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Investigation of District Heating System by Utilizing Waste Heat Sources of a Biogas Plant

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Abstract: The heating day degree method has been studied in this work. A new approach was taken to meet the energy demands of a building in the countryside. Calculation of the thermal requirements was made by considering TS 825 standard. The waste heat potential of gas engine in the biogas plant is determined. In the calculations done, utilization rate of the waste heat of biogas plant with the consumption scenario for a dormitory is determined. Consequently, the building is heated more efficiently and 13.66% saving is achieved. An environmentally friendly system is designed and less CO_2 released to the atmosphere.

Keywords: *District heating, energy efficiency, performance, biogas plant, cogeneration.*

Introduction

Using energy resources efficiently and minimize the environmental impacts requires great consideration (Hergul *et al.*, 2016). In a region with high energy density buildings, the most efficient heating system for sustainable rural development can be achieved with district heating systems. The first example of regional district heating in the world has been implemented in cold northern European countries. In Denmark (Copenhagen), garbage was collected by horse carts and the first garbage incineration plant was established in 1903 and steam production and heating were done (Werner, 2017). Numerous systems have been established in Europe, particularly in Germany, Finland and Greece, for the purpose of district heating (Zhang & Lucia, 2015). The projects usually have been developed for the use of waste heat released from thermal power plants. Currently, biomass-based regional district heating systems are not widely known in the world. However, both economic and environmental benefits can be made with cost-effective evaluations (Hendricks *et al*., 2016).

Providing heating with biomass or waste heat is important because of lowering the CO_2 level of the atmosphere by avoiding emissions (Madlener & Koller, 2007). Calculations made with the emission reduction approach required that the average emission value of each fuel should be known, as well as the overall efficiency of the system and the calculation of the primary energy content. Execution of the work is done according to defined standards so that system boundaries can be drawn more easily. Çanakçı and Elele (2001) calculated using the current climatological database. There are many models developed in the calculation of the heating requirement and the climatic model is one of them. In the previous models developed for this purpose, scenarios are drawn based on monthly average temperature values and carbon dioxide emission value is taken as a reference (Cartalis et al., 2001). Different parameters are taken into account in terms of area selection in district heating systems. The performance evaluation of the building varies depending on the insulation condition of the building and the desired comfort conditions (Kohler et al., 2016). In this study, the heating demand of the building, as well as usage water requirement determined. Waste heat energy of a biogas power plant analysed and energy, environment and economic analysis performed to meet the heating and hot water demands of a building which is close to the biogas power plant using the environmental energy production technologies.

Materials and Methods

The TS 825 standard includes thermal insulation rules in buildings. For this purpose, using a calculation program (IZODER) TS 825 the annual total heating energy requirement by summing daily average heating energy needs based on the heating degree day rating and accepting the building as a

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whole. The concept of heating degree day (HDD) can be used in the design of district heating systems. The purpose of this study is to determine building energy demand using simple correlations. In the study, the threshold temperature value was determined to take into account the comfort conditions. In addition to the reference external temperature value, internal activities such as lighting, cooking or solar energy gains, reference internal temperature which is 19 ºC will rise up to 21 ºC to 22 ºC degree. Comfort conditions are provided in this view. The table below gives HDD and CDD (cooling degree day) values for the Kocaeli province.

Table 1. General directorate of meteorology HDD-CDD values for Kocaeli

Province	G/D	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Oct	Sep	Now	Dec	Year
Kocaeli	HDD	329	274	270	184	3					41	106	323	1530
	T≤15 °C	29	25	29	24	1					9	20	31	168
	CDD					6	10	90	127	56				289
	T>22 °C					7	7	30	31	26				101

The cost of heating is directly proportional to the one-year heating degree day concept. For this purpose, annual heating costs are deducted from the cost of heating an HDD by dividing the annual heating day by year. This value is referred to in subsequent calculations. The use of heat recovery equipment for the efficient use of energy becoming widespread and payback period can be reduced due to increases in energy costs (Selbaş, 1992).

$$Q_{mon}=\left[H(\theta_i-\theta_e) - \eta_{mon}(\phi_{i,mon}+\phi_{s,mon})\right]\times t \quad (1)$$

Thermal losses & Thermal gains

Specific heat losses (H) are the sum of the losses due to conduction and convection (HT) and ventilation (HV).

- Heat loss by conduction;
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$$H_T = \sum AU + IU_I \quad (2)$$

$$\sum AU = U_D A_D + U_p A_p + U_k A_k + 0,8\, U_T A_T + 0,5\, U_t A_t + U_d A_d + 0,5 U_{ds} A_{ds} \quad (3)$$

- Heat loss through ventilation;

$$H_V = \rho.c.V^I = \rho.c.n_h.V_h = 0,33.n_h.V_h \quad (4)$$

- Heat gain calculations is done as following in residential buildings;

$$\phi_{i,mon} \leq 5\times A_n \ \ (W) \quad (5)$$

$$A_n = 0,32\times V_{gross} \ \ (m^2) \quad (6)$$

- Monthly average solar energy gain;

$$\phi_{s,mon} = \sum r_{i,mon}\times g_{i,mon}\times I_{i,mon}\times A_i \quad (7)$$

$$g_{i,mon} = F_w\times g_{i,mon} \quad (8)$$

$$\text{Solar heat gain; } \phi_{s,mon} = \sum r_{i,mon}\times g_{i,mon}\times I_{i,mon}\times A_i \quad (9)$$

$$\text{Gain loss ratio; } GLR_{mon} = (\phi_{i,mon}+\phi_{s,mon})/H(\theta_i-\theta_e) \quad (10)$$

$$\text{Gain usage factor; } n_{month} = 1-e^{(-1/GLR_{month})} \quad (11)$$

At the point of using energy efficiently, conscious consumption habits, as well as the efficiency of the system, are also important. The design of the heat distribution center in district heating systems is also important. In addition to the selection and sizing of system components, ease of operation affect the total system' technical economic life. The profit margin in such enterprises is not very high. For this reason, additional revenues can be vital for that kind of plants. Also, in the power plants cooling towers or dry coolers are currently used to remove waste heat. The removal of this heat is also cost money and in terms of plant operation which means domestic consumption.

Results

The following table shows biogas engine parameters. The distance from the biogas plant to the building is 150 meters away. Using mathematical equations given in the previous section calculated the total heat loss through conduction from the building is 4665.4 W/K. Heat loss through ventilation 475.2 W/K. As total, specific heat loss is 5140.6 W/K. Annual heating energy requirement is 241722.48 kWh.

Table 2. Guascor SFGLD180 biogas engine parameters

Guascor SFGLD180 Biogas Engine Parameters	
Mechanical Power	315 kW
Electrical Power	304 kW
Fuel Consumption	781 kW
HT Thermal Jacket Water	188 kW
LT Auxiliary Water Circuit	76 kW
Exhaust Thermal Power	135 kW
Radiation Heat of the Motor&Alternator	28 kW
HT Cycle Flow Rate	25 m^3/h
LT Cycle Flow Rate	18 m^3/h
HT Circuit Temperature	90 °C
Exhaust Gas Temperature	374 °C
LT Circuit Temperature	55 °C

The water in the motor jacket has a temperature of approximately 85-95 °C. This water is used to remove the residual heat from the combustion generated power and the heat given to the engine block by spreading from the cylinders (Kaya et al., 2015). As a general practice, this heat is given to the atmospheres with dry cooler which consume electricity. The temperature of the exhaust gases is released from the gas engine between 370-540°C. In cogeneration systems, most of this heat can be saved (Wu&Wang, 2006).

The fermenter in the biogas plant needs a certain amount of heating. For this reason, HT and LT lines heat is all fed to the fermenter. This demand reaches up to the maximum value in winter. The demonstration has been adopted in the P&I diagram because it can be used for a short time. However, this gain is very low and is not included in the calculation. The plant, on average was operating at 270 kW of electrical power when the operating period was considered. For this reason, catalog value of the HT line is reduced to 165 kW from 188 kW and to 119 kW at the exhaust from 135 kW.

When the total specific heat demand and heat losses are calculated in the winter months of the building, total heat loss is realized 82 kW in January average. The sum of internal heat gain is 9 kW. During the coldest January, heat needs to be provided at 73 kW of power. The average minimum temperature is 3.3 ºC, so it can be seen that the only exhaust gas can provide the building heating demand. As a result of the above calculation 119 kW heat recovered from the flue gas. The 6 kW part will disappear along with the line. Consequently, 113 kW heat will be recovered.

In the figure, the red line shows the heating demand. The green line shows the total internal gains. The blue line shows the total demand by subtracting internal heat gains. The power required to supply hot water is 18 kW. At the final stage, in figure 1b, in addition to the heating demand, hot water demand is taken into consideration. In this figure, the demand load value in January is 91 kW. It is seen that the heat demand can be met with the exhaust.

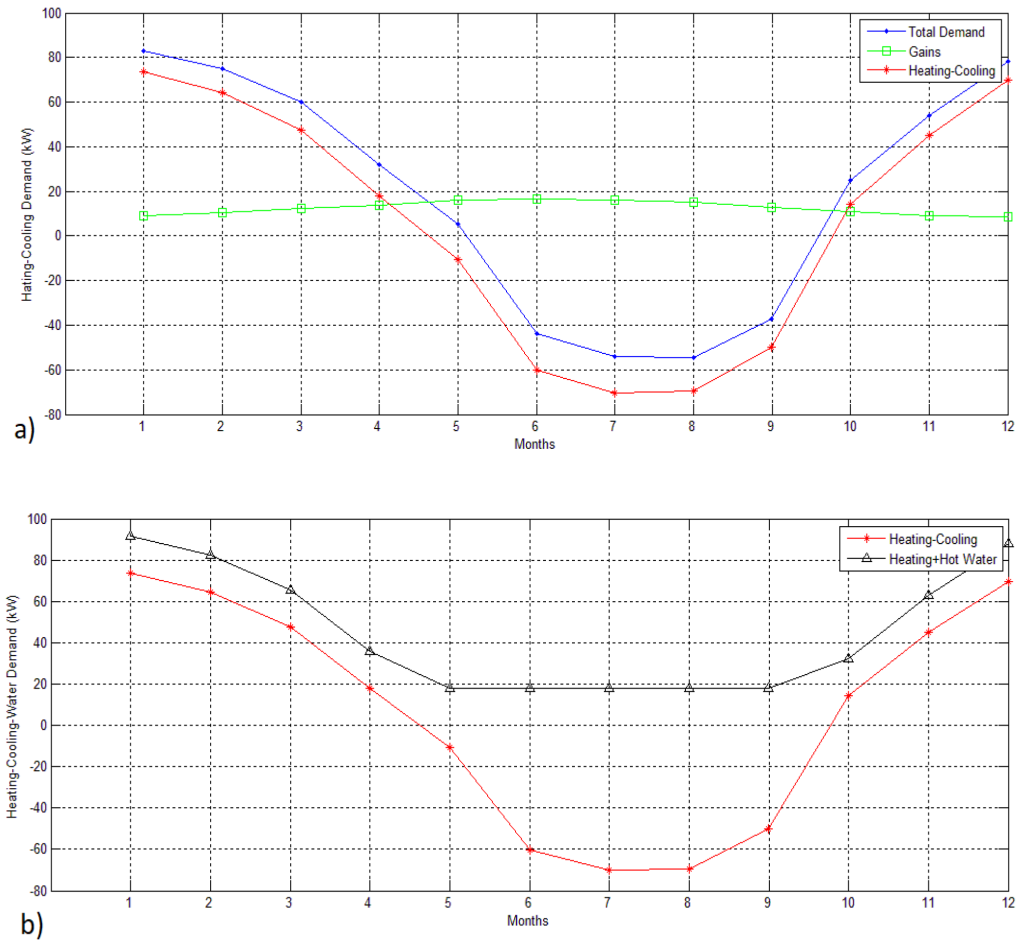

Figure 1: a) Gain and total demand b) Hot water and total demand

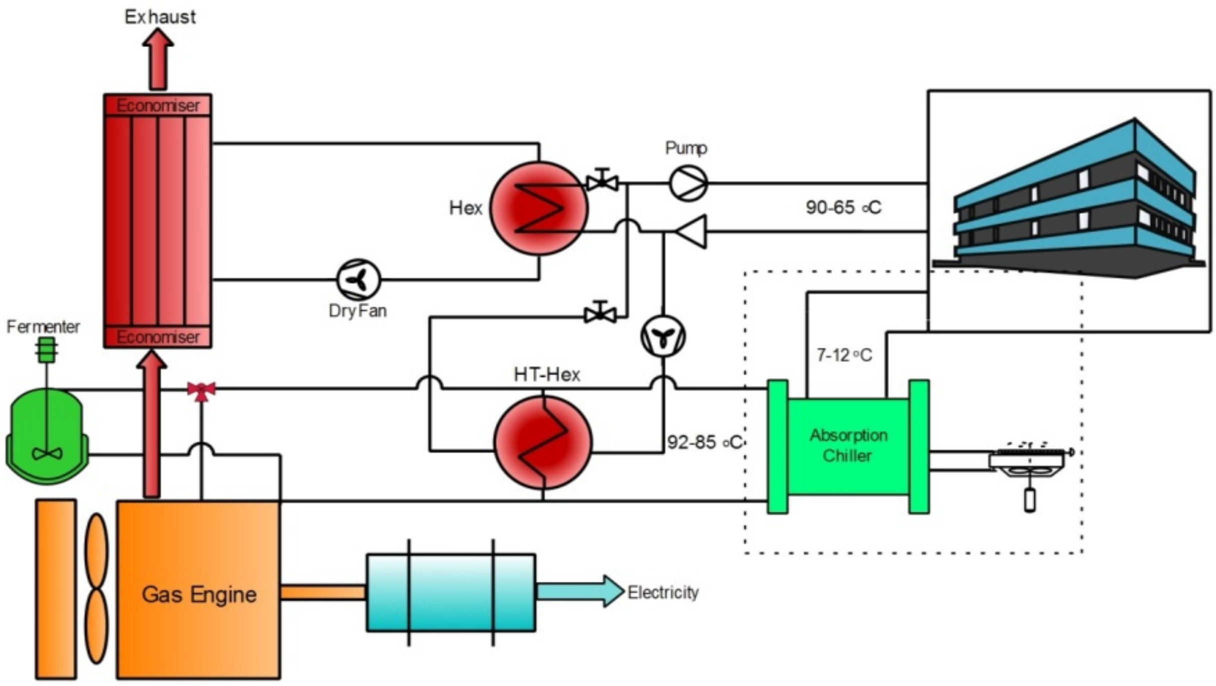

Figure 2. P&I diagram of the heating system

The facility P&I diagram is given above. The absorption chiller option is not economical when pre-feasibility of the system is done, so that is not included in the calculation.

Table 3. Unit price chart

Natural Gas Price				**0.26**	**€/m³**
Naturel Gas LHV	8500	kcal/m³	=	9.88	kWh/m³
Heat Cost (0.26 €/m³ ; 9.88 kWh/m³ : 0.80)	0.033	€/kWh			

As a result of the analysis, the unit price determination stage for energy sale is done. In the following table plant' income and expense balance is shown.

Table 4. Plant income-expense balance

Investment Expenses	**2017**	**2018**	**2019**	**2020**	**2021**
Economizer	11000 €	0	0	0	0
Hot Water Exchanger Plant Side	1200 €	0	0	0	0
Hot Water Exchanger Building Side	1200 €	0	0	0	0
Central Heating Exchanger	5500 €	0	0	0	0
Installation	3300 €	0	0	0	0
Electricity Cost	1100 €	1100 €	1100 €	1100 €	1100 €
Maintenance	2000 €	2000 €	2000 €	2000 €	2000 €
Total Cost	25300 €	3100 €	3100 €	3100 €	3100 €
Income	**2017**	**2018**	**2019**	**2020**	**2021**
Hot Water Income	3918.75 €	4076 €	4232.25 €	4389.00 €	4575.75 €
Heating Income	6043.05 €	6284.77 €	6526.49 €	6768.21 €	7009.93 €
Total Income	9961.80 €	10360.27 €	10758.74 €	11157.21 €	11585.68 €
Cumulative Profit / Loss	-15338.20 €	7260.27 €	7658.74 €	8057.21 €	8485.68 €

The break-even point of the whole system is 3.03 years. The total emission gain of the district heating is calculated as follows. In the calculation of emissions from electricity generation in Turkey "Using the instrument for the calculation of emission coefficient for an electrical system - UNFCC 2011" the following calculations are presented with the reference work being done. According to the Intergovernmental Panel on Climate Change (IPCC) panel data, the average emission factor for natural gas is 56.1 kg CO_2/GJ. An average of 545.9 kg CO_2/$MWh_{elec.}$ is given for unit electricity generation (Kumbaroğlu, 2012, Aslanoğlu & Köksal, 2012).

Table 5. Emissions & energy gains

Energy Gain	Fuel Equivalent	Emission Gain
498090.41 kWh	50414 Sm³	100594.33 kg CO_2

Conclusion

District heating systems are among the promising applications for efficient use of energy. In this study, waste heat energy of a biogas plant is analysed and energy, environment and economic analysis performed to meet the heating and hot water demands of a building. As a result, building demand which is 241722.48 kWh heating per year can be met. The power plant income is 8271.45 € in the average of four years while the dorm building paid 3.41 € heating and hot water fee for the unit area. According to the existing conventional system, more efficient heating system is designed. Energy savings of 13.66% have been achieved. Emission values are also reduced. Using proposed system, 100594.33 kg/yr CO_2 less released to the atmosphere.

References

Aslanoğlu SY, Köksal, MA, (2012) Elektrik üretimine bağlı karbondioksit emisyonunun bölgesel olarak belirlenmesi ve uzun dönem tahmini, *Hava Kir. Araş. Der.*, **1**, 19–29.

Cartalis C, Synodinou A, Proedrou M, Tsangrassoulis A, Santamouris M, (2001) Modifications in energy demand in urban areas as a result of climate changes: an assessment for the southeast Mediterranean region, *En. Con. and Man.,* 42, **14**, 1647–1656.

Elele S, Çanakçı C, (2001) Bölgesel ısıtma sistemleri ısı merkezleri tasarımı, *Jeo. En. Sem.*, **270**, 131-140.

Hendricks MA, Wagner JE, Volk TA, Newman DH, Brown TR, (2016) A cost-effective evaluation of biomass district heating in rural communities, *Ap.En*., **162**, 561–569.

Hergul AS, Kaya D, Coban V, (2016) Energy, environment and economic analysis of designed trigeneration system, *Int. J. Ecos. & Ecol Sci*., **6**, 575-580.

Kaya D, Abut N, Hergül AS, Sapmaz S, (2015) Siemens - Dresser Rand & Guascor Power gaz motorları teknik uygunluk değerlendirme raporu, Kocaeli Üniversitesi, 27156, 1-175.

Kohler M, Blond N, Clappier A, (2016) A city scale degree-day method to assess building space heating energy demands in Strasbourg Eurometropolis (France), *Ap. En.,* **184**, 40–54.

Kumbaroğlu G, (2012) Nükleer enerjiye geçişte Türkiye modeli – II: Türkiye'nin iklim değişikliği stratejisi ve nükleer enerjiye geçiş, *Tech. Doc*. **1,** 31.

Madlener R, Koller M, (2007) Economic and CO_2 mitigation impacts of promoting biomass heating systems: An input–output study for Vorarlberg, Austria, *En. Pol.*, 35, **12**, 6021–6035.

Selbaş R. (1992) Atık Isı Enerjisinden Yararlanma Yöntemleri ve Uygulamaları, Yüksek Lisans Tezi, Akdeniz Üniversitesi Fen Bilimleri Enstitüsü, Antalya.

Werner S, (2017) International review of district heating and cooling, *Energy*, **205,** 991-1001.

Wu DW, Wang R Z, (2006) Combined cooling, heating and power, a review, *Prog. En. & Comb. Sci.*, **32**, 459–495.

Zhang J, Lucia LD, (2015) A transition perspective on alternatives to coal in Chinese district heating, *Int. J. Sust. En. Pl. & Man*., **6**, 49-68.