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Economic and Environmental Benefits of Heating of Poultry Houses with Geothermal Energy: A Case Study for Nevşehir Province of Turkey

Nesrin Ilgin Beyazit and Hasan Huseyin Ozturk

ABSTRACT

In this study, as an example of the use of geothermal energy resources for the air-conditioning of animal shelters, the technical, economic and environmental gains that will be achieved in the case of heating a chicken coop with a total floor area of 480 m^2 in Nevşehir province of Turkey in the winter months have been evaluated. For this purpose, a standard chicken coop with a length of 40 m, a width of 12 m and a height of 2.5 m and a capacity of 4320 chickens has been considered. The optimum indoor temperature for adult chickens is considered to be 22 °C. The total heat losses related to the different structural components of the considered standard house were determined. The annual total highest heat load for the poultry house was calculated as Q_t = 197.32 kW. For geothermal resources suitable for house heating in the region, the amount of heat to be gained from the geothermal fluid to the house environment was calculated, taking into account the lowest physical properties (the lowest temperature T_{geo} = 30 °C and the lowest flow rate m_{geo} = 30 m^3/h). Since the amount of heat energy gained to the poultry environment with geothermal fluid (Q_{geo}=278.96 kW) is higher than the total heat losses (Q_t = 197.32 kW) of the poultry house (Q_{geo}>Q_t), it can be used for poultry heating with geothermal fluid. In case the considered poultry house is heated with geothermal energy, a total of 45073 kg of fuel will be saved annually from LPG consumption and 42186.4 kg of diesel fuel consumption will be saved. If Diesel or LGP fuel is used instead of geothermal fluid for poultry heating, the annual total fuel cost will be 266 211.6 TL for LPG usage and 274 585.2 TL for Diesel usage. In case the considered house is heated with geothermal energy, 136 571.2 kgCO$_{2\text{-eq}}$ or 133 798.3 kgCO$_{2\text{-eq}}$ from the annual total greenhouse gas emissions will save compared to the use of LPG and Diesel, respectively.

Keywords: Geothermal energy, Heating, Poultry houses.

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1. INTRODUCTION

The temperature range in which the sensible heat value transferred from the animals to the outside remains constant is called the thermal comfort zone (Fig. 1). In this temperature range, the feed conversion rate of the animals is at the highest level. The temperature range, which is defined as the thermal comfort zone for animals and where the feed efficiency ratio is the highest, can be determined by race, age, gender, pregnancy status, etc. Many studies have been conducted to determine these values.

In order for poultry to gain live weight at each developmental stage, an appropriate temperature range is required, as shown in Fig. 1. The temperature range where the birds use the energy of the feed, they take for growth most efficiently will be narrow (by 1 or 2 °C). At each stage of bird development, there is a very narrow temperature range in which the energy requirement for survival is the lowest, and the animals use the feed energy mostly for growth. This temperature range is called the optimum yield range. In the optimum yield range, with adequate feed and water, the animals will achieve maximum economic performance.

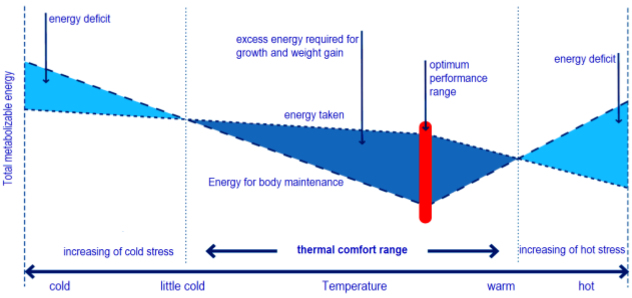

Fig. 1. Optimum temperature range in poultry farming [1].

If the temperature is several degrees colder or warmer than the optimal performance range, the animals use a higher portion of their feed energy for survival and a lower amount for growth. If the temperature in the poultry house is too low, the animals increase their feed consumption. In this way, they use most of the energy from the feed to warm their bodies. At low ambient temperatures, animals spend a significant portion of the feed they consume to keep their body temperature constant. As a result, feed conversion rates decrease. If the temperature is too high, the animals limit their feed consumption to reduce heat production. In hot climatic conditions, the feed consumption of animals decreases. Therefore, decreases are observed in development and productivity.

The optimum temperature values for the fastest development of broilers vary depending on the growth stages. Air temperatures in the house are usually around 30−32 °C when the animals are one day old and close to or below 20 °C by the age of slaughter, depending on the weight of the animals and other factors. It is reported that the target temperature is approximately 22 °C during the period of live weight gain after the chick growing period. It is very important to maintain the optimum temperature in the early stages of growth. Performance losses in young animals cannot be compensated later. For broilers, the optimum temperature is around 32 °C at one day of age and gradually decreases to 21 °C by the age of six weeks [1].

The possibility to adopt geothermal heat pump systems in animal farms was investigated only recently by some authors [2]–[10]. Wang *et al*. [4] performed an economic comparison among different systems for a typical swine farm in Beijing, China. They concluded that considering the cooling effect obtained without increasing indoor relative humidity, as well as the energy saving in the heating period and the avoided air pollution from PM 2.5, the Ground Source Heat Pump (GSHP) system is likely to be preferred in the future. Islam *et al*. [3] experimentally investigated the performance of a GSHP and a conventional electrical heating system in a nursery pig house in Korea. GSHP provided a 46% reduction of energy consumption, and CO_2 and other noxious gas emissions were significantly lowered [5].

In chicken coops, it should be known how much the daily target temperature should be during the growth period of the animals, and air conditioning should be provided to maintain this temperature. In order to create a suitable environment for chickens in chicken coops, many heating methods are applied using different energy sources. Among these methods, applications of heating with hot water from conventional heating boilers are widely used. Economic feasibility study conducted in this paper, the hot water from the heating boilers is replaced by the hot fluid from the geothermal source. A detailed monthly calculation was made to determine the benefits in terms of energy conservation, economic gains and environmental protection if geothermal energy is used to meet the heating needs of the poultry house.

2. Material and Methods

In order to heat a standard house using geothermal energy, first of all, the heat loads of the house must be calculated. Next, it is calculated whether the amount of geothermal heat (feed loads) from the source in the geothermal field is sufficient to meet the heat loads of the house. Finally, the economic feasibility of house heating with geothermal energy is explored. In order to make all these calculations, some data belonging to the henhouse and the living things to be raised in the henhouse are used.

2.1. Climate Characteristics

Semi-continental climate type is generally dominant in the region. The climate of Nevşehir is semi-arid-slightly humid, mesothermic 1 (moderately hot throughout the year), moderate continental climate type with little or no excess water. When temperature and precipitation data of Nevşehir province for many years (1975–2007) are examined, it is seen that total precipitation is 24.75 cm in cold period and 16.84 cm in hot period and is less than 70% of annual precipitation in both periods. Nevşehir shows the character of the steppe climate. The main characteristics of the Nevşehir climate are that summers are hot and dry, and winters are cold and less rainy. 59.5% of total precipitation occurred in cold periods. Maximum precipitation occurred in spring; minimum precipitation occurred in summer. Average total precipitation is in the range of 250–500 mm (415.9 mm). The average winter temperature is 0.4 °C, the average summer temperature is 20.5 °C, and the annual average temperature is 10.5 °C.

With these features, Nevşehir reflects a semi-arid, moderately continental climate type. Monthly average, high and low temperature, and wind speed values, which are important in terms of poultry house heating in the Nevşehir region, are given in Table I. Considering the lowest and highest temperatures, it is important to benefit from geothermal energy in poultry house heating applications in Kozaklı Region in terms of economic and environmental sustainability.

2.2. Geothermal Energy Potential of Nevşehir Region

The most important geothermal area in Nevşehir province is Kozaklı geothermal field. According to available data, there are 30 geothermal wells in Kozaklı geothermal field. Almost all of wells are east of Kozaklı settlement. The depth of these wells varies between 70–1493 m, their temperature 30–105 °C, and their flow rates between 1.5–95 l/s. Most of the wells belonging to state and private companies are artesian, and water taken from the source during the summer months is drawn from wells with the help of a pump. It is used for heating, greenhouse, and tourism purposes in the region. In the deepest well, N-4 (1493 m), Miocene-Pliocene units were completely cut, and after 800 meters, units belonging to Kırşehir massif were entered [12], [13]. Waters at a depth of 150 m and warmer than 90 may indicate presence of a still cooling magma chamber under Kozaklı geothermal field. There is a reinjection well at 3016 m depth in the region.

Kozaklı geothermal field is located 75 km east of Kırşehir in Central Anatolia. Paleozoic schist, quartzite and marbles form the basis in area. On this basement, Eocene (Lutetian) sandstone, limestone, and marl series are unconformably found. Oligocene at the top: Contains gypsum, silt, marls, as well as pebble and sandstone bands and lenses. Stacking of Neogene consisting of tuff, ignimbrite, marly limestone, and limestone unconformably overlies old formations. Travertine and alluvial cover are the youngest units [14]. General fracture extensions are NE-SW and NW-SE striking, dip slip normal fault characteristics. There are a total of 40 operation wells and one reinjection well in Kozaklı, Ürgüp, Avanos and Acıgöl in Nevşehir province. 15 of these wells are not working actively.

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TABLE I: TEMPERATURE VALUES OF THE REGION [11]

Temperatures	Month												Mean
	1	2	3	4	5	6	7	8	9	10	11	12	
Average temperature (°C)	-0.4	0.4	4.5	9.9	14.4	18.5	21.7	21.3	17.0	11.5	5.6	1.3	10.5
Maximum temperature (°C)	16.7	18.2	25.0	30.0	32.6	34.2	39.5	37.9	35.2	32.0	23.2	23.0	39.5
Average monthly maximum temperature (°C)	3.6	4.8	9.7	15.6	20.3	24.7	28.3	28.4	24.5	18.1	10.9	5.4	16.2
Average monthly minimum temperature (°C)	-3.9	-3.3	0.1	4.9	8.5	11.2	13.3	13.1	10.0	6.3	1.6	-2.1	5.0
Minimum temperature (°C)	-21.2	-21.1	-18.0	-10.7	-2.3	2.0	5.3	3.1	0.5	-6.8	-14	-18.1	-21.2
Number of days temp. is lower than -0.1 (°C)	21.7	18.9	13.5	3.2	0.4					2.0	10.7	18.8	89.2

2.3. *Climate and Geothermal Fluid Data*

The lowest temperature of the geothermal fluid is T_{geo} = 30 °C, and the lowest flow rate is taken into account as m_{geo} = 30 m^3/h. The lowest outdoor temperature is 3 °C, the ground temperature is 10.4 °C, and the wind speed is 3.3 m/s. The optimum indoor temperature range for adult chickens has been taken as 22 °C [15].

2.4. *Characteristics of the Standard Poultry House*

The design features of the poultry house considered for poultry farming are given in Fig. 2. The dimensions of the house are length 40 m, width 12 m, and height 2.5 m. The house has a ventilation area, which corresponds to about 6% of the floor area. There are two steel doors in the henhouse with dimensions (2 m × 2.5 m).

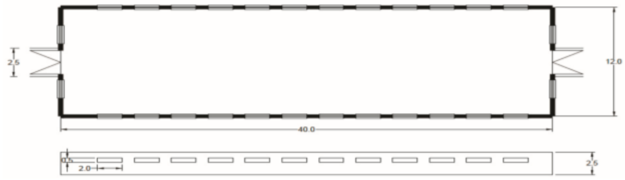

Fig. 2. Dimensions of a standard poultry house [16].

2.5. *Calculation of Heating Load for the Poultry House*

Heating loads at minimum outside air temperature for different structural components of the house were calculated as follows:

2.5.1. *Heat losses from different components of the house*

The total heat loss from the house walls, doors, floor, and ceiling was calculated using the following equations.

$$Q = U \times A(T_i - T_o) \tag{1}$$

$$U = \frac{1}{R_o + \frac{x}{k} + R_i} \tag{2}$$

where Q is total heat loss (W), U is total heat transfer coefficient (W/m^2 °C), A is heat transfer area (m^2), T_i and T_o are the air temperatures inside and outside the house (°C). In equation (2), x is the thickness of the wall, k is the heat transfer coefficient of material, R_o is the air thermal resistance for the outside of material, and R_i is the air thermal resistance for the outside of material.

The total heat transfer coefficient (W/m^2 °C) for doors and floor has been considered to be 2.7 W/m^2 K and 0.136 W/m^2 K, respectively [17].

2.5.2. *Heat losses from the poultry house by ventilation*

The heat loss from the poultry house by ventilation was calculated using the following equations.

$$Q_v = m \times c_p (T_i - T_o) \tag{3}$$

$$m = V \times \rho \tag{4}$$

$$V = C \times M \times v \tag{5}$$

where Q_v is the heat loss from the poultry house by ventilation (kW), c_p is specific heat (kJ/kg °C), V is required ventilation rate for chickens (m^3/s), C is total number of chickens, M-average chicken mass (kg), and v is specific ventilation rate (m^3/skg).

The specific ventilation rate (v; m^3/skg) is the required ventilation rate (m^3/s) per 1 kg of chicken mass in the poultry house. In order to maintain the indoor air temperature at 22 °C, v = 0.885×10^{-4} m^3/skg [18]. If there are 9 chickens per square meter of floor area of the hen house, the total number of chickens in the hen is:

$$C = 9 \text{ chickens/m}^2 \times 480 \text{ m}^2 = 4320 \text{ chickens} \tag{6}$$

Assuming that the chickens in the house have an average mass of 2 kg, the total ventilation rate (V) is calculated as follows:

$$V = 4320 \text{ chickens} \times 2 \text{ kg} \times 0.885 \times 10^{-4} \text{ m}^3\text{/skg} = 7.643 \text{ m}^3\text{/h} \tag{7}$$

Air density ρ = 1.29 kg/m^3 and specific heat c_p = 1.005 kJ/kg °C are taken into account in calculating the total heat loss with ventilation from the poultry house.

2.6. *Heat Transfer from Geothermal Fluid to the House*

In order to meet the annual total maximum heat load for the poultry house with geothermal energy, first of all, the amount of heat to be gained to the indoor environment of the poultry house with the geothermal fluid must be determined. The amount of heat to be gained by the geothermal fluid in the indoor environment of the poultry house has been calculated with the following equation:

$$Q_{geo} = m_{geo} \times c_{p_{geo}} (T_{geo} - T_i) \tag{8}$$

2.7. *Energy Savings*

The energy savings (ES, kJ) to be achieved as a result of using geothermal energy for heating of poultry house for a certain month of the year; in other words, the heat loss values to be met by using geothermal fluid are calculated as follows:

$$ES = N_d \times T_d \times HL_m \times 3600 \tag{9}$$

where N_d is number of days in the month, T_d is daily duration (h), and HL_m is monthly total heat loss value.

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If Diesel or LGP fuel is used instead of geothermal fluid for house heating, monthly fuel savings (FS_{Dizel} and FS_{LPG}, kg) are determined as follows:

$$FS_{Diesel} = ES / LHV_{Diesel} \quad (10)$$

$$FS_{LPG} = ES / LHV_{LPG} \quad (11)$$

The lower heating values (LHV) of diesel and LPG fuels are taken into account as LHV_{Diesel} = 39 845.76 kJ/kg and LHV_{LPG} = 37 235.86 kJ/kg.

2.8. Economic Gains

Depending on the purchase price (PP, TL/l) and amount (m, L) of Diesel and LPG fuels used for heating of poultry house, monthly economic gains (EG_m, TL) are calculated as follows:

$$EG_{m\text{-}Diesel} = m_{Dizel} \times PP_{Diesel} \quad (12)$$

$$EG_{m\text{-}LPG} = m_{LPG} \times PP_{LPG} \quad (13)$$

The monthly economic gains (EG_m, TL) are calculated based on the Diesel and LPG prices (PP_{Diesel} =5.5 TL/L and PP_{LPG} =3.2 TL/L) valid for the province of Nevşehir at the beginning of April 2020.

2.9. Emission Savings

Depending on the greenhouse gas emissions (GHG, $kgCO_{2\text{-}eq}$/unit) released per unit mass or volume as a result of the constant burning of Diesel and LPG fuels used for poultry house heating, the monthly emission values (GHG_m, $kgCO_{2\text{-}eq}$) are calculated as follows:

$$GHG_{m\text{-}Diesel} = m_{Diesel} \times GHG_{Diesel} \quad (14)$$

$$GHG_{m\text{-}LPG} = m_{LPG} \times GHG_{LPG} \quad (15)$$

Monthly emissions (GHG_m), (GHG_m, $kgCO_{2\text{-}eq}$) were calculated depending on the greenhouse gas emissions (GHG_{Dizel}=2.68 $kgCO_{2\text{-}eq}$/L and GHG_{LPG}=3.03 $kgCO_{2\text{-}eq}$/kg) resulting from the constant burning of Diesel and LPG fuels in unit mass or volume.

3. Results and Discussions

3.1. The Total Heat Loss from the Poultry House

As a result of the calculations, the different structural components of the house and the total heat losses determined by the ventilation are given in Table II. The annual total highest heat load for the poultry house was calculated as Q_t = 197.32 kW.

TABLE II: Heat Losses for the Poultry House

Structural components	Rate of heat loss (kW)
Walls	2.253
Doors	0.513
Ceiling	5.04336
Floor	1.24032
Ventilation	188.266
Total	197.32

3.2. Heat Gain from Geothermal Fluid to the House

Considering the lowest physical properties (the lowest temperature T_{geo}= 30 °C and the lowest flow rate m_{geo}= 30 m^3/h) for geothermal resources suitable for poultry heating in the Nevşehir region, the amount of heat to be gained from the geothermal fluid to the environment of the poultry house was calculated as 278.96 kW. In this case, the amount of heat energy gained to the poultry environment with the geothermal fluid (Q_{geo}=278.96 kW) is higher than the total heat losses (Q_t = 197.32 kW) from the poultry house (Q_{geo}>Q_t), the geothermal fluid can be used for the purpose of heating the poultry house.

3.3. Energy Savings

Two basic fuels, LPG and Diesel, are generally used in boilers used for heating. A detailed monthly calculation was made to find the amounts of geothermal energy saved to meet the heating needs of the poultry house (Table III). As can be seen from Table III, the lowest average temperature is at the levels where heating is not needed in the summer months from May to September.

The energy saving (ES, kJ) to be achieved as a result of using geothermal energy for house heating for January is determined as 389 412 576 kJ. If Diesel or LGP fuel is used instead of geothermal fluid for house heating, the fuel amounts to be saved for January have been determined as mD_{iesel} = 9,773 kg or m_{LPG} = 10,458 kg. The monthly fuel savings are given in Fig. 2. If Diesel or LGP fuel is used instead of geothermal fluid for house heating, a total of 45,073 kg LPG or 42186.4 kg Diesel fuel will have to be consumed annually. In this case, if the hen considered is heated with geothermal energy, the specified amounts of fuel will be saved.

3.4. Economic Gains

The monthly economic gain for January has been calculated as EG_{Diesel}= 63,611.24 TL/month or EGD_{LPG}=61,073.33 TL/month. The monthly economic gains are given in Fig. 3. If Diesel or LGP fuel is used instead of geothermal fluid for poultry house heating, the annual total fuel cost will be 266,211.6 TL for LPG usage or 274,585.2 TL for Diesel usage. In this case, if the hen considered is heated with geothermal energy, the specified amount of fuel costs will be saved.

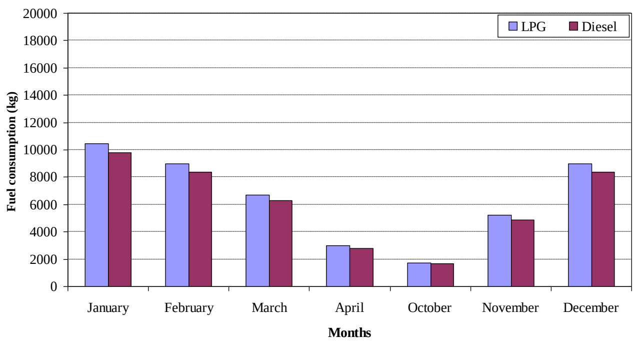

Fig. 2. Diesel and LPG fuel consumption for heating of the poultry house.

TABLE III: HEAT LOSSES FROM THE POULTRY HOUSE

Thermal Power Loss (kW)												
Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Walls	1.66	1.42	1.06	0.47	0.41	0.29	0.23	0.17	0.29	0.11	0.83	1.42
Doors	0.37	0.32	0.24	0.10	0.09	0.06	0.05	0.04	0.06	0.02	0.18	0.32
Ceiling	3.71	3.18	2.38	1.06	0.92	0.66	0.53	0.39	06.6	0.26	1.85	3.18
Floor	138.7	118.9	89.1	39.6	34.6	24.7	19.8	14.8	24.7	9.91	69.3	118.9
Vent	0.91	0.78	0.58	0.26	0.22	0.16	0.13	0.09	0.16	0.06	0.45	0.78
Total	145.3	124.6	93.4	41.5	36.3	25.9	20.7	15.5	25.9	10.3	72.7	124.6

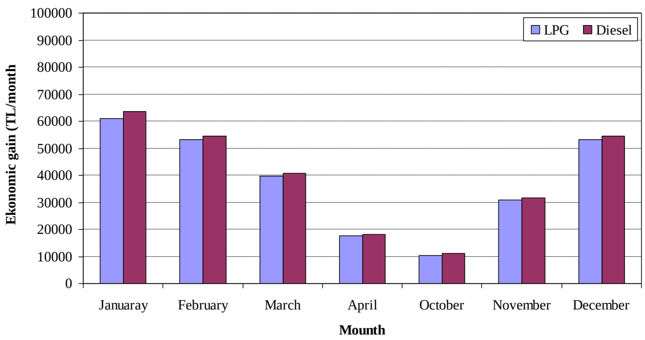

Fig. 3. Economic gains in fuel consumption for house heating.

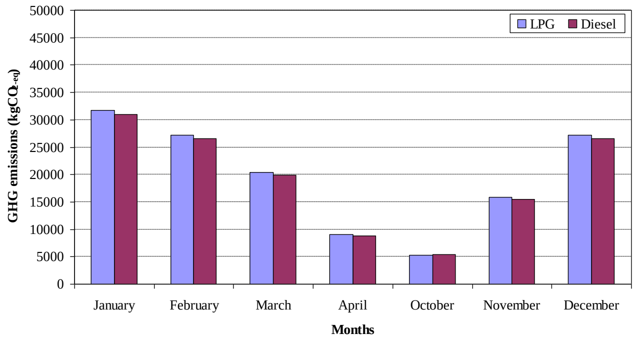

Fig. 4. GHG emissions savings for poultry house heating.

3.5. Emission Savings

Emissions released monthly for January are calculated as $GHG_{m\text{-}Diesel}$ = 30,996 $kgCO_{2\text{-}eq}$ or $GHG_{m\text{-}LPG}$ = 31,687.74 $kgCO_{2\text{-}eq}$. The monthly greenhouse gas emissions (GHG_m, $kgCO_{2\text{-}eq}$) are given in Fig. 4. If Diesel or LGP fuel is used instead of geothermal fluid for poultry house heating, the annual total greenhouse gas emission will be 136,571.2 $kgCO_{2\text{-}eq}$ in LPG use or 133,798.3 $kgCO_{2\text{-}eq}$ in Diesel use. In this case, if the hen is considered to be heated with geothermal energy, the specified amounts of greenhouse gas emissions will be saved.

4. CONCLUSION

As a result of the calculations, it was determined that if the geothermal resources in the Nevşehir region of Turkey are used for heating the animal shelters, significant energy, economic, and emission savings can be made.

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