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Investigation of a Small Scale Wind Turbine-Heat Pump Hybrid System for a Detached House

Levent Bilir[#1], Nurdan Yildirim[#2]

[#1,2]Department of Energy Systems Engineering, Yaşar University
Üniversite Caddesi, No:37-39, Ağaçlı Yol, Bornova, İzmir, TURKEY.

[1]levent.bilir@yasar.edu.tr
[2]nurdan.yildirim@yasar.edu.tr

Abstract

Heat pumps are widely used in order to meet cooling and heating needs of residential buildings and houses. Even if the thermal energy supplied by heat pumps is greater than the electrical energy they consume, a great amount of annual electricity consumption is present for the operation of such devices. Although the electricity consumption of these devices decreases as their efficiency (COP) value increases, the source of the electricity they consume is a major problem. If all or a portion of the electrical energy consumption can be covered from renewable energy resources, the emission of greenhouse gases, produced in electricity generation using conventional plants, may be lowered. In the present study, a 100 m^2, single storey, detached residential house in Bornova region of İzmir, Turkey is considered. The monthly and annual heating and cooling energy need values of the house, performed using Energy Plus software, is taken from a previous study. The electricity consumption of a selected ground source heat pump (with a COP value of 4 in heating and 3 in cooling), which will supply the necessary annual cooling and heating needs of the house, is calculated. A small scale wind turbine is taken into account in order to generate the required electricity consumption of the heat pump. Finn Wind Tuule E200 wind turbine is selected in the study because of its smaller cut-in and rated wind speed values, which enable a high capacity factor value. In order to calculate wind turbine annual electricity generation value, monthly Weibull distribution function parameters, derived in another study performed for Bornova region, are used. Consequently, estimated monthly and yearly electrical energy generation amount of the wind turbine for the region is calculated. As the result, it is estimated at what level the heat pump electricity consumption can be covered using the selected small scale wind turbine. The results indicate that the total annual electricity consumption of the heat pump is 4541.67 (kWh) and a great percentage (about 68.9%) of this electrical energy need can be supplied by the selected wind turbine.

Keywords – small scale wind turbine, ground source heat pump, hybrid system

1. Introduction

Residential buildings need a considerable amount of energy for heating and cooling purposes. Heat pump systems are generally accepted as an efficient way to cover these needs since they supply more heat or cool than their electricity consumption. However, the annual electricity consumption for the operation of such devices is still high. If all or a portion of the electrical energy consumption of these devices can be covered from renewable energy resources, the emission of greenhouse gases, produced in electricity generation using conventional plants, may be lowered. For this purpose, a small scale wind turbine is considered to supply electrical energy need of a heat pump, which will in turn provide the required heating and cooling for a 100 m^2, single story, detached residential house. The house was modeled and the required heating and cooling needs were calculated using Design Builder and Energy Plus softwares in [1, 2]. Using the Weibull parameters for Bornova region in İzmir, Turkey, derived in [3], monthly electricity generation of the selected wind turbine is determined. Finn Wind Tuule E200 wind turbine is selected in the study because of its smaller cut-in and rated wind speed values, which enable a high capacity factor value. As a result, it is estimated how much of monthly and yearly electricity need of the selected heat pump can be supplied by the selected wind turbine. The coefficient of performance (COP) value of heat pumps depends on the heat source they use. Since there is relatively small temperature change inside soil, ground source heat pumps can typically achieve a COP value of 4 in heating and a COP value of 3 in cooling. In this study, the use of a ground source heat pump is considered to cover the heating and cooling demand of the examined house.

As wind energy is a free, renewable energy resource, the use of wind turbines are widespread in appropriate regions for different purposes, ranging from water pumping to assist heat pump systems for residential houses. Small scale wind turbines are more appropriate for the regions where average wind speed value is relatively low. On-grid and off-grid applications are possible for small scale wind turbines. Li et al. [4] considered the average annual electricity consumption of a house in Ireland and investigated the economic viability of six different micro wind turbines for domestic applications. Hedegaard and Münster [5] examined the effect of heat pump usage on wind power investments in Denmark. They concluded that individual heat pumps facilitate wind power plant installations. Another heat pump use with wind power integration application was investigated by Ostergaard [6] for Aalborg municipality. Waite and Modi [7] took into consideration the electricity consumption of heat pumps for space heating and domestic hot water production in New York and examined large scale wind power coupling with the mentioned electrical need. Campana et al. [8] compared the use of photovoltaic panels and wind turbines for water pumping in in China. Girard et al. [9] examined solar thermal collector assisted ground source heat pump use for residential buildings in 19 different European cities. They reported that

COP value ranges between 4.3 and 5.1 in the case there is no assistance for ground source heat pump, and COP value changes between 4.4 and 5.8 when ground source heat pump is assisted with solar collectors.

2. Investigated House and Its Monthly Heating and Cooling Needs

The house taken into consideration is illustrated in Fig. 1 [1]. It is a one storey detached house in İzmir city, Turkey. The house with a living room, a kitchen, a bathroom and two living rooms, was modeled using Design Builder software [1].

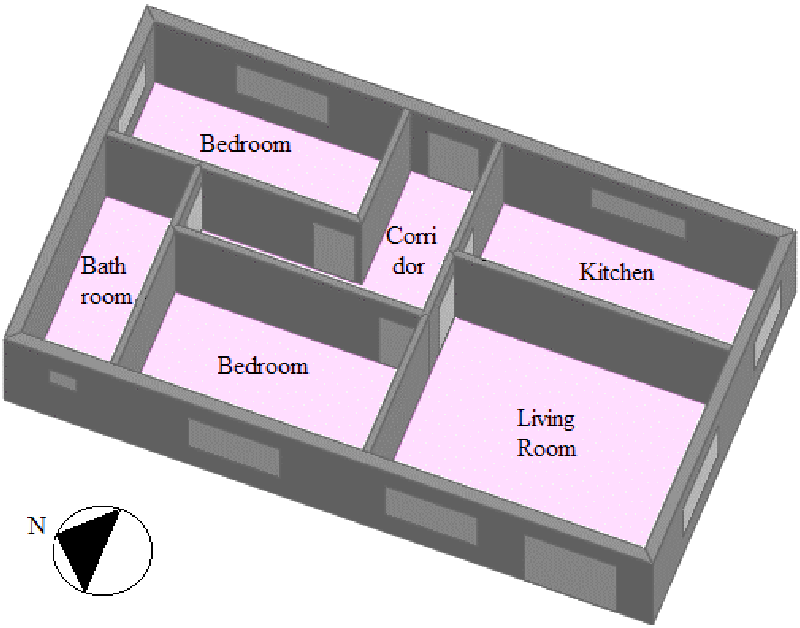

Figure 1. View of the investigated house [1]

The construction material areas are summarized in Table 1 along with their directions [1].

Table 1. Area Values for the Investigated House [1]

	Floor area (m^2)	Direction	Net wall area (m^2)	Window area (m^2)	Door area (m^2)
Living Room	28.85	S	10.60	2.60	-
		W	9.73	2.60	4.20
Bedroom	14.50	N	5.43	1.89	-
		E	12.39	2.60	-
Bedroom	18	W	12.39	2.60	-
Kitchen	16	S	5.37	1.95	-
		E	14.73	1.85	-
Bathroom	9.60	N	13.20	-	-
		W	5.14	0.36	-
Corridor	13.50	E	3.19	-	2.31
Total Area	100.45				

The cooling and heating needs of the aforementioned house were calculated using Energy Plus software for each month in [1]. The indoor design temperature was selected as 22 (^oC) in heating season and 26 (^oC) in cooling season. Additionally, the occupancy of the house was assumed as given in Table 2 [1].

Table 2. Occupancy Scenario and Operation Regime for the Investigated House [1]

		Week days	Weekend days
Occupied Hours	Heating	18:00-08:00	Whole day
	Cooling	18:00-08:00	Whole day
Operation regime	Heating	17:00-08:00	Whole day
	Cooling	18:00-24:00	11:00-24:00

Monthly heating and cooling requirement according to these assumptions, taken to be used in the present study, are given in Table 3.

Table 3. Heating and Cooling Need of the Investigated House [1]

Month	Heating Need (kWh)	Cooling Need (kWh)
January	2984.4	0
February	2676	0
March	2133.6	0
April	1383.2	0
May	389.7	121.5
June	0	254.1
July	0	301.4
August	0	261.2
September	243.1	159.7
October	1229.5	0
November	2264.1	0
December	3399.2	0
Total	16702.8	1097.9

It is seen that the total heating and cooling need of the house is 17800.7 (kWh) yearly.

3. Selected Small Scale Wind Turbine

A Finn Wind Tuule E 200 wind turbine, which is connected to electricity grid, is taken into consideration in the study so that there will be no need to store the electrical energy with batteries. The hub height of the wind turbine is selected as 12 (m) and its rated output power is 3600 (W), the cut-in and rated wind speed values for the wind turbine are 2.1 (m/s) and 10 (m/s), respectively [10].

4. Weibull Parameters for Bornova Region, İzmir

Weibull distribution function given in (1) is generally used in order to express the wind speed probability at a region.

$$\boldsymbol{f(v)} = \left(\frac{\boldsymbol{k}}{\boldsymbol{c}}\right)\left(\frac{\boldsymbol{v}}{\boldsymbol{c}}\right)^{\boldsymbol{k-1}} \boldsymbol{exp}\left[-\left(\frac{\boldsymbol{v}}{\boldsymbol{c}}\right)^{\boldsymbol{k}}\right] \tag{1}$$

where, f(v) is the probability of observing the wind speed v, k and c are the shape and scale parameters of Weibull distribution, respectively.

The two Weibull parameters for Bornova region were calculated using a 5-year wind speed data collected at 15 m height from a measurement station, which is installed at Solar Energy Institute at Ege University in Bornova region [3]. The scale and shape parameters found in [3] are given in Table 4.

Table 4. Weibull Parameters for Bornova Region at 15 m Height [3]

Month	k	c (m/s)
January	1.616	3.514
February	1.437	3.007
March	1.645	3.445
April	1.598	2.432
May	1.475	2.670
June	1.563	3.232
July	1.720	3.893
August	1.705	3.652
September	1.551	3.015
October	1.544	3.272
November	1.518	3.062
December	1.544	3.497

Weibull parameters at a different height using the known parameters can be calculated using the following relations [11].

$$k_z = k_a \times \frac{\left[1-0.088\times ln\left(\frac{z_a}{10}\right)\right]}{\left[1-0.088\times ln\left(\frac{z}{10}\right)\right]} \tag{2}$$

$$c_z = c_a \times \left(\frac{z}{z_a}\right)^n \tag{3}$$

$$n = \frac{[0.37-0.088\times ln c_a]}{\left[1-0.088\times ln\left(\frac{za}{10}\right)\right]} \tag{4}$$

where, k_a and c_a are the parameters at the measurement height (z_a) and k_z and c_z are the parameters at the desired height (z).

The values in Table 4 are used in the present study in order to calculate Weibull parameters at 12 (m) height, which is the hub height of the selected wind turbine. The shape and scale parameters at 12 (m) height for each month are tabulated in Table 5.

Table 5. Weibull Parameters for Bornova Region at 12 m Height

Month	k	c (m/s)
January	1.584	3.309
February	1.408	2.823
March	1.612	3.243
April	1.566	2.273
May	1.446	2.500
June	1.532	3.039
July	1.686	3.674
August	1.671	3.442
September	1.520	2.831
October	1.513	3.077
November	1.488	2.876
December	1.513	3.293

5. Power Generation Estimation and Total Electrical Energy Provided by the Selected Small Scale Wind Turbine

Having known the wind turbine characteristics and the Weibull parameters at the hub height, the average power generation of a wind turbine (P) can be calculated as [12];

$$P = P_R \times \left[\frac{exp\left[-\left(\frac{v_{ci}}{c}\right)^k\right] - exp\left[-\left(\frac{v_R}{c}\right)^k\right]}{\left(\frac{v_R}{c}\right)^k - \left(\frac{v_{ci}}{c}\right)^k} - exp\left[-\left(\frac{v_{co}}{c}\right)^k\right] \right] \qquad (5)$$

where, v_{ci}, v_R and v_{co} are cut-in, rated and cut-out wind speed values, respectively.

Using (5), the monthly average power generation estimation values for the selected small scale wind turbine are summarized in Table 6.

Table 6. Average Power Generation Estimation for the Selected Small Scale Wind Turbine

Month	Average Power Generation (W)	Month	Average Power Generation (W)
January	415.64	July	480.36
February	349.29	August	419.18
March	385.75	September	307.76
April	160.14	October	377.98
May	248.73	November	332.15
June	359.91	December	439.63

Using the average power generation values, the monthly electrical energy that the small scale wind turbine can provide to the grid are calculated and presented in Table 7. As a result, it can be seen that the selected wind turbine provide a yearly total of 3128.75 (kWh) electrical energy to the grid.

Table 7. Monthly Electrical Energy Generation of the Selected Small Scale Wind Turbine

Total Day #	Month	Monthly Energy Generation (kWh)	Total Day #	Month	Monthly Energy Generation (kWh)
31	January	309.24	31	July	357.39
28	February	234.72	31	August	311.87
31	March	287.00	30	September	221.59
30	April	115.30	31	October	281.22
31	May	185.05	30	November	239.15
30	June	259.13	31	December	327.09
			365	Total	3128.75

6. Comparison of the Heat Pump Electrical Energy Need with the Electrical Energy Generated by the Selected Wind Turbine

A ground source heat pump is selected in order to cover the heating and cooling need of the house. As the main purpose of the study is to demonstrate what percentage of the electrical energy need of a typical heat pump can be covered by the selected small scale wind turbine, detailed COP calculations are not included in the study. Instead, a typical COP value of 4 in heating and 3 in cooling are selected for the considered ground source heat pump. In this case the electrical energy needed for this heat pump according to the heating and cooling need of the house are calculated and summarized in Table 8.

Table 8. Comparison of Heat Pump Electrical Energy Need and Wind Turbine Electrical Energy Generation

Month	Electrical Energy Need of Heat Pump (kWh)	Electrical Energy Provided by Wind Turbine (kWh)	Coverage Ratio (%)
Jan	746.10	309.24	41.5
Feb	669.00	234.72	35.1
Mar	533.40	287.00	53.8
Apr	345.80	115.30	33.3
May	137.93	185.05	134.2
Jun	84.70	259.13	305.9
Jul	100.47	357.39	355.7
Aug	87.07	311.87	358.2
Sep	114.01	221.59	194.4
Oct	307.38	281.22	91.5
Nov	566.03	239.15	42.3
Dec	849.80	327.09	38.5
Total	4541.67	3128.75	68.9

The results indicate that, the selected small scale wind turbine is unable to cover all the monthly electrical energy need of the heat pump between October and April. However, it can produce more electrical energy than the monthly need of the heat pump, which can be given to the grid, between May and September. A total of 3128.75 (kWh) electrical energy is estimated as the yearly electrical energy generation of the wind turbine. This amount can cover 68.9% of the yearly electrical energy need of the selected heat pump, which will provide necessary heating and cooling for the investigated house.

7. Conclusions

The use of a ground source heat pump is considered for a 100 m^2, one storey, detached house in İzmir, Turkey. The monthly heating and cooling demand of the house is taken from a previous study and the monthly electricity need of the heat pump is calculated, taking its COP value as 4 in heating and 3 in cooling. The monthly electrical energy generation of the selected Finn Wind Tuule E 200 turbine is calculated using its characteristics and the Weibull parameters at its hub height, derived from the parameters calculated for Bornova region in a previous study. The results show that the selected small scale wind turbine can supply all electrical energy need of the heat pump between May and September, while it is unable to cover all of the heat pump electrical energy need between October and March. However, as the wind turbine is operated as on-grid, the surplus energy generation in the relevant months can be given to the grid and the electrical energy lack in the relevant months can be covered from the grid. It is seen that the yearly electrical energy generation of the wind turbine is 3128.75 (kWh) while the ground source heat pump yearly electrical energy need is 4541.67 (kWh) to provide necessary heating and cooling to the investigated house. Hence, it is concluded that 68.9 % of the heat pump electrical energy need can be covered by the selected wind turbine in a yearly base.

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