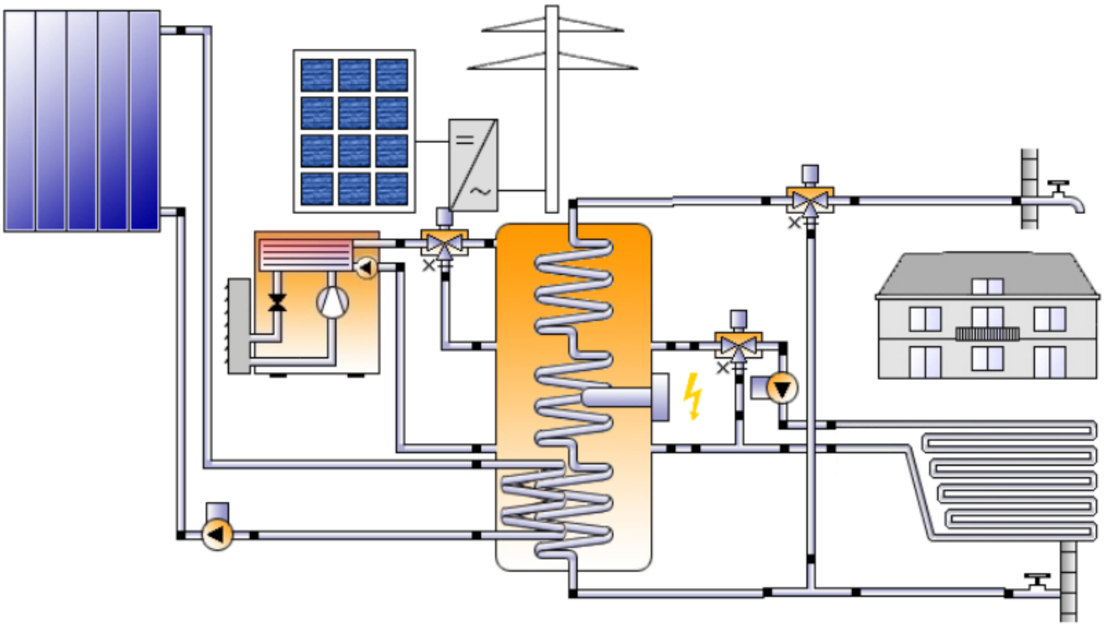

Figure 12. PV, SWH, and GSHP schematics.

Table 23. PV, SWH, and GSHP technical analysis.

	Supplying DHW and the main segment of the heating load	**Supplying DHW and part of the heating load**
The total gross area of solar water (SW) heating panels	27	9
The total gross area of PV panels	36	36
Solar fraction total	49 %	49 %
Amount of SW modules	9	3
SW annual field yield	15242 kWh	6242 kWh
Heat pump yearly energy harvest	16242kWh	16242kWh
Supplying heating load/ DHW	80 % / 100 %	25 % / 100 %
Amount of PV modules	20	20
Power of PV modules	20*200W=4 kW	20*200W=4 kW
PV annual field yield	6337 kWh	6337 kWh
Amount of gas saving	8200m^3	1500m^3
Income from the feed-in grid	775$	775$
Saving's profit	350$	55$
National cost savings	606$	110$$
Emission reduction (GHG)	12160kg	5061kg
Emission reduction profit	180$	75$
Maintenance cost	40$	30$
CC of CWH	5000$	1750$
CC of GSHP	5100$	5100$
CC of PV panels	5200$	5200$

Table 24. PV, SWH and GSHP economic analysis.

	Supplying DHW and the main segment of the heating load	**Supplying DHW and part of the heating load**
	Result with national and GHG profit	
The rate of return (ROR)	9 %	11 %
Return of Capitals (ROC)	8.2 year	7 year
	Result without national GHG profit	
The rate of return (ROR)	-2 %	3 %
Return of Capitals (ROC)	17 year	12 year

3.3.5. Combination of heat and power (CHP) and Photovoltaic panel (PV)

Given that CHP system meets the full potential for satisfying ZEB concept in both heating and electric loads, this scenario has been developed and reviewed for the sake of distributed generation and electricity sales (Tables 25 and 26).

3.4. Analytic hierarchy process (AHP)

Considering that in the studies on the return on capital, the profit from the emission reductions and the national income and its separate absence have been examined separately, these two scenarios are also calculated separately in AHP analysis.

Reference indicators (Figure 12) are based on surveys conducted by about 50 people including mechanical engineering students and engineers, maintenance technicians, property owners, and ordinary people. The average results are shown in Tables 27-30.

Table 25. CHP and PV's technical analysis.

Amount of gas saving[11]	7500m^3
Profit from gas saving	340$
Annual gas consumption	75000
Cost of CHP unit yearly gas usage	free
Income from selling all generated power	7625$
Annual electric power consumption	275$
Maintenance cost	200$
The total gross area of PV panels	36
CC of PV panels	5200$
CC of CPH system	20500$
Amount of gas saving compare to same energy unit that was generated via local boilers	67500m^3
Saving's profit	7865$
CHP emission reduction (GHG) In macro perspective	150 ton
Emission reduction profit	2250$
PV emission reduction (GHG)	5750 kg
Emission reduction profit	235$

Table 26. CHP and PV's economic analysis.

Result with national and GHG profit	
The rate of return (ROR)	62 %
Return of Capitals (ROC)	1.6 year
Result without national GHG profit	
The rate of return (ROR)	23 %
Return of Capitals (ROC)	4.1 year

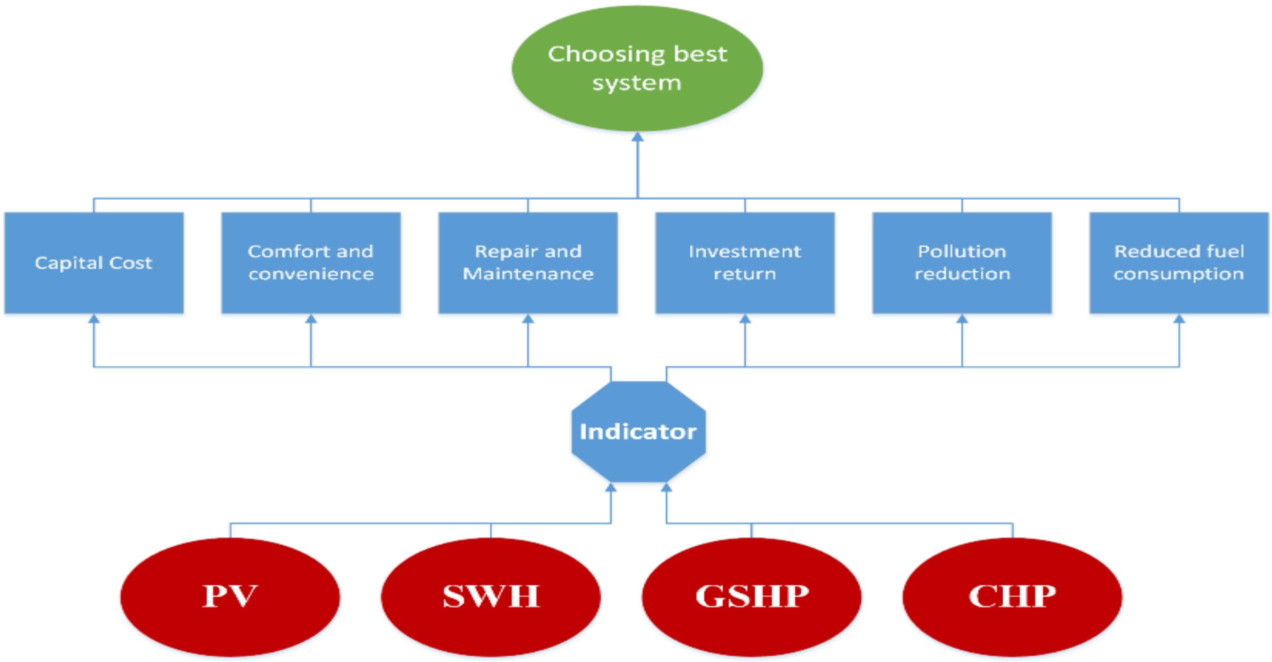

Figure 13. Schematic of the AHP selection process.

11 Yearly amount of gas that will not be used via boiler

Table 27. Reference indicators for the first scenario.

rating	CC	Convenience and comfort	Repair and maintenance	ROR	Pollution reduction	Reduced fuel consumption
CC	1	4	4	3	7	6
Convenience and comfort	0.23	1	3	2	6	4
Repair and maintenance	0.27	0.31	1	2	5	4
ROR	0.31	0.43	0.55	1	6	5
Pollution reduction	0.14	0.17	0.19	0.17	1	3
Reduced fuel consumption	0.18	0.24	0.24	0.19	0.38	1

Table 28. Normalized weights for the first scenario.

Criteria	Normalized weight	
CC	0.408	40.8 %
Convenience and comfort	0.210	21 %
Repair and maintenance	0.149	14.9 %
ROR	0.144	14.4 %
Pollution reduction	0.051	5.1 %
Reduced fuel consumption	0.038	3.8 %

Table 29. Reference indicators for the second scenario.

Rating	CC	Convenience and comfort	Repair and maintenance	ROR
CC	1	4	4	3
Convenience and comfort	0.23	1	3	2
Repair and maintenance	0.27	0.31	1	2
ROR	0.31	0.43	0.55	1

Table 29. Normalized weights for the second scenario.

Criteria	Normalized weight	
CC	0.519	51.9 %
Convenience and comfort	0.228	22.8 %
Repair and maintenance	0.140	14 %
ROR	0.113	11.3 %

The weights of the individual criteria are calculated. These weights are already normalized by Equations; their sum is 1.

At the end of the AHP process, it arranges and totals the priorities for each of the alternatives. Their grand total is 100 %, which is identical to the priority of the goal. Each alternative has a priority corresponding to its "fit" to all the judgments about all those aspects of CC, Convenience and comfort, Repair and maintenance. Here is a summary of the priorities of the alternatives (Tables 31 and 32).

Table 30. Alternative's priorities with respect to the AHP.

Factor	Alternative	Priority for the 1st scenario	Priority for the 2nd scenario
CC	0 – 6250 $	24 %	30 %
	6250 – 12500 $	11 %	13 %
	12500 - 18750 $	5 %	6 %
	18750 – 25000 $	2 %	3 %
Convenience and comfort	good	13 %	14 %
	average	5 %	6 %
	poor	2 %	2 %
Repair and maintenance	good	9 %	9 %
	average	4 %	4 %
	poor	2 %	1 %
ROR	0-5 years	9 %	7 %
	5-10 years	4 %	3 %
	10-15 years	2 %	1 %
Pollution reduction	15 tons up	3 %	-
	10-15 tons	1 %	-
	5-10 tons	1 %	-
	0-5 tons	0 %	-
Reduced fuel consumption	150,000 cubic meters up	2 %	-
	10,000-15,000 cubic meters	1 %	-
	5000-10000 cubic meters	0 %	-
	0-5000 cubic meters	0 %	-

According to the weight of the indices, the weight of the sub-branches is calculated, and the systems under consideration are weighted (Figures 13 and 14) according to the calculations and are prioritized in order.

Table 31. Weighing of each system due to AHP.

Reduced fuel consumption (m^3)	Pollution reduction (ton)	ROR (year)	Repair and maintenance ($)	Convenience and comfort	CC ($)	System
2000	4	7	good	good	280,000,000	PV (1)
0 %	0 %	4 %	9 %	13 %	12 %	
2000	4	9	good	good	280,000,000	PV (2)
0 %	0 %	3 %	9 %	13 %	12 %	
4500	8	7.5	average	average	200,000,000	SW (1)
0 %	1 %	4 %	4 %	5 %	20 %	
975	2	7.1	good	average	70,000,000	SW (2)
0 %	0 %	4 %	9 %	5 %	28 %	
4000	6.5	8	average	average	210,000,000	GSHP
0 %	1 %	4 %	4 %	5 %	20 %	
67500	150	1.4	poor	average	820,000,000	CHP (1)
2 %	3 %	9 %	2 %	5 %	3 %	
67500	150	1.2	poor	average	820,000,000	CHP (2)
2 %	3 %	9 %	2 %	5 %	3 %	
5500	9.5	10	average	average	450,000,000	PV with SW (1)
0 %	1 %	4 %	4 %	7 %	9 %	
3000	6	10.5	good	good	350,000,000	PV with SW (2)
0 %	1 %	2 %	9 %	13 %	10 %	
5500	12.5	7	good	average	410,000,000	PV with GSHP
0 %	1 %	4 %	9 %	5 %	9 %	
6200	12	13	average	average	400,000,000	SW with GSHP (1)
0 %	1 %	2 %	4 %	5 %	9 %	
4200	8	12	average	average	280,000,000	SW with GSHP (2)
0 %	1 %	2 %	4 %	5 %	11 %	
10000	18	7.6	average	average	620,000,000	PV with SW and GSHP (1)
1 %	3 %	4 %	4 %	5 %	6 %	
8126	12.5	7	average	average	470,000,000	PV with SW and GSHP (2)
0 %	1 %	4 %	4 %	5 %	10 %	
67700	155	1.6	poor	poor	1,020,000,000	PV with CHP
2 %	3 %	9 %	2 %	2 %	2 %	

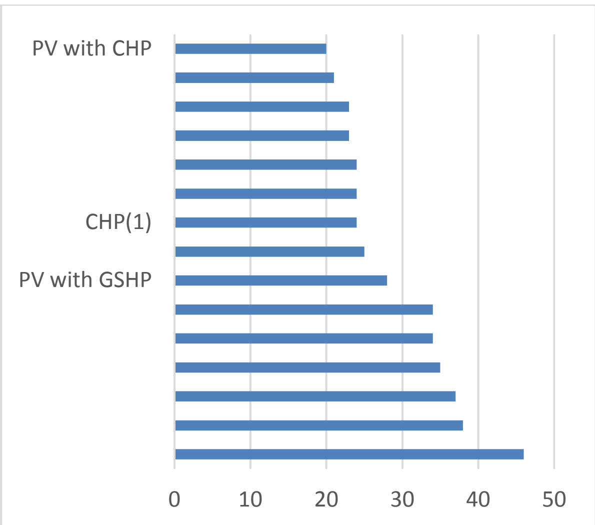

Figure 14. The final weight of the first scenario.

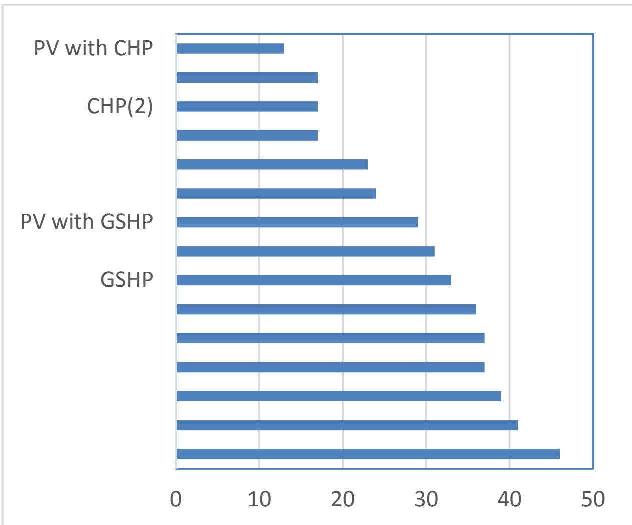

Figure 15. The final weight of the second scenario.

4. DISCUSSION

The present study aimed to extensively introduce various energy and heat generation systems and investigate their technical and economic benefits in an attempt to realize the concept of energy buildings. As mentioned in the previous chapters, with regard to the new concepts of zero-energy buildings, achieving complete independence from the perspective of network interactions is a difficult task in most buildings. Hence, this concept was redefined, and a Nearly Zero-Energy Building (NZEB) was introduced. In this study, roughly 30 scenarios were defined, through which complete building independence, or the closest case possible, was achieved.

Three significant conclusions were obtained in this study: (a) Conclusion from macro-engineering, macro-energy, and macro-economic perspectives, (b) statistical conclusion by both considering and disregarding the effects of pollution reduction profits and national profits from fuel consumption, and (c) conclusion from the perspective of NZEBs.

4.1. Outcome-based on macro-engineering and economic perspectives

In this section, it was concluded that the combined Heat and Power (CHP) generator systems is the most appropriate method considering the governmental support for the infrastructure of the technology, short return of capital, the ability to supply the thermal and electrical loads, significant effects on fuel consumption reduction from a macroeconomic perspective, and, finally, a high revenue potential (Table 33).

Table 32. Specifications of the selected system from the macro-engineering and economic perspectives.

Fuel consumption reduction	Pollution reduction	Profits from electricity sale	Electrical load	Thermal load	Return of capital
67500m^3	Ton 150	6800$	38kW	65kW	2-3 years

4.2. Statistical conclusion

In this section, the conclusion was based on the analytic hierarchy process (AHP) as a decision-making method. In this process, two questionnaires with 4 and 6 parameters were distributed among a statistical population of 50 individuals including mechanical engineering students, facilities engineers, maintenance and repair technicians, and landowners.

4.2.1. Outcome by considering the effects of profits from pollution reduction and national profits of fuel consumption reduction

In this conclusion, the systems were compared concerning the effects of parameters such as the return of capital and initial capital in terms of pollution reduction and national profit. The most appropriate scenarios based on the conducted surveys were: (1) Solar water heating (SWH) with an overall weight of 46 used for the supply of hot water and (2) Solar panels with a final weight of 36.

4.2.2. Outcome without taking into account the effects of profits from pollution reduction and national profits of fuel consumption reduction

In this conclusion, the systems were compared concerning the effects of parameters such as the return of capital and initial capital. The most appropriate scenarios based on the conducted surveys were: (1) Solar water heating (SWH) with an overall weight of 46 used for the supply of hot water and (2) SWH with a final weight of 41 by converting geothermal energy.

4.3. Outcome based on NZEB definition

Different systems were compared based on their ability to meet the requirements of NZEBs with an index score of 5/5 and considering the results obtained from computations and calculation. Moreover, the reliability coefficient of these systems was taken into account (Table 34).

Table 33. Overall score of each scenario to achieve NZEB.

System name	Ability to supply thermal load	Ability to supply the electrical load	An overall score of NZEB
Solar panel 1	No	Fully	2.5
Solar panel 2	No	Fully	2.5
Solar water heating 1	Limited	No	2
Solar water heating 2	Limited	No	1.5
Geothermal	Limited	No	2.25
CHP(1)	Fully	Fully	5
CHP(2)	Fully	Fully	5
Solar panel along with SWH 1	Limited	Fully	3.5
Solar panel along with SWH 2	Limited	Fully	3
Solar panel along with geothermal energy	Limited	Fully	3.5
SWH with geothermal energy 1	Limited	No	3
SWH with geothermal energy 2	Limited	No	2.5
Solar panel along with SWH and geothermal energy 1	Limited	Fully	4.5
Solar panel along with SWH and geothermal energy 2	Limited	Fully	3.5
Solar panel with CHP	Fully	Fully	5

The CHP system can be selected as the most appropriate option as it meets the requirements of ZEBs and offers a high-reliability coefficient; however, if greater attention is given to having more of the district generation, then using solar panels along CHP unit is a great system and a scenario to apply. Moreover, both are capable of consistently and fully supplying electrical and thermal energies over the year (Figure 15).

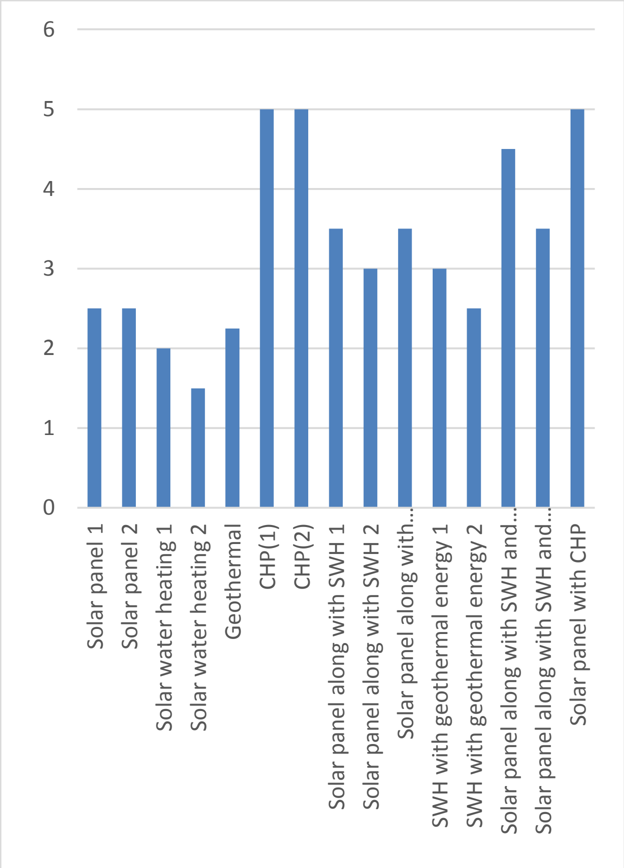

Figure 16. Overall score of NZEB.

5. CONCLUSIONS

The need for distributed energy production has increased in recent years due to the growth of industries and the population of Iran. With the rise of pollution and the number of unhealthy days with low air quality in Tehran, ZEBs can be the solution to these obstacles. Unfortunately, the government has provided poor support in order to expand ZEBs (or NZEBs). Thus, to confront the energy and pollution crises, the implementation of ZEBs must be as efficient as feasible. Therefore, it is necessary to take appropriate and principal measures seriously during the construction process rather than in the reconstruction. As a result, in the construction process, the pressure and amount of investment needed will become more rational and economical. Moreover, it decreases the intra-building problems such as the need for specific air conditioning equipment compatible with the old system.

In conclusion, in this paper, three methods have been considered to include various conditions and different aspects of a comprehensive review.

1. CHP system is the most suitable system that considers macro-engineering and economic perspectives with 32 % ROR, 20500$ CC, Minimum Yearly electric power generation of 247000 kWh and potential of 150 ton of Emission reduction.
2. Two statistical scenarios were developed considering criteria such as capital cost, convenience, and comfort, ROR, etc. with a comprehensive survey of over 50 people:
   a. Considering profits from pollution reduction and national profits of fuel consumption reduction, the top two systems that can prove most effective are: Solar water heating (2) with an overall weight of 46 and photovoltaic panels (1) with an overall weight of 38.
   b. Without considering profits from pollution reduction and national profits of fuel consumption reduction, the top two systems are Solar water heating (2) with an overall weight of 46 and Solar water heating with geothermal energy (2) with an overall weight of 41.
3. To meet the requirements of NZEB definition, the thermal and electrical load supply percentages of each and every introduced system were analyzed; in addition, the result was the CHP system unit because it could supply both thermal and electrical loads; besides, because of excessive electric energy production, power suppliers of electric cars in next generations can play greater roles.

Furthermore, as for the future studies, different climates in Iran can be investigated, and different scenarios can be defined in which small, vertical wind turbines and fuel cells can be utilized.

6. ACKNOWLEDGEMENT

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7. N0MENCLATURE

A_{geo}	Heat exchange area
AHP	Analytic hierarchy process
C_a	Collector array
CAPEX	Capital costs
CHP	Combined heat and power
Ci	The nominal cash flow
C_Y	Collector yield
DHW	Domstic hot water
DWH	Domestic hot water
ENVEX	Greenhous gas emissions/national profit
gpm	Gallons per minute
GSHP	Ground source heat pump
h_{REAL}	The real energy conversion efficiency
h_{STC}	Standard conversion efficiency
HWD	Hot water demand of kitchen
kWp	Kilowatts peak, the peak power of a PV system or panel
LCC	Life Cycle Cost
n	The number of years considered
Nm^3/ year	Normal cubic meter
NZEB	Near zero energy buildings
OPEX	Profitability
P_{mpp}	Maximum power point
P_s	The average daily consumption of power per unit area
PV	Photovoltaic
Q_s	The total heat capacity of the storage tank
r	The discount rate or the annual rate of return
ROC	Return of capital
ROR	Rate of return
SHGC	Solar heat gain coefficient
S_R	Solar radiation
SWH	Solar water heater
T_{geoin}	The inlet temperature of the ground-loop fluid to the ground
T_{geoout}	The exit temperature of the ground-loop fluid from the ground
T_{ground}	The effective temperature of the ground
$(UA)_{geo}$	Product of the overall heat transfer coefficient
V_{st}	Storage for solar water heating

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