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Feasibility of using biogas in a micro turbine for supplying heating, cooling and electricity for a small rural building

Gh. Rajaei[1], F. Atabi[*1] and M.A.Ehyaei[**2]

[1]Department of Environmental and Energy Engineering, Science and Research Branch, Islamic Azad University, Tehran 13967-33364, Iran
[2]Department of Mechanical Engineering, Pardis Branch, Islamic Azad University, Pardis New City 14778-93855, Iran

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Abstract. In this study, the use of a micro gas turbine system using biogas to supply heating, cooling and electricity loads of a rural building located in rural area around Tehran has been studied. Initially, the amount of energy needed by the farmhouse was calculated and then the number of needed microturbines was determined. Accordingly, the amount of substances entering biogas digester as well as tank volume were determined. The results of this study showed that village house loads including electrical, heating and cooling and hot water loads can be supplied by using a microturbine with a nominal power of 30 kW and 33.5 m^3/day of biogas. Digester tank and reservoir tank volumes are 67 m^3 and 31.2 m^3, respectively. The cost of electricity produced by this system is 0.446 US$/kWh. For rural area in Iran, this system is not compatible with micro gas turbine and IC engine system use urban natural gas due to low price of natural gas in Iran, but it can be compatible by wind turbine, photovoltaic and hybrid system (wind turbine& photovoltaic) systems.

Keywords: biogas; micro turbine; technical; feasibility; electricity; loads; cost

1. Introduction

A sharp reduction in fuels amount such as oil, coal and natural gas and non-renewability of these fuels and prediction of price increases emphasizes more than before the importance and need to replace current energy system; one of these options is the use of energy comes from biomass sources (Berglund 2006). In some impassable areas, where there is no access and possibility to use other sources of energy, creation of biogas devices can respond many energy problems required by the region; the use of animal and organic wastes with the help of very simple and inexpensive methods with biogas technology. (Borjesson and Berglund 2007). Biogas as one of these energies is obtained from decomposition and fermentation of garbage and other agricultural residues, human and animal excreta and industrial wastewaters by methane production. Biogas as an energy carrier can be a suitable substitution for fossil fuels and have been also used abundantly as a new

*Corresponding author, Ph.D., E-mail: aliehyaei@yahoo.com
**Corresponding author, Ph.D., E-mail: far-atabi@jamejam.net

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and readily available source of energy in recent decades throughout the world, especially in countries such as China, South Korea and India. There have been many studies on the use of biogas (Borjesson and Berglund 2006), (Goodarzirad *et al.* 2005), (Salamon and Lora 2009), (Park *et al.* 2009), (Riccio and Chiramonti 2009).

In researches by that were conducted by Karlas *et al.* in Greece in 2010, the development for investment for the production of biogas from agricultural wastes was discussed. The studies have shown that anaerobic digestion of agricultural wastes is a suitable solution for treatment, pollution prevention, as well as energy production. In this study, whilst different types of biogas reactors (anaerobic digestion tanks) and their capacities in accordance with the input raw material are investigated, the raw material used to produce biogas energy is studied. The raw materials for biogas production can include a variety of organic waste materials (animal waste such as pig excreta and sludge from wastewater treatment plants) and agricultural products (sorghum, sunflower, wheat, sugar beet, etc.). Depending on what materials are available or depending on the type of agricultural activity as well as economic issues, performance of biogas production process will be different. In this study, three types of raw materials including pig excreta, wheat stalk and glycerol for biogas and methane gas production were studied, for example, if input raw materials are 20000 tons/year of pig excreta and the total amount of solids is 56 g/kg and volatile waste materials is 44.80 g/kg, the amount of output CH_4 will be equal to 324800 Nm^3 CH_4/year and biogas production rate will be equal to 523.871 Nm^3 Biogas/year. If the input materials are 10000 tons/year of crushed stalks of wheat, the total amount of solids is 850 g/kg and the volatile solids rate is 799 g/kg, the amount of output CH_4 will be equal to 2675800 Nm^3CH_4/year and generated biogas will be equal to 4315806 Nm^3 Biogas/year. If our input raw material is 15000 tons / year of glycerol that its total solids is equal to 800 g/kg and its volatile solids is equal to 760 g/kg in that case our output CH_4 will be 7200000 Nm^3CH_4/year and generated biogas will be equal to 11612903 Nm^3biogas/year (Karellas *et al.* 2010).

In researches carried out in Canada by White *et al.* in 2010, the use of biogas production systems in small scale in cattle farm of Ontario for production of electricity has been investigated and studied economically. The cattle farm in Ontario is evaluated based on size, farm biogas production potential, cost of anaerobic digester system on a small scale, and desired profit and return of FIT program (Feed - in Tariff). The potential of biogas production will be different for every farm per input raw material; in Ontario farm, biogas production potential is on average between 1.19 m^3 to 2.5 m^3 per cattle (beef and dairy cattle). For Ontario farm alone, renewable electricity generation capacity which is also economically under attention is 120 MWe. This quantity will be even more if other sources of biogas such as organic wastes, energy productions, animal wastes or other organic compounds are added to it. Considering the FIT program, farms by having 33-77 dairy cattle and 78-122 beef cattle will be economically under consideration for biogas production and farms by having 30 cattle or even fewer which their excreta synthesize with other organic materials, again it is economically significant for energy production (White *et al.* 2011). Hosseini et.al conducted a research about the potential use of bio-energy in Iran. According to this research, bio-energy produced from the waste material could play an important role among other renewable energy sources (Hosseini *et al.* 2014). Hosseini and Wahid examined various methods in biogas combustion such as: biogas conventional, hydrogen-enriched bioga, biogas flameless mode and hydrogen-enriched biogas flameless. They concluded that Flameless combustion of biogas is one the best method among other methods of combustion biogas (Hosseini and Wahid 2014).

In this paper, a rural house with an area of 174 square meters located around Tehran with 4-5 people living in it was considered. Requirement electrical, heating, cooling and domestic hot water loads were calculated. For heating and cooling loads, Carrier HAP 4.5 software was used. With regard to the software outputs, maximum energy needed by farm house was determined. Then, considering the amount of energy needed by farmhouse, the number of needed micro turbine units with a specified nominal capacity was determined. Taking into account the type of fuel, the micro turbine compatible with biogas was selected from Capstone Company and information about micro turbine function and its characteristics was acquired through the manufacturer catalog. In the next step, biogas volume required for setting up microturbine was calculated according to the potential of biogas production in rural areas, the system of using biogas-fueled microturbine was designed and information about the lives of villagers and the number of animals kept by each household was collected. The human and livestock wastes were considered as the main feed of biogas digester and where raw materials of biogas are organic compounds, agricultural and household wastes as secondary feeds of digester were added to animal and human excreta to increase the volume of biogas production. In order to comparison of electricity cost of this system with other resources, detail electricity cost calculation was investigated considering initial, operational and maintenance, engineering costs.

Novelty of this research is as following:

Detail calculation of electrical, heating, cooling and domestic hot water loads of the building in 8760 hours a year

Propose a new method to design a bio-gas fueled micro turbine system according to economical, geographical and rural culture of Iran.

Electricity cost calculation based on meteorological and economic conditions of Iran and comparison with other electrical production systems for rural area in Iran

2. Calculating the electricity, heating and cooling and domestic hot water of energy needs of rural building

In this study, a sample rural villa building with an area of about 174 square meters around Tehran (capital of Iran) has been considered. Tehran is characterized by low yearly speed wind. This city is geographically placed at 35 41′ N latitude and 51 19′ E longitude. Monthly average temperature of this city is shown in Fig. 1 (http://www.irimo.ir).

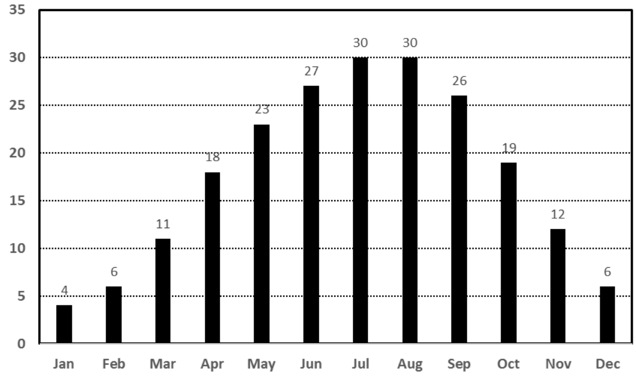

Fig. 1 Monthly average temperature in different months of a year (^{o}C) (Location: Tehran)

Table 1 The rate of electricity consumption of each electrical equipment and operating hours for the fifteenth day of December

Electrical Devices	Consumption electrical power (W)	Working hours
Iron	900	19-19:30
Electrical bulb	110	6-6:30 (2); 6:30-7:00 (3); 16:30-20:00(4); 20:00-23:00 (3)
TV	60	17:00-21:00
Refrigeration	203	All hours
Washing machine	330	9:00-10:30
Other electrical devices	190	18:00-21:00

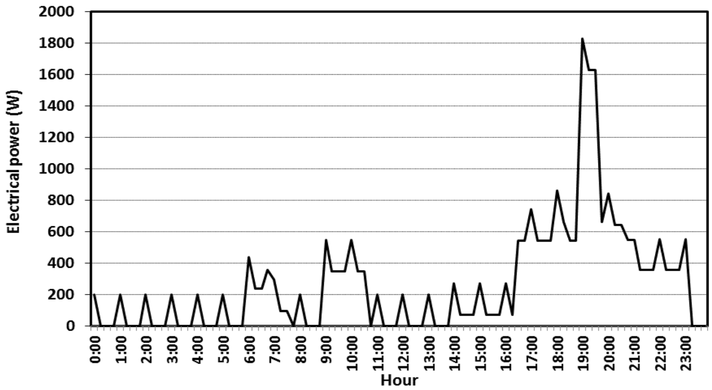

Fig. 2 Total consumption rate of electrical energy for rural villa on the fifteenth day of December

The exterior wall of the building with a thickness of 22 cm and interior wall with a thickness of 12 cm made of brick and plaster and roof of the building with a thickness of 22 cm made of asphalt. The windows areas are 30% and 20% of the areas of south and north walls and east and west walls, respectively.

• Specifications of walls and roof

Color of exterior wall: semi-bright

Type of walls: Brick

The total thickness of the wall: 203.200 mm

The outer surface color of the roof: dark

Type of Roof: Brick

The total roof thickness: 212.740 mm

• Specifications of windows

Single-glazed window

• Information on indoor spaces

The considered building has an area of 174.5 square meters which has three bedrooms, kitchen, hallway, bathroom and a hall. The information on each of these spaces will be considered individually. Each of these spaces are considered as one zone.

Bedroom (1): Area: 20 m^2

Bedroom (2): Area: 16 m^2

Hallway: Area: 23.5 m^2

Kitchen: area: 15 m^2
Main room: Area: 30 m^2
Hall: Area: 70 m^2
The average height of the ceiling to the floor is three meters.

The amount of power consumed by electronic equipment for villa rural building with four people living in it has been calculated. The rate of electricity consumption of each electrical equipment and operating hours for the fifteenth day of December has been brought in the Table 1. Fig. 2 shows the total consumption rate of electrical energy for rural house located around Tehran on the 15th day of December.

In other months of the year with respect to the fact that energy consumed by electrical appliances except for light bulb and refrigerator (such as iron, television and other devices...) is nearly constant. Light bulb electrical consumption is strongly dependent on sunrise and sunset times. So, it can be estimated the time of turn on and off of light bulbs and power consumption. Refrigerator electrical consumption is strongly dependent on temperature of fruits and vegetables that can be placed on refrigerators. It is assumed that these items can be bought every week and at maximum temperature of day. Amount of fruit and vegetables is 8 kg per week. Other food staff can be stored in frozen state. So, difference electrical consumption of refrigerator in other day of a year is calculated. For other electrical appliance such as Iron, Tv…. Is assumed that power consumption is constant. For Validation the model, electrical consumption is measured in three typical day of year 15th of January, 10th of May and 18th of August. Based on comparison between model and measurement electrical consumption maximum deviation is about 3.7%. So, 7% margin for electrical consumption is considered.

The differentials of electricity consumed by refrigerator and lighting is calculated and thus the amount of electricity consumed in other months of the year is calculated. Table 2 shows average amount of power consumed in electrical devices in different months of the year.

Thus, after analyzing conditions of consumption in real mode, the results obtained from the sample have been compared with the amount of electricity bill in different months, that the maximum error is in August and equivalent to 5% and the minimum error is in December

Table 2 Amount of electrical power consumed by electrical appliances in different months

Hour	Jan (W)	Feb (W)	Mar (W)	Apr (W)	May (W)	Jun (W)	Jul (W)	Aug (W)	Sep (W)	Oct (W)	Nov (W)	Dec (W)
0:00	200	190	195	212	246	270	290	280	252	225	210	205
2:00	200	190	195	212	246	270	290	280	252	225	210	205
4:00	200	190	195	212	246	270	290	280	252	225	210	205
6:00	436	426	195	212	246	270	290	280	258	463	210	441
8:00	200	190	195	212	246	270	290	280	252	225	210	205
10:00	545	535	540	557	591	615	635	635	597	570	555	550
12:00	200	190	195	212	246	270	290	280	252	225	210	205
14:00	270	260	262	282	316	340	360	350	322	295	280	275
16:00	270	260	262	282	316	340	360	350	322	295	280	275
18:00	863	853	858	282	437	461	481	471	443	888	873	868
20:00	840	948	758	947	1004	1028	930	1038	1010	888	850	845
22:00	554	544	549	566	600	624	644	634	606	579	564	559

Table 3 Amount of heating load required by the building

Load/hour	Jan (W)	Feb (W)	Mar (W)	Apr (W)	May (W)	Jun (W)	Jul (W)	Aug (W)	Sep (W)	Oct (W)	Nov (W)	Dec (W)
0:00	28998	25545	10400	1200	0	0	0	0	0	3400	17803	25998
2:00	30269	26992	12400	2400	0	0	0	0	0	4232	18886	27043
4:00	31940	28536	15900	4900	0	0	0	0	0	7629	19956	29121
6:00	32060	30200	16900	5700	0	0	0	0	0	8000	20800	30846
8:00	31052	29702	16000	4200	0	0	0	0	0	6600	19950	29500
10:00	29172	28400	14200	2800	0	0	0	0	0	5300	17779	28000
12:00	25800	23600	0	0	0	0	0	0	0	4500	16234	25901
14:00	22500	19732	0	0	0	0	0	0	0	0	15348	21800
16:00	21700	19884	0	0	0	0	0	0	0	0	14000	21442
18:00	24960	21436	0	0	0	0	0	0	0	0	15248	22300
20:00	26242	22841	0	0	0	0	0	0	0	1800	16190	23887
22:00	27901	24332	9700	0	0	0	0	0	0	2231	17000	24890

Table 4 Amount of cooling load required by the building

Load/hour	Jan (W)	Feb (W)	Mar (W)	Apr (W)	May (W)	Jun (W)	Jul (W)	Aug (W)	Sep (W)	Oct (w)	Nov (W)	Dec (W)
0	0	0	0	0	19900	32100	34800	33700	25900	0	0	0
2	0	0	0	0	18062	29100	32900	27200	23500	0	0	0
4	0	0	0	0	15500	25500	28100	25200	20400	0	0	0
6	0	0	0	0	14400	22800	26900	25200	19500	0	0	0
8	0	0	0	0	16200	26200	27900	27200	20800	0	0	0
10	0	0	0	0	19800	30900	29000	31800	22900	0	0	0
12	0	0	0	0	25600	36600	33600	34200	25180	0	0	0
14	0	0	0	0	29800	41800	40000	38600	28700	0	0	0
16	0	0	0	0	31700	41600	43600	42000	32000	0	0	0
18	0	0	0	0	29800	40100	43000	40900	29600	0	0	0
20	0	0	0	0	28100	39100	41500	39020	28100	0	0	0
22	0	0	0	0	24200	35300	39500	37200	26300	0	0	0

equivalent to 0.8%. The average error in general is equal to 2.34%. Carrier HAP 400 software was used to calculate heating and cooling loads of the target house. Accordingly, calculation of heating and cooling loads has been calculated hourly and as average monthly value of heating and cooling load. The working of this software is that, to determine the maximum load heating and cooling, it is necessary to Tehran's climate parameters, parameters related to the building (specifications walls and roof, of windows Specifications and information about the interior of the house) Software is, after entering the information, software calculations in the form of hours per month, according to Tables 3 and show. With regard to the results of implementation of Carrier software, heating and cooling load of intended Village House was obtained. In accordance with the Tables 3 and 4, heating load starts in early September and will continue until late April and we have cooling load which starts from early September and will continue until late April and we have cooling load which starts from mid-May and will continue until late September. The most heating load is at 5 am in January in the winter, in fact, when the air temperature is in its coldest degree; and maximum cooling load is at 15 noon in July, in fact when it is the hottest day of summer.

Fig. 3 shows monthly average of electrical, heating and cooling loads of the rural villa. From this figure, it can be concluded that largest shares of load are related to cooling and heating loads, respectively. Electrical load cannot play an important role for selection of number of IC engine and Organic Rankine cycle.

Fig. 4 shows percent annual consumption of electrical, heating and cooling loads through a year. Only 1.8% of annual consumption is related to electrical energy consumption and other shares are related to heating and cooling loads.

To determine the rate of energy required for hot water, it is assumed that hot water use to be uniformly and between 5 am to 11 pm and in remaining hours of the day not to have any hot water use. Also, cold water temperature has been assumed to be equal to ambient temperature. The energy needs of domestic hot water is determined through the following Eq. (1) (Ehyaei and Bahadori 2007)

$$Q = \rho_w C_w [V_1(T_1-T_0) + V_2(T_2- T_0)] \quad (1)$$

That in this Eq., Q is heating energy need (kJ/day), ρ_w is density of water (kg/l), C_w is specific heat of water (kJ/kg), V_1 is volumetric flow rate of water for shower (l/day), T_1 is temperature of hot water used for bathroom (^oC), T_2 and V_2 are temperature and volumetric flow of washing water and T_0 is the average air temperature plus 5 centigrade degrees (^oC).

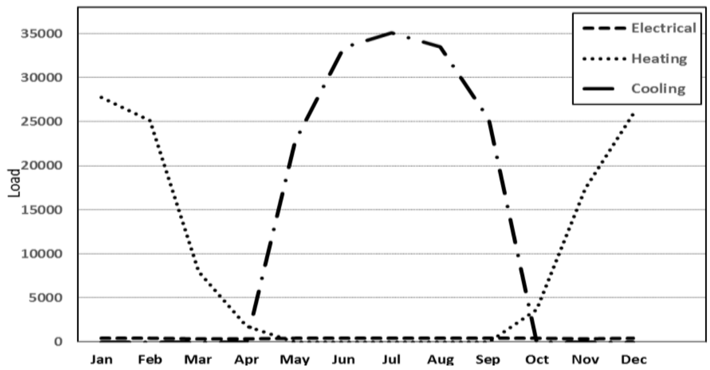

Fig. 3 Monthly average consumption rate of electrical, heating and cooling loads for rural villa on the fifteenth day of December

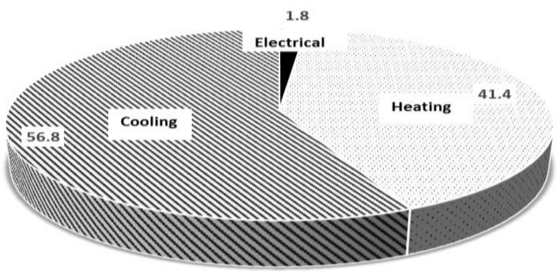

Fig. 4 Percent use of annual cooling, heating and electrical loads for rural villa through a year

3. Calculation number of micro gas turbine unit

The general plan to supply electrical, cooling and heating power as well as domestic hot water a farm house in summer and winter using biogas and microturbine has been presented in Figs. 5 and 6. In Figs. 5 and 6 micro gas turbines produce electricity to meet electrical loads of rural villa. A portion of heating and cooling loads can be met by micro gas turbine. Also, energy in hot exhaust gas of micro gas turbines can be recovered in CHP heat exchanger to meet domestic hot water heater and a portion of heating loads in winter. In summer, a portion of cooling loads can be met by heat pump. Remain of cooling loads can be met by absorption chiller that it uses recovered energy from micro gas turbine exhaust gas in absorption chiller generator. Also, one auxiliary boiler is placed in system shown if Fig. 5. If mentioned system cannot meet cooling load in summer, it will be operated.

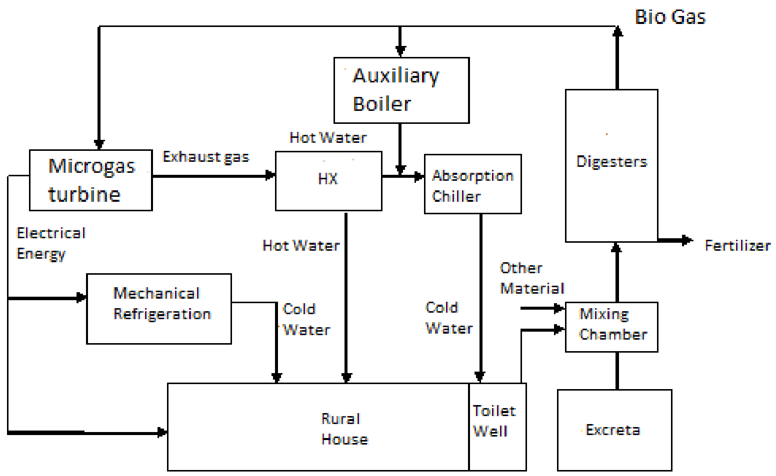

Fig. 5 A schematic of method to supply the energy needed by the rural house using biogas-fueled microturbine in summer

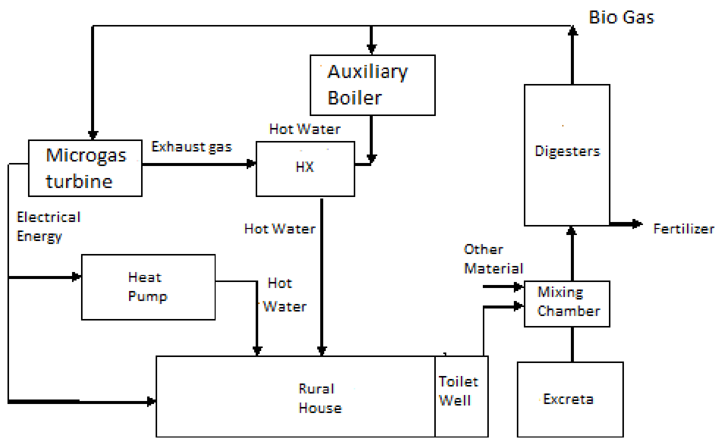

Fig. 6 A schematic of method to supply the energy needed by the rural house using biogas-fueled microturbine in winter

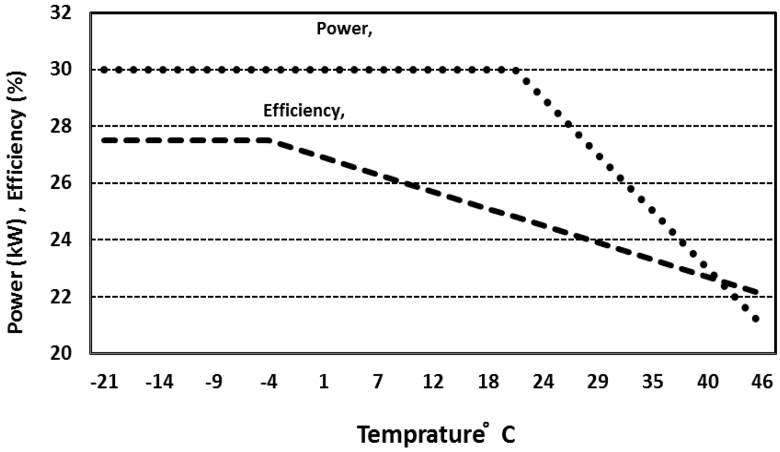

Fig. 7 Changes of e power and η efficiency in Capston C30 microturbine, considering the ambient temperature (www.capstonemicroturbine.com)

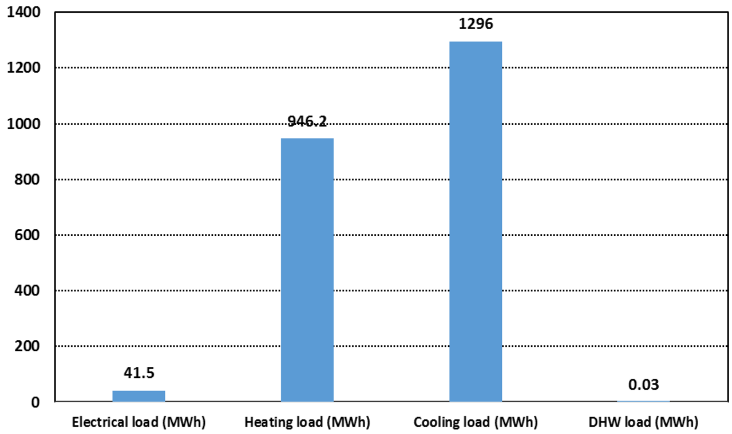

Fig. 8 Diagram of annual consumption of electrical, heating, cooling and DHW loads

Heat recovered from micro gas turbine is calculated by the following Eq.

$$q = e\,(\frac{1}{\eta}\text{-}1) \qquad (2)$$

Where q (kW) is the heat produced by the micro gas turbine, e (kW) is the electric power generated by micro gas turbine.

Eq. (3) can be used to determine the required number of microturbines in cold seasons (Ehyaei and Bahadori 2007)

$$(\mathrm{ne} - \mathrm{e}')\beta_{hp} + \mathrm{nq}\alpha - \mathrm{q}' = Q_h \qquad (3)$$

That in this Eq., n is the number of needed microturbines, e is the electrical power produced by each gas turbine (kW), e is the amount of needed electricity (kW), β_{hp} is coefficient of performance of the heating pump, q is the amount of energy contained in exhaust gas (kW), α is the impact factor of heat exchangers using energy to produce hot water or steam for heating, q' is the amount of energy required for domestic hot water (kW) and Q_h is heating load required by the rural house (kW). The units e, e', q, q' and Q_h are based on kW.

The Eq. (4) can be used for performance in the summer, when the cooling load is required (Ehyaei and Bahadori 2007)

$$(\mathrm{ne} - \mathrm{e}')\beta_{ref} + (\mathrm{nq}\alpha - \mathrm{q}')\beta_{abs} = \mathrm{Qc} \quad (4)$$

That in this Eq., β_{ref} is the coefficient of performance of the heat pump in refrigeration mode, β_{abs} is the coefficient of performance of absorption refrigeration and Qc is the cooling load of rural house (kW).

In this study, Capston C-30 microturbines, with a nominal capacity of 30 kW were considered. This microturbine is the lowest nominal capacity microturbine which is existed in market.

E and η changes for this microturbine considering the ambient temperature is available in the manufacturer's manual (www.capstonemicroturbine.com). Fig. 7 shows changes in e and η of Capston C30 microturbine based on air inlet temperature (www.capstonemicroturbine.com).

Using the Eqs. (3)-(4), the following items are assumed for target system:

β_{hp}=3, β_{ref}=2.5, β_{abs}=0.7 , α=0.8

First, the Eq. (3) is used to find out the number of microturbines. Considering tables 2 to 4, it can be concluded that major portion of electrical load is cooling and heating loads, so number of micro gas turbine is calculated in coldest hour (5 am of 27th of December) and warmest hour (3 pm of 12 July), respectively.

To determine the heating load for 5 am at the morning of 27th of December (Coldest temperature of year) by having the available information and the following values are obtained:

e=30 kW, q′=0.04 kW, Q_h=32.6 kW, e′=0.25 kW, Ta=2.8℃

And

η=27%

By entering these values in the Eq. (3), n is intended equal to 0.3 that one micro turbine is considered.

For the 12th July at 3 pm (Warmest temperature of a year), the values

e=28 kW, q′=0.01 kW, Q_h =44 kW, e′=0.3 kW, Ta=34℃

by entering these values in Eq. (3), n=0.4 or in fact one microturbine was obtained, thus, by having one (1) microturbine all the needs of electrical, heating and cooling energy of the rural house is supplied. Also, maximum value of (ne-e') β_{hp} and (ne-e') β_{ref} is equal to heat pump capacity which is equal to 90 kW. (nqα - q′) β_{abs} is absorption capacity which is equal to 90 kW.

Summary the following steps should be considered to estimation number of micro gas turbine to meet electrical, heating, cooling and domestic hot water loads in residential buildings:

1) Calculation heating, cooling, electrical and domestic hot water loads of a residential building
2) Distinguish an hour in a year that we have maximum cooling energy consumption load
3) Distinguish an hour in a year that we have maximum heating energy consumption load
4) Calculate electrical production by Fig. 7 for this hour
5) Calculate number of micro gas turbine unites by Eqs. (3) and (4)
6) Calculate amount of organic waste material

Fig. 8 shows diagram of annual demand of energy through a year.

For control system, based on the load consumption, system can be worked based on the percent of nominal capacity.

4. Calculation biogas tank volume

In order to determine the potential of biogas production, biogas production volume in terms of cubic meters for each cattle must be identified. Additionally, the potential of biogas production in terms of cubic meters from different types of material entering the digester should be available. The gas production volume based on the weight of each cattle is different, whatever weight of cattle is more and has a better nutrition, the volume of biogas produced from cattle excreta will be more. Also, methane compounds available in biogas depends on the type of cattle diet. In this study, the amount of methane in the produced Biogas is assumed to be 60%. The biogas production potential of each animal based on various sources has been brought in Table 5 (White *et al.* 2011).

Table 5 Biogas production potential of each animal based on various sources (White *et al.* 2011)

Sources	Biogas production potential of each animal based on various sources
Burke	89.1
Nelson	84.1
Nelson	28.3
Wood	42.1
US EPA	19.1
OMAFRA	2.5

Table 6 Potential of biogas production from livestock waste (White *et al.* 2011)

Number of animals	Bio-gas production Nm^3/year	Energy production MJ/year
1-5	2800	65266
5-10	5600	130533
10-15	8400	195800

Table 7 Compound of produced biogas (Karellas *et al.* 2010)

Composition	CH_4	CO_2	N_2	H_2S
Mole fraction (%)	60	25	14	<1-10 (mg/m^3)

Table 8 Volume of biogas produced from a variety of organic waste materials in the digester (White *et al.* 2011)

Inlet material	Bio gas production volume lit/kg
Municipal wastes	380-550
Mixture wastes	450
Kitchen waste	420
Liquid waste	160-640
Crop residue	550
Biomass	680

Table 9 Volume of biogas produced in the rural house (White *et al.* 2011)

Inlet material to biogas tank	Material (kg/day)	Bio gas production (m^3/day)
Human excreta (4-5)	1.2-1.5	0.6-0.75
Hen excreta (20)	1.5	0.82
Agricultural wastes	6	4-5
Cow and sheep excreta (10-20)	1.5	10-20
Household waste (4-5)	3.2	1.6

Based on the table above, the average biogas production per animal per day will be between 1.5 to 2 cubic meters. By carried out investigation in villages around Tehran, it became clear that if any of rural families has more than 3 dairy cows, they are economically in a good position and if the number of dairy or beef cattle is less than 3, they are economically weak. To calculate the volume of biogas tank, it is necessary to determine the number of cattle and raw material entering the biogas tank. Therefore, the number of livestock was considered between 3 and 15 cattle per household. Table 6 shows the potential of biogas production from livestock waste (White *et al.* 2011).

Table 7 shows the composition of the produced biogas (Karellas *et al.* 2010). A pressure booster is required to increase the fuel pressure to enter the combustion chamber.

The volume of biogas entering microturbine if two days is concerned for gas storage is calculated as follows (8-9)

$$V_{pb}= n(v_f 86400 m_f) \tag{5}$$

in which, n is number of storage days, m_f is fuel mass flow rate (kg/sec) and v_f is fuel specific volume (m^3/kg).

Based on the above tables and Eq., the volume of biogas to set up microturbine for one day is equivalent to 33.5 cubic meters and for gas storage in two days is equivalent to 67 cubic meters. As a result, digester tank must have a volume of 33.5 cubic meters. According to Table 6, if a rural family has an average of 5 to 10 cattle, the potential of produced biogas is equal to 2800-5600 m^3/year and will be approximately 8-20 m^3/ day and this amount of produced biogas will not be enough to supply fuel of microturbine; so, to increase the produced biogas, it is necessary to enhance amount of materials entering biogas digester. Given that the number of people living in the rural house is 4-5 people and each person produces 0.8-1 kg of garbage per day and 80% of them are organic materials, therefore, this amount of produced garbage can be added to raw material entering the biogas digester and since in addition to animal husbandry, agriculture is the main occupation of villages around Tehran, agricultural wastes can also be part of the raw material input to the digester tank. Table 8 shows the volume of biogas produced from waste products (White *et al.* 2011).

According to Tables 5 to 8, the materials entering the biogas digester for a rural house can be considered as follows: in the target rural house 4 or 5 people are living that this family supplies their life the needs from traditional livestock and farming, this family kept an average of 5 to 10 cows and 10 chickens in their stable. In order to supply the biogas needed for setting up the microturbine, it is necessary to connect toilet well of house as well as stalls to the digester by PVC pipes. To increase the efficiency, when using several kinds of input materials, it is necessary to mix materials with each other before entering the tank. The volume of Biogas produced in target rural house has been shown in Table 9. (White *et al.* 2011).

A common method for providing feed to the bioreactor is as follows:

1-water at a rate of 50%

2. Livestock waste, organic waste and stems of plants (40%)

3- Excreta (with moisture) (10%)

According to the new scientific estimations, fresh excreta produce methane gas three times more than old excreta. Considering foregoing, the amount of produced biogas can be increased up to 30 m^3/ day. The size of biogas tank or reservoir to store the input material for gas production depends on the number of livestock kept by each rural household and the amount of raw materials entering the reservoir. Generally, calculation of the volume of biogas digester depends on excreta and residuals generated in each house, retention time in the tank, degree of concentration of input materials, amount of water in raw materials and so on. The following formula can also be used to calculate the volume of the tank (White *et al.* 2011)

$$V=V_{gas} + V_{dig} \tag{6}$$

that in this Eq. V_{gas} is the volume of gas in the digester chamber (m^3), V_{dig} is the volume of input material in the tank (m^3). V_{dig} and V_{gas} are obtained from Eqs. (7) and (8) (White *et al.* 2011)

$$V_{dig} = T \times V_{dm} \tag{7}$$

$$V_{gas} = h \times S \tag{8}$$

that in this Eq. T is the retention time of livestock waste and input materials in tank (day), S is the smooth surface of tank floor based on square meters, h is the distance from tank floor up to static surface of liquid inside the digester (it is usually between 35 to 40 centimeters up to one meter) (m) and V_{dm} is calculated from the following Eq. (White *et al.* 2011)

$$V_{dm} = (w+nL)T \tag{9}$$

where w is the amount of water needed to dilute input materials per cow or kg of input materials (m^3/day), n is the number of livestock and L is the amount of livestock waste that each one produces during the day (m^3/day). The best mode of dilution is 1:5 ratio of water to input materials; by entering 5 nL in Eq. (9) and the Eqs. (6), (7) and (8) we will have (Hosseini *et al.* 2014)

$$V=Vgas + (5\ nL+nL)\ T= Vgas +6\ nLT = hS + 6\ nLT \tag{10}$$

For a rural family, by having 5 to 10 dairy cows, tank volume will be calculated as follows:

The number of dairy cows: 5 to 10 heads

The rest of input material: 30 liters

Retention time in the tank: between 30 to 40 days

The length of biogas tank: 4.8 m

The width of biogas tank: 3 m

By having the above information, we will have:

n (number of cows) = 5 to 10 heads

T (retention time) = 40 days

L_1 (the amount of excreta produced by each animal) = 4 (Liters / day)

L_2 = 30 (Liters / day)

And height of the tank is equal to 2.2 meters and its volume will be about 31.2 cubic meters. If the number of livestock increases or input food to the digester increases, volume of the tank will become greater.

5. Economic feasibility study of the biogas system

The objective function to calculate the cost for electricity produced from gas turbine system is defined by following equations. (Horgren 1992)

$$C_E = C_1 + C_O + C_F \tag{11}$$

C_E is the cost of electricity, C_1 is the cost of initial installation, C_o is the cost related to maintenance, C_F is the cost of fuel. Units of all are (US$/kWh).

The cost of electricity related to initial installation cost can be calculated from the following Eq. (Horgren 1992)

$$C_I = \frac{CI}{C_f\, 8760 \dot{W}_{net}} \tag{12}$$

C is initial installation cost of ($) and I is profit of initial cost, C_f is capacity factor which is calculated by the following Eq.

$$C_f = \frac{e_{mean}}{e_{nominal}} \tag{13}$$

e_{mean} is annual average electricity production by system (kW) and e_{nominal} is nominal power production of system (kW)

The initial cost benefit is calculated as the following Eq. (Horgren 1992)

$$\mathrm{I} = \frac{1}{12}\frac{\mathrm{i}(1+\mathrm{i})^{\mathrm{L}}}{(1+\mathrm{i})^{\mathrm{L}} - 1} \tag{14}$$

L is lifetime of gas turbine (Year), which is equal to 20 years and i is interest rate which is equal to 3% per year.

The cost of maintenance is considered to be equivalent to 4% of initial installation cost.

The cost of fuel price is calculated by the following Eq.

$$C_F = \frac{Fuel\,\mathrm{cost}\ (\frac{US\$}{kWh})}{\eta_I} \tag{15}$$

The cost of machinery and equipment required for starting up the system is as Table 10.

The cost of materials and components used for construction, installation and commissioning of microturbine and biogas system is as Table 11. Summary of costs, are summarized in Table 12.

Table 10 Cost of machinery and equipment (White *et al.* 2011)

No	Equipment	Number	Cost (US$)	Cost (US$/kW)
1	Purchase and installation of micro gas turbine	1	57000	1900
2	Biogas digester	1	3800	126.7
3	Gas compression	1	8700	290
Total: 69500 (US$) or 2316.7 (US$/kW)				

Table 11 Cost of necessary materials and components

No.	Description	Unit	No.	Unit cost (US$)	Total cost (US$)	%
1	Brick (6×10×20)	No	4,200	0.04	156	4,73
2	Cement	Bag (50 kg)	36	1.2	43	12
3	Sand	Bag (40 kg)	5	2.86	14.3	4
4	Gravel	m3	2	2.86	5.7	2.1
5	Steel pipe	No	1	4.29	4.3	2.1
6	PVC (mm 20)	m	12	0.29	3.4	1
7	Elbow (PVC)	Bag	4	1.43	5.7	6.1
7	Pipe to conveying gas to micro gas turbine	m	50	0.29	14.5	4
9	pipe lines	Pack	1	14.3	14.3	4
10	Others: Jimmy, Shovel, Pick, Basket	No	1	100	100	8.27
Total cost: 361.2 (US$) or 12.04 (US$/kW)						

Table 12 Summary of costs

No.	Description	(US$)	(US$/kW)
1	Total Equipment	69500	2316.7
2	Labor/Materials	361	12.04
3	Project & Construction Management	7500	250
4	Engineering and Fees	6900	230
5	Project Contingency	2100	70
6	Total Other Costs	15000	50
Total cost: 101361 (US$) or 3378 (US$/kW)			

Regarding to Tables 10-12 and Eqs. (11)-(15), cost of produced electricity is equal to 0.466 US dollars per kilowatt hour.

By comparison this cost with other electricity production systems, following sentences can be concluded:

• In comparison cost of electricity with micro gas turbine or IC engine employing natural gas as a fuel, this system is not economical due to low cost of natural gas in Iran (Ehyaei and Mozafari 2010), (Ehyaei *et al.* 2010).

• In comparison with fuel cell with after burner and reformer employing natural gas, cost of electricity produced by mentioned system is less than half of cost of electricity produced by fuel cell system with urban gas (Ashari *et al.* 2012). Since initial cost of fuel cell system is more than twice of PEM fuel cell system (Ashari *et al.* 2012).

• Costs of electricity produced by wind turbine, photovoltaic and hybrid system are more than studied system in this paper, 110%, 45% and 83%, respectively (Mohammadnezami *et al.* 2015).

• In order to reduction of electricity cost produced by studied system, the following methods can be applied:

-Production of micro gas turbine with nominal capacity less than 30 kW in order to increase of capacity factor near one (Eq. (13)). So initial cost of system will be reduced (Eq. (12))

-Biogas micro gas turbine meets electrical loads of rural area included 3 or 4 rural buildings that maximum electrical consumption is near micro gas turbine capacity, so capacity reaches around one, so electricity cost will be reduced.

-Since a majority portion of electrical loads is related to heating and cooling loads. So by the following methods, electricity cost can be reduced:

1) Employing double-glazed window
2) Insulate walls, roofs and ceiling of rural building
3) Use curtain in sunny hours in summer

By employing these methods, cooling and heating loads can be reduced 59% and 86%, respectively.

• Employing IC engine with biogas instead of micro gas turbine. Since initial cost of IC engine is less than micro gas turbine and different nominal capacities of IC engine coupled with generator.

6. Conclusions

In this study, the use of a micro gas turbine system using biogas to supply heating, cooling and electricity of a rural building in an area of 174 square meters located around Tehran with maximum need of 1.83 (kW) electricity, 0.45(kW) of hot water, 32.6 (kW) of heating load, and 44(kW) of cooling load has been studied. This research found that 1 set microgas turbine with 33.5 m^3/day of bio gas was needed to meet electrical, heating and cooling loads of rural building. Digester tank and reservoir tank volumes are 67 m^3 and 31.2 m^3, respectively. Cost of electricity for this system is 0.446 US$/kWh. For rural area in Iran, this system is not compatible with micro gas turbine and IC engine system use urban natural gas due to low price of natural gas in Iran, but it can be compatible by wind turbine, photovoltaic and hybrid system (wind turbine& photovoltaic) systems.

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