Black Sea Journal of Engineering and Science
doi: 10.34248/bsengineering.1405324

Open Access Journal
e-ISSN: 2619 – 8991

Research Article
Volume 7 - Issue 2: 277-297 / March 2024

ANALYSIS OF THE ENERGY EFFICIENCY OF POULTRY HOUSES IN TÜRKİYE

Asiye ASLAN[1]*

[1]*Bandırma Onyedi Eylül University, Gönen Vocational School, 10900, Balıkesir, Türkiye*

Abstract: Türkiye is an important producer, consumer and exporter in the poultry farming industry across the world. The poultry farming is one of the fastest growing sectors in the field of food and agriculture and has become one of the strongest sectors over time. Especially with the development of industrial sectors, the effective usage and management of energy, which is the most important issue of almost every business, has recently become an important structure in the building sector in Türkiye. This study examined optimum insulation layer thickness, energy savings, and emissions of CO_2 for the exterior walls and roofs of poultry farming facilities. The study used the degree day method, which is widely used in standard insulation calculations, in accordance with broiler production. As the equilibrium temperature, the desired temperature values of broilers for each week in the 6-week period were taken as the basis (31, 29, 25, 23.50, 22.50, 20.50°C). Life cycle cost analysis (LCCA) was applied to identify the optimal values of insulation thickness in the facilities. Accordingly, the optimum insulation layer thickness, savings amount, and payback period for the walls and roofs ranged between 0.043-0.270 m and 0.022-0.094 m, 7.53-164.65 \$/m² and 12.85-319.62 \$/m², 1.19-2.19 years and 1.18-1.99 years, respectively. It has been calculated that a 70-80% reduction in CO_2 emissions could be managed by applying the optimum insulation layer thickness.

Keywords: Poultry farms, Insulation, Energy saving, Life-cycle cost analysis

***Corresponding author:** Bandırma Onyedi Eylül University, Gönen Vocational School, 10900, Balıkesir, Türkiye
E mail: aaslan@bandirma.edu.tr (A. ASLAN)
Asiye ASLAN https://orcid.org/0000-0002-1173-5008

Received: December 15, 2023
Accepted: February 21, 2024
Published: March 15, 2024
Cite as: Aslan A. 2024. Analysis of the energy efficiency of poultry houses in Türkiye. BSJ Eng Sci, 7(2): 277-297.

1. Introduction

Energy efficiency is explained as the usage of lower rates of energy for performing perform the same task or achieving the same outcome. To achieve efficiency in terms of energy use, it is essential to use less energy for heating and cooling buildings and operating electronic devices. In addition, one of the most effortless and least costly methods to fight global climate change, raise the competitive power of firms and lower the cost of energy for consumers is energy efficiency. Energy efficiency also has a critical part in efforts to reach net zero carbon dioxide emissions by achieving decarbonization.

Another way of fighting against climate change is to use renewable energy resources instead of traditional energy resources and to create a significant effect on each aspect of energy policies of countries. Geothermal energy is a national, renewable, clean, and environmentally friendly underground resource. Türkiye is rich in terms of geothermal energy thanks to its geological and geographical location among world countries, and there are approximately 1,000 geothermal resources with varying temperatures spread across the country. 78% of geothermal resources are in West Anatolia Region, which is followed by Central Anatolia Region (9%), Marmara Region (7%), East Anatolia Region (5%), and other regions (Anonymous, 2023a).

Based on the size of livestock, poultry represents the greatest inventory of domesticated animals worldwide. Poultry has become the fastest growing component of global meat production in the early 21st century. Poultry production is economically important worldwide, for example, it is an industry of more than \$20 billion per year in the United States. In 2021, the global production rate of poultry meat was estimated as 137.8 million tons. As of 2020, the United States (22,705 million), China (19,500 million), Brazil (14,076 million), and the EU (13,769 million) were the largest producers of poultry meat. The vast majority of poultry meat production within the EU takes place in five states, among which Poland (19.2%) is the largest poultry producer. Consecutively, Germany (13.1%), France (12.8%), Spain (10.1%), and Italy (9.9%) follow Poland. In general, the worldwide production of poultry has grown steadily, with a rate of 1.32% over the previous decade (Gržinić et al., 2023).

Considering the number of broiler chickens in Türkiye by regions, the East Marmara and Aegean Regions had a collective portion of 59.8% in 2019. The region of East Marmara was the leader broiler producer in with a share of 33.5%, followed by the Aegean Region (26.3%) and the West Marmara (14.3%). More than half (56.4%) of the broilers in Türkiye were collected in five provinces in 2019. Manisa had the highest proportions of broiler chickens at a rate of 12.6%, followed by Sakarya (12.6%), Balıkesir (11.6%), Bolu (10.8%), and Mersin (8.7%) (Anonymous, 2023b).

In this context, there are two significant factors affecting productivity in broiler farming: genetic composition and environmental conditions. Considering the environmental conditions, the most important factor is temperature (Arıtürk et al., 1986). Several factors such as ensuring the poultry house to be least affected by cold in winter and hot in summer, preventing sudden indoor temperature changes and moisture condensation, and maintaining the appropriate indoor temperature should be considered when planning a good poultry house construction (Özdemir and Poyraz, 1997).

To increase efficiency and protect broiler chickens from the negative effects of climate, it is important to design and plan poultry houses according to proper rules and regulations. It is only possible with isolation to ensure the desired environmental conditions effectively in the poultry houses throughout the year (Özdemir and Poyraz, 1997). Insulation prevents losses of heat in winter and the accumulation of heat in summer. Economic benefits are achieved by reducing heating and cooling costs, allowing controlling sweating, condensation, and humidity. In addition, it is obligatory to reduce energy consumption in buildings and to obtain minimum values according to national regulations (Akpınar and Demir, 2018).

There are several studies about insulation in buildings. Annibaldi et al. (2019) presented a multidisciplinary approach to raise the performance of historic buildings in terms of energy utilization, allowing them to compare the optimized values of insulation thickness, which are found with the permeability parameters of walls in situ, and those in the relevant literature. This set of techniques involves an initial examination of the building envelope and an investigation of the insulation materials and thickness to identify the optimum combination between the building's energy performance and the investment cost. The methodology was implemented for a case study in Italy. The authors revealed that the specific usage of data in the relevant literature to organize an energy recovery plan of an existing historic building can cause substantial errors. Hou et al. (2022) calculated the optimum thickness for the exterior walls of rural traditional residences in the northeast of Sichuan hills using the degree-day method and the P1-P2 economic model. They also evaluated the energy savings and economic advantages according to the EnergyPlus and dynamic investment payback time model. As a result, they found that the optimum insulation layer thickness varied between 0.081 m and 0.144 m, considering the local climate and economic context. By using Mathcad software program, Malka et al. (2022) proposed removing the heating degree day limits for some materials used for insulation (EPS Graphite, EPS, GW and RW) and a set of different energy resources (electricity, diesel, natural gas, LPG and biomass). They considered additional economic variables (i.e., inflation, interest rate, lifetime and present value factor) and properties of heating systems to determine the optimum insulation layer thickness, and applied the RETScreen Expert model for various types of structures in Albania. As a result, they stated that the overall heat transfer value (U) must equal or be smaller compared to 0.30 (W/m^2K), and suggested that the proposed method could be implemented not only in Albania, but also in other parts of the world with comparable climate characteristics. Dombaycı et al. (2017) have examined optimum insulation layer thickness values for the exterior walls of homes in select cities in different climate zones of Türkiye. They applied a thermoeconomic method, considering inflation and interest rates with Life Cycle Cost Analysis (LCCA), and calculated maximum and minimum thicknesses for polystyrene and polyurethane insulation materials, respectively, for cold and hot climatic regions, thus obtained maximum and minimum savings amounts in these regions. Açıkkalp and Kandemir (2019) have presented an alternative technique to combine financial and environmental impacts in determining the optimum insulation layer thickness, which is known as the United Economic and Environmental Method (CEEM). They have made analyses for Bilecik province in Türkiye, using stone wool and glass wool insulation materials, compared their results with those of other methods, and calculated annual savings and energy savings. Ustaoğlu et al. (2020) have conducted an energy analysis using various polyurethane insulation materials for various climate zones and fuels to determine energy performance in buildings. They have used coal, natural gas, liquefied petroleum gas (LPG), fuel oil, and electricity as fuels. Accordingly, they reported that polyurethane foam in which 3% paper mill sludge (PMS) was added had the most favorable thermal resistance values. Depending on the fuel used, they found that savings ranged from \$8.86 to \$54.6/m² with a thickness of 0.0245 m, and the payback period varied from 1.37 to 8.76 years.

In addition, some studies have also aimed to identify the energy needs and comfort conditions of poultry houses. Kapica et al. (2015) presented the simulation results of CO_2 reduction potential for poultry houses by replacing traditional heating system with hybrid sun-wind system. They calculated heat requirements for 2400 poultry houses and presented basic models for solar collectors, wind turbines and heat storage tanks in these houses. Their system was modelled in a MATLAB/Simulink environment by analyzing different settings of systems for climatic conditions specific to the Central Europe. As a result, they found that larger systems provided higher CO_2 reduction but their energy usage rates decreased. Yang et al. (2022) proposed a new pair of ventilation system by combining the advantages of exhaust air heat recovery system and perforated channel ventilation for poultry houses in China. As a result, they stated that a better interior can be created with improved ventilation performance and low cost with a new double-channel ventilation system. Unlike traditional energy analysis approaches in Ghana, Akolgoa et al. (2022) analyzed environmental conditions and energy inputs in poultry houses using the Energyplus simulation and compared them using the artificial nervous system. They estimated the annual energy consumption and equipment use as 2,044 kWh and 1,452 kWh, respectively, and stated that the ANS model was applicable to the determination of energy consumption by poultry houses. Dağtekin (2012) aimed to meet the electrical energy need for a henhouse of 20,000 capacities by using photovoltaic solar energy system. By designing a PV system of 15 kW power, he made a techno-economic assessment of the system. The amount of energy to be generated in PV power plants, the cost of electricity, investment and business costs, and payback period were calculated. As a result of these calculations, payback period of the PV system was determined as 9.2 years, and electricity generation cost was found as 0.1100 TL/kWh. The efficiency of the system was calculated as 12.1% and CO_2 emission reduction rate as 20,259 kg/year. Özlü et al. (2017) investigated the use of paper industry waste as underlay in broiler facilities. In the study, 468 broilers with various genders were used. Underlay material consisted of rice hull, waste paper, and a mixture of the two in equal ratios. As a result, in week 6, the live weight of the group in which waste paper was used as underlay was determined to be about 60 g higher than the other groups. It was also determined that underlay type did not have any effect on factors such as living power and feed evaluation rate.

Despite the numerous studies conducted for buildings used for different purposes and especially for residential buildings, there exists limited research to determine the insulation thickness for energy efficiency in poultry houses. This study used the degree day method for the poultry farming sector and calculated the degree of day (DD) values for the insulation of poultry farming facilities considering the region’s climate and temperatures. As the equilibrium temperature, the desired temperature values of broilers for each week in the 6-week period were taken as the basis (31, 29, 25, 23.50, 22.50, 20.50°C). The optimum insulation layer thickness of the exterior walls and roofs according to HDD and CDD numbers was calculated. This procedure was used as an alternate choice of method for building insulation accounts to achieve optimum results in poultry farming facilities. The calculations were made for all provinces with poultry farming facilities in Türkiye. There is no study that covers all cities with poultry farming facilities in Türkiye and deals with both the exterior walls and roofs of poultry farming facilities. The optimum insulation layer thicknesses are determined for Extruded Polystyrene and Expanded Polystyrene for the walls and sandwich panel for the roofs as insulation materials. This study used the meteorological data between 2018-2022 and considered natural gas, coal, fuel oil, LPG and electricity as fuel. In addition, geothermal energy was evaluated as an alternative energy source in broiler facilities in cities where geothermal energy sources suitable for heating were available, and optimum insulation layer thickness was calculated and compared with other fuels. Energy savings, payback periods, and CO_2 emissions were calculated as a result of the use of insulation in poultry farming facilities. By conducting this study, it was aimed to make Türkiye gain an important place in the poultry farming sector worldwide.

2. Materials and Methods

2.1. HDD and CDD Calculation

The degree-day (DD) method is among the most preferred techniques to determine the energy needed for the heating or cooling of buildings (Eto, 1988; Büyükalaca et al., 2001). A reference temperature is used in calculating the degree-day number. The reference temperature for heating degree days is defined as the outside temperature at which the building's heating demand begins, and for cooling degree days, it is defined as the outside temperature at which the cooling demand begins. The degree-day number is calculated by subtracting the reference temperature from the daily temperature average and then adding the values for the designated time interval. In this study, HDD and CDD were determined using equations 1 and 2 (Christenson et al., 2006; De Rosa et al., 2014).

For $T_{out}<T_{base}$,

$$\mathrm{HDD} = \sum_{1}^{n}(\mathrm{T_{base}} - \mathrm{T_{out}}) \tag{1}$$

For $T_{base}<T_{out}$,

$$\mathrm{CDD} = \sum_{1}^{n}(\mathrm{T_{out}} - \mathrm{T_{base}}) \tag{2}$$

where, n is the total number of days specified for the period. T_{base} and T_{out} are the reference temperature and the average outside air temperature, respectively.

In broiler production, the production period in poultry houses is recommended as 41 or 42 days. In this study, 7 production periods per year were taken into account, considering 42 days of production and a 12-day break (Table 1). The temperature values required weekly by broilers during the 42-day process are the equilibrium temperature values recommended by the researchers and given in Table 2.

Table 1. Annual rotation dates of poultry production (Lindley and Whitaker, 1996; Matzarakis and Balafoutis, 2004).

Annual rotation	Dates	Number of days
Production Season 1	1 January - 11 February	42
Closed	12 February - 23 February	12
Production Season 2	24 February - 6 April	42
Closed	7 April - 18 April	12
Production Season 3	19 April - 30 May	42
Closed	31 May - 11 June	12
Production Season 4	12 June - 23 July	42
Closed	24 July - 4 August	12
Production Season 5	5 August - 15 September	42
Closed	16 September - 27 September	12
Production Season 6	28 September -8 November	42
Closed	9 November - 20 November	12
Production Season 7	21 November - 31 December	42

Table 2. Basic temperatures according to weeks (Lindley and Whitaker, 1996; Matzarakis and Balafoutis, 2004).

Time	T_{base}(°C)
First week	31.00
Second week	29.00
Third week	25.00
Fourth week	23.50
Fifth week	22.50
Sixth Week	20.50

2.2. Optimum Insulation Layer Thickness on Walls and Roofs of Poultry Farms

The optimum insulation layer thicknesses of basic structure components vary according to financial criteria such as degree days, temperature, fuel, type of insulation material, inflation, and interest rates. In this study, the life cycle cost analysis (LCCA) method covering these criteria was utilized when calculating the optimum insulation layer thicknesses of exterior walls and roofs in poultry houses (Şişman et al., 2007; Bolattürk, 2008).

Table 3 shows the structural properties of exterior walls and roof structure components in poultry farming facilities. Sheathing method, which is the most common and efficient technique for building insulation, was used on the exterior walls to surround the outer shell of the building, fully insulating the columns and beams. Poultry houses are mostly constructed using the cradle roof. It is important for the roof not to pour rain and to protect the interior from heat in sunny weather. The roof should be rain-proof and provide good isolation. Sandwich panel was applied as an insulation material on the roofs. Table 4 shows the parameters and economic variables that were used in the computations.

Table 3. Optimum insulated wall and ceiling constructions and U values

Building Component	Thickness (m)	Thermal Conductivity (W/mK)
Walls		
Interior plaster	0.02	0.87
Hollow brick	0.19	0.45
Insulation (XPS, EPS)	x_{opt}	0.032 – 0.035
Exterior plaster	0.03	1.4
	$U = 1/(R_{ins}+0.637)$	
Roofs		
Roof construction	-	-
Roof covering (Particle board)	0.011	0.205
Waterproofing	0.002	0.19
Roof cover profile	-	-
Roof cover (Sandwich panel)	x_{opt}	0.023
	$U = 1/(R_{ins}+0.329)$	

Table 4. Data and financial values (Anonymous, 2022a; Anonymous, 2022b; Anonymous, 2022c)

Fuel	Cost
Naturalgas	
H_u=34.542x10^6 J/kg, η=93%	0.2868 $/kg
Coal	
Hu=25.122x10^6 J/kg, η=65%	0.1921 $/kg
LPG	
46.442x10^6 J/kg, η=88%	1.75 $/kg
Fuel-Oil	
41.317x10^6 J/kg η=80%	0.73 $/kg
Geothermal energy	
36.000x10^6 J/kg η=98%	0.4482 $/kg
Electricity	
2.5 (COP)	0.1252 $/kWh
Insulation material	Cost
Extruded polystyrene (XPS)	
(λ=0.032 W/mK)	85 $/m^3
Expanded polystyrene (EPS)	
(λ=0.035 W/mK)	50 $/m^3
Roof cover (Sandwich panel)	
(λ=0.023 W/mK)	275 $/m^3
Financial values	
Life (N)	10 years
PWF	8.11

2.3. Calculating the Heat Load

In buildings, heat losses are encountered either by heat transfer from the building's structural components or by leakage through doors and windows. The total heat transfer coefficient (U) of building components can be calculated as follows, considering the resistances and physical properties of the different layers of the structural component (equation 3);

$$U = \frac{1}{R_i + R_{sc} + R_{ins} + R_o} \tag{3}$$

where R_i and R_o represent the thermal resistances of the inner and outer surfaces, successively, R_{sc} is the total thermal resistance value of the uninsulated building component layers, and R_{ins} is the thermal resistance value of the insulation layer (equation 4).

$$R_{ins} = \frac{x}{\lambda} \tag{4}$$

In the equation, x (m) and λ (W/mK) are the thickness and thermal conductivity of the insulation material, respectively. If R_{sct} is the total heat resistance of the uninsulated building component, Eq (3) can be adjusted as follows (equation 5):

$$U = \frac{1}{R_{sct} + R_{ins}} \tag{5}$$

The unit surface heat loss of the building component is as follows (equation 6):

$$q = U\Delta T \tag{6}$$

Here, ΔT shows the difference between the fixed indoor temperature and the changing temperature outside throughout the day. The heat loss per unit area in a year due to the degree-day values of the building component is as follows (equation 7):

$$q_A = 86400\ DDU \tag{7}$$

Here, DD is the degree-day value. In this case, the annual energy requirement for heating (E_A) and annual fuel consumption are as follows (equations 8 and 9).

$$E_A = \frac{86400\ DD}{\left(R_{sct} + \frac{x}{\lambda}\right)\eta_s} \tag{8}$$

$$m_{fA} = \frac{86400\ DD}{\left(R_{sct} + \frac{x}{\lambda}\right)H_u\eta_s} \tag{9}$$

The annual heating and cooling cost per unit area is shown below (equations 10 and 11).

$$C_{A,H} = \frac{86400\ HDDC_f}{\left(R_{sct} + \frac{x}{\lambda}\right)H_u\eta_s} \tag{10}$$

$$C_{A,C} = \frac{86400\ CDDC_f}{\left(R_{sct} + \frac{x}{\lambda}\right)COP} \tag{11}$$

In the equation, C_f ($/kg) and H_u (J/kg; J/m^3) refer to fuel cost and the lower heating value of the fuel, respectively. The value of the coefficient of performance (COP) for the cooling system was presumed to be equal to 2.5 (Bolattürk, 2008).

2.4. Optimum Insulation Layer Thickness Calculation

The LCCA technique was used to calculate the optimum insulation layer thickness values in this study. The total heating cost is calculated considering the life cycle and present worth factor (PWF) of N years. The present worth factor (PWF), which is found according to the inflation rate g and the interest rate i can be expressed as shown in the following (equation 12):

i>g then,

$$r = \frac{i - g}{1 + g}$$

i<g then,

$$r = \frac{g - i}{1 + i}$$

$$PWF = \frac{(1 + r)^N - 1}{r(1 + r)^N} \tag{12}$$

By considering the life cycle cost analysis (LCCA) of all system-related expenses, the total heating cost of the insulated building can be expressed as follows (equations 13 and 14):

$$C_t = C_A PWF + C_I x \tag{13}$$

or

$$C_t = \frac{86400\ HDDC_f PWF}{\left(R_{sct} + \frac{x}{\lambda}\right)H_u\eta_s} + C_I x \tag{14}$$

In the equation, C_I ($/m^3) and x (m) refer to insulation material cost and insulation thickness, respectively. The optimum insulation layer thickness x_{opt} is found by the minimization of equation 15).

$$X_{opt} = 293.94\left(\frac{DDC_fPWF\lambda}{H_uC_I\eta_s}\right)^{1/2} - \lambda R_{sct} \tag{15}$$

2.5.Environmental Analysis

The general chemical formula for combustion in fuels can be written as follows (equation 16).

$$C_aH_bO_dS_eN_f + \alpha X(O_2 + 3.76N_2) \rightarrow a + \frac{b}{2}H_2O + eSO_2 + YN_2 \tag{16}$$

X and Y can be calculated using the equilibrium formula for oxygen as shown below (equations 17 and 18):

$$X = a + \frac{b}{4} + e - \frac{d}{2} \tag{17}$$

$$Y = 3.76\alpha\left(a + \frac{b}{4} + e - \frac{d}{2}\right) + \frac{f}{2} \tag{18}$$

Equation16) neglects CO and NOx emissions. The CO_2 emission value caused by the combustion of 1 kg of fuel can be determined as follows (equation 19):

$$M_{CO_2} = \frac{kCO_2}{M} \equiv kgCO_2/kgfuel \tag{19}$$

The total CO_2 emission can be calculated as shown below (equations 20 and 21).

$$M_{CO_2} = \frac{44a}{M}m_{fA} \tag{20}$$

$$M_{CO_2} = \frac{3801600\ DD\ a}{M\eta_sH_u}\left(\frac{\lambda}{\lambda R_{wt} + x}\right)\ \ kg/year \tag{21}$$

The molar weight of the fuel, which is denoted by M, can be found using the equation below (equation 22):

$$M = 12a + b + 16d + 32e + 14f\ \ kg/kmol \tag{22}$$

3. Results and Discussion

More than half (56.4%) of poultry farming facilities in Türkiye are located in five provinces. Manisa and Sakarya have the highest number of facilities with a share of 12.6%, followed by Balıkesir (11.6%), Bolu (10.8%) and Mersin (8.7%). Figure 1 shows the all provinces with poultry farming facilities in Türkiye.

The present study calculated the optimum insulation layer thickness, energy saving values, and payback period for exterior walls and roofs of poultry farming facilities in Türkiye. For each region, values of heating and cooling degree days were calculated to provide an internal environment in accordance with broiler breeding. Table 5 presents the calculated HDD and CDD numbers. Figure 2 graphically shows the HDD and CDD according to the equilibrium temperatures in all cities.

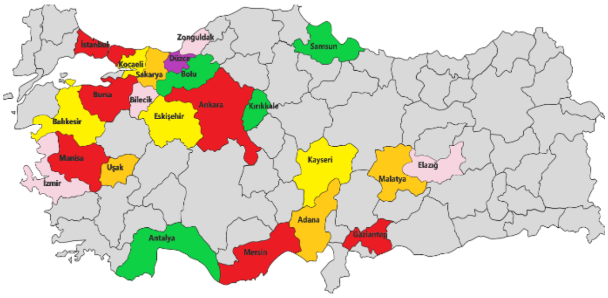

Figure 1. Cities where broilers are produced in Türkiye.

Table 5. HDD and CDD values for cities with poultry buildings in Türkiye

City	HDD	CDD	City	HDD	CDD
Adana	1871	416	İzmir	2089	343
Ankara	3485	89	Kayseri	3936	34
Antalya	1786	387	Kocaeli	2686	94
Balıkesir	3040	108	Malatya	3201	279
Bilecik	3436	27	Manisa	2504	320
Bolu	4146	2	Sakarya	2732	82
Bursa	2851	116	Samsun	2768	88
Elazığ	3318	238	Uşak	3455	66
Eskişehir	3686	25	Zonguldak	2950	30
Gaziantep	2808	350	Kırıkkale	3366	120
Mersin	1680	420	Düzce	3096	38
İstanbul	2716	118			

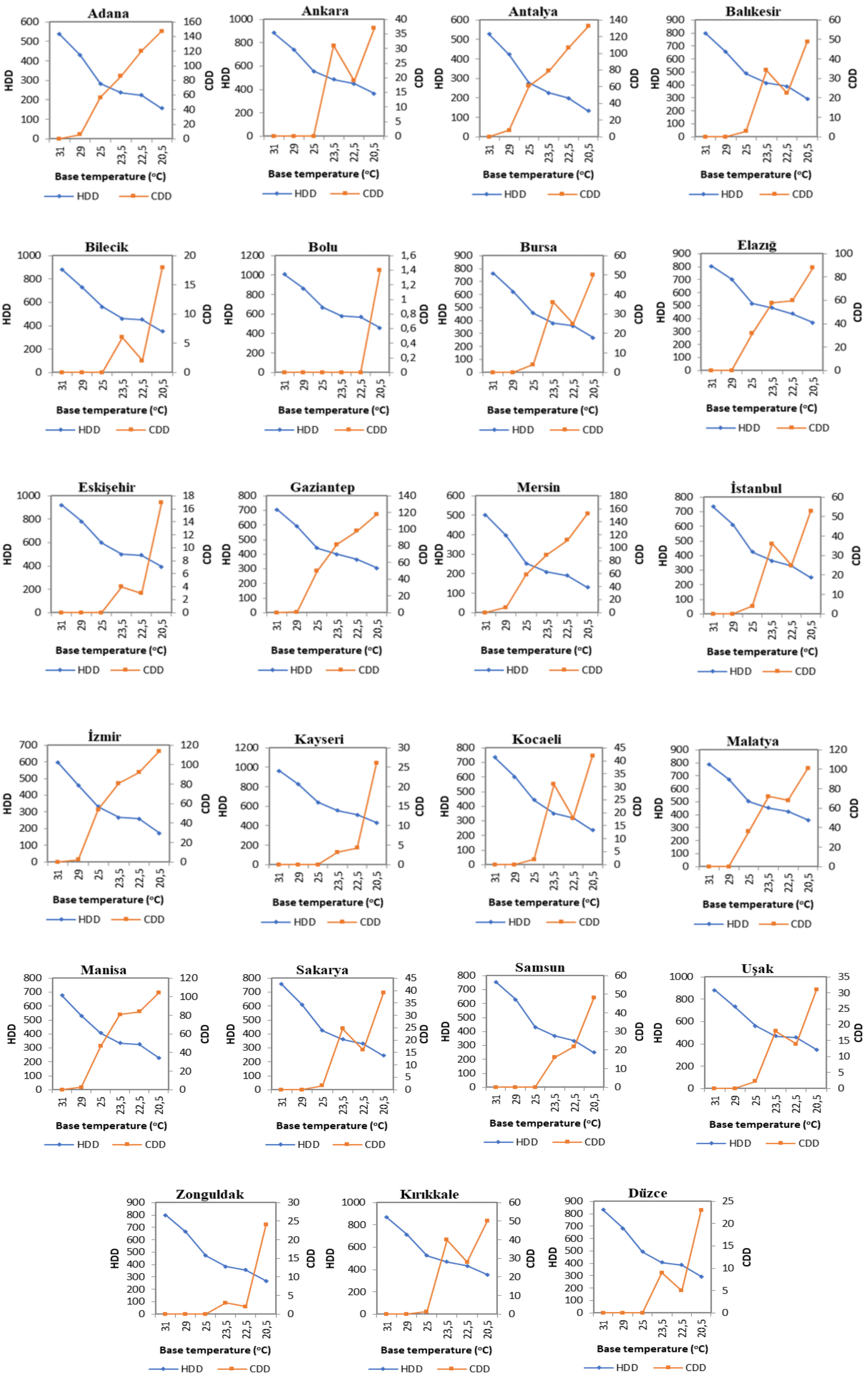

Figure 2. HDD and CDD values according to the equilibrium temperatures in all cities.

Tables 6, 7 and 8 show the values recorded at the optimum point for all provinces and the extent of energy savings and payback period calculated from the unit area in case of optimum insulation layer thickness with various insulation materials and fuel types on the exterior walls and roofs. Tables 6 and 7 present the values when XPS and EPS are used on the exterior walls, respectively; and Table 8 gives the values when sandwich panel is used on the roofs. The optimum insulation layer thickness varied according to varying types of fuel and insulation materials. As expected, the greatest amounts of savings and the shortest payback period in all tables were obtained for the same situation. In the tables, calculations for geothermal energy were done for provinces where there are geothermal resources suitable for heating. The highest savings amount was obtained in Bolu, which is the 4th province of Türkiye with the highest number of poultry farming facility. The lowest savings amount was obtained in Mersin, which is the 5th province of Türkiye with the highest number of poultry farming facility. The highest savings amount and the shortest payback period were obtained when EPS and LPG were used for heating, while the lowest savings amount and the longest payback period were obtained when XPS and natural gas used for heating. In addition, the highest savings amount and the shortest payback period were obtained when EPS insulation material was used for cooling. The payback period was found to be over 10 years for some provinces. In general, the order of savings by fuels was found to be LPG, fuel oil, geothermal energy, coal, and natural gas. Although geothermal energy was determined to be third in this order, it provides more advantages compared to other fuels in terms of the environmental dimension.

In case of heating in Manisa, Sakarya, Balıkesir, Bolu and Mersin, which are the first 5 provinces in Türkiye with the highest number of poultry farming facility, climatic conditions using natural gas fuel and XPS insulation materials on the walls, the optimum thickness values for the insulation materials were obtained as 0.056, 0.060, 0.064, 0.078 and 0.043 m, respectively. For the scenario of the usage of natural gas fuel and EPS on the walls for heating in the same provinces, the optimum insulation layer thickness results were obtained as 0.080, 0.090, 0.090, 0.110 and 0.060 m, respectively. When the case of the usage of natural gas fuel and sandwich panel on the roof in the same provinces was considered, the optimum insulation layer thicknesses were obtained as 0.029, 0.032, 0.039 and 0.022 m, respectively.

Figures 3, 4 and 5 show the effects of annual savings and payback periods on insulation thickness for varying energy resources (natural gas, coal, LPG, fuel oil and geothermal energy) in case of using XPS and EPS on the exterior walls and sandwich panels on the roof for different HDDs. When the fuels were compared, the highest amount of savings and the shortest payback period were obtained in case of using LPG due to its high cost.

Carbon dioxide has the highest greenhouse effect among gases. Fossil fuels are the most important source of carbon dioxide. It is important and necessary to apply optimum insulation layer thickness in buildings in reducing fuel consumption and emission values. Moreover, today, using clean and renewable energy resources such as geothermal energy and increasing the use of these resources is not a matter of preference but a necessity in terms of not creating irreversible environmental problems. Tables 9-11 present the fuel consumption and CO_2 emissions for all provinces with poultry farming facilities using optimum thickness insulation materials. Among the provinces, Bolu and Mersin had the highest and lowest fuel consumption and CO_2 emission values, respectively.

In case of using XPS insulation material on the walls, CO_2 emission amounts varied between 10.81-16.79 kg/m^2-year for coal, 6.13-9.60 kg/m^2-year for natural gas, 4.63-7.24 kg/m^2-year for fuel oil and 2.51-3.93 kg/m^2-year for LPG (Table 9). In case of using EPS insulation material on the walls, CO_2 emission amounts varied between 8.58-13.50 kg/m^2-year for coal, 4.90-4.69 kg/m^2-year for natural gas, 3.71-5.83 kg/m^2-year for fuel oil and 2.01-3.16 kg/m^2-year for LPG (Table 10). In case of using sandwich panel insulation material on the roof, CO_2 emission amounts varied between 16.52-25.60 kg/m^2-year for coal, 9.30-14.58 kg/m^2-year for natural gas, 7.04-11.15 kg/m^2-year for fuel oil and 3.83-6.02 kg/m^2-year for LPG (Table 11).

Figures 6, 7 and 8 show the annual fuel consumption and CO_2 emission values for heating according to insulation thickness in case of using XPS and EPS on the exterior walls and sandwich panels on the roof for different HDDs. As the insulation thickness rises, both annual consumption of fuel and emissions of CO_2 decline. Although the decline here varies slightly according to the type of insulation material, it becomes horizontal after a point. It has been observed that there can be a reduction of up to 70-80% in CO_2 emissions in case of insulation.

Table 6. Optimum insulation layer thickness, energy saving and payback period for XPS on walls

	Heating															Cooling		
	Natural gas			Coal			LPG			Fuel Oil			Geothermal Energy			Electricity		
	x_{opt} m	S $/m^2	pp year	x_{opt} m	S $/m^2	pp year	x_{opt} m	S $/m^2	pp year	x_{opt} m	S $/m^2	pp year	x_{opt} m	S $/m^2	pp year	x_{opt} m	S $/m^2	pp year
Adana	0.046	8.83	2.08	0.056	13.01	1.86	0.125	65.20	1.35	0.084	29.47	1.54	0.059	14.4	1.81	0.042	7.26	2.21
Ankara	0.070	19.83	1.73	0.084	28.32	1.59	0.178	130.62	1.26	0.122	61.05	1.39	0.088	31.2	1.56	0.008	<0	<0
Antalya	0.044	8.25	2.13	0.054	12.20	1.90	0.122	61.76	1.36	0.082	27.80	1.56	-	-	-	0.040	6.51	2.30
Balıkesir	0.064	16.80	1.78	0.077	24.10	1.63	0.165	112.58	1.27	0.113	52.34	1.41	0.081	26.5	1.60	0.011	<0	<0
Bilecik	0.070	19.49	1.73	0.083	27.85	1.60	0.177	128.63	1.26	0.121	60.09	1.39	0.087	30.6	1.57	<0	<0	<0
Bolu	0.078	24.33	1.67	0.093	34.59	1.55	0.196	157.40	1.24	0.135	73.98	1.36	0.098	38.0	1.52	<0	<0	<0
Bursa	0.062	15.51	1.81	0.074	22.30	1.66	0.159	104.92	1.28	0.109	48.64	1.42	0.077	24.6	1.62	0.012	<0	<0
Elazığ	0.068	18.69	1.74	0.081	26.73	1.61	0.173	123.85	1.26	0.119	57.78	1.40	0.085	29.4	1.57	0.027	2.64	3.49
Eskişehir	0.073	21.20	1.71	0.087	30.22	1.58	0.184	138.76	1.25	0.126	64.98	1.38	0.091	33.2	1.55	<0	<0	<0
Gaziantep	0.061	15.22	1.81	0.073	21.89	1.66	0.158	103.18	1.28	0.108	47.80	1.43	-	-	-	0.037	5.55	2.44
Mersin	0.043	7.53	2.19	0.052	11.19	1.94	0.117	57.46	1.38	0.079	25.73	1.59	-	-	-	0.042	7.37	2.20
İstanbul	0.060	14.59	1.83	0.071	21.02	1.67	0.155	99.45	1.29	0.105	46.00	1.44	-	-	-	0.013	<0	<0
İzmir	0.050	10.32	1.99	0.060	15.07	1.79	0.133	74.04	1.33	0.090	33.73	1.51	0.063	16.7	1.75	0.036	5.37	2.47
Kayseri	0.076	22.90	1.69	0.090	32.60	1.56	0.190	148.89	1.25	0.131	69.87	1.37	0.094	35.8	1.53	<0	<0	<0
Kocaeli	0.059	14.38	1.84	0.071	20.74	1.68	0.154	98.23	1.29	0.105	45.41	1.44	0.075	22.9	1.64	0.009	<0	<0
Malatya	0.066	17.89	1.76	0.079	25.62	1.62	0.170	119.11	1.27	0.116	55.49	1.40	-	-	-	0.030	3.70	2.91
Manisa	0.056	13.14	1.87	0.068	19.01	1.71	0.148	90.86	1.30	0.100	41.85	1.45	0.071	21.0	1.67	0.034	4.77	2.59
Sakarya	0.060	14.70	1.83	0.072	21.17	1.67	0.155	100.10	1.29	0.106	46.31	1.43	0.075	23.3	1.63	0.007	<0	<0
Samsun	0.060	14.94	1.82	0.072	21.52	1.67	0.156	101.56	1.28	0.107	47.02	1.43	0.076	23.7	1.63	0.008	<0	<0
Uşak	0.070	19.62	1.73	0.083	28.03	1.60	0.177	129.40	1.26	0.122	60.46	1.39	0.087	30.8	1.56	0.004	<0	<0
Zonguldak	0.063	16.18	1.79	0.075	23.24	1.64	0.162	108.93	1.28	0.111	50.58	1.42	-	-	-	<0	<0	<0
Kırıkkale	0.069	19.02	1.74	0.082	27.19	1.60	0.175	125.79	1.26	0.120	58.72	1.39	-	-	-	0.013	<0	<0
Düzce	0.065	17.18	1.77	0.078	24.63	1.63	0.167	114.85	1.27	0.114	53.44	1.41	-	-	-	<0	<0	<0

Table 7. Optimum insulation layer thickness, energy saving and payback period for EPS on walls

	Heating															Cooling		
	Natural gas			Coal			LPG			Fuel Oil			Geothermal Energy			Electricity		
	x_{opt} m	S $/m²	pp year	x_{opt} m	S $/m²	pp year	x_{opt} m	S $/m²	pp year	x_{opt} m	S $/m²	pp year	x_{opt} m	S $/m²	pp year	x_{opt} m	S $/m²	pp year
Adana	0.024	15.06	1.89	0.028	21.81	1.72	0.061	135.04	1.26	0.042	63.03	1.40	0.030	24.11	1.68	0.022	17.12	1.82
Ankara	0.035	33.67	1.57	0.041	47.35	1.48	0.086	265.99	1.19	0.060	127.28	1.29	0.043	51.96	1.45	0.006	<0	<0
Antalya	0.023	14.08	1.93	0.028	20.46	1.75	0.059	128.14	1.27	0.041	59.65	1.41	-	-	-	0.021	15.51	1.87
Balıkesir	0.032	28.54	1.62	0.038	40.31	1.51	0.080	229.88	1.21	0.055	109.57	1.31	0.040	44.28	1.49	0.007	0.03	320.48
Bilecik	0.035	33.11	1.58	0.041	46.57	1.48	0.085	262.01	1.20	0.059	125.33	1.29	0.043	51.12	1.46	0.000	<0	<0
Bolu	0.039	41.30	1.53	0.046	57.81	1.44	0.094	319.62	1.18	0.066	153.59	1.27	0.048	63.37	1.42	<0	<0	<0
Bursa	0.031	26.36	1.65	0.037	37.31	1.53	0.077	214.55	1.21	0.053	102.04	1.31	0.039	41.02	1.50	0.008	0.47	18.50
Elazığ	0.034	31.75	1.59	0.040	44.70	1.49	0.084	252.44	1.20	0.058	120.63	1.29	0.042	49.08	1.46	0.015	7.24	2.46
Eskişehir	0.036	35.99	1.56	0.043	50.53	1.46	0.089	282.30	1.19	0.062	135.28	1.28	0.045	55.43	1.44	0.000	<0	<0
Gaziantep	0.031	25.86	1.65	0.036	36.63	1.54	0.076	211.06	1.21	0.053	100.33	1.32	-	-	-	0.019	13.46	1.95
Mersin	0.022	12.85	1.99	0.026	18.79	1.79	0.057	119.54	1.28	0.039	55.43	1.43	-	-	-	0.022	17.34	1.81
İstanbul	0.030	24.80	1.67	0.036	35.18	1.55	0.075	203.60	1.22	0.052	96.67	1.32	-	-	-	0.008	0.58	15.22
İzmir	0.025	17.57	1.81	0.030	25.26	1.66	0.065	152.73	1.25	0.044	71.71	1.37	0.032	27.87	1.62	0.019	13.07	1.96
Kayseri	0.038	38.87	1.54	0.045	54.48	1.45	0.092	302.58	1.19	0.064	145.23	1.27	0.047	59.75	1.43	0.001	<0	<0
Kocaeli	0.030	24.46	1.67	0.035	34.70	1.55	0.075	201.16	1.22	0.051	95.47	1.32	0.037	38.17	1.52	0.006	<0	<0
Malatya	0.033	30.40	1.60	0.039	42.85	1.50	0.082	242.95	1.20	0.057	115.98	1.30	-	-	-	0.016	9.52	2.19
Manisa	0.029	22.36	1.70	0.034	31.82	1.58	0.072	186.40	1.23	0.049	88.23	1.34	0.036	35.03	1.55	0.018	11.79	2.03
Sakarya	0.030	24.99	1.66	0.036	35.43	1.55	0.075	204.90	1.22	0.052	97.30	1.32	0.038	38.97	1.52	0.005	<0	<0
Samsun	0.030	25.40	1.66	0.036	36.00	1.54	0.076	207.82	1.21	0.052	98.74	1.32	0.038	39.59	1.51	0.006	<0	<0
Uşak	0.035	33.33	1.58	0.041	46.87	1.48	0.086	263.56	1.20	0.059	126.09	1.29	0.043	51.45	1.45	0.004	<0	<0
Zonguldak	0.032	27.50	1.63	0.038	38.88	1.52	0.078	222.58	1.21	0.054	105.98	1.31	-	-	-	0.000	<0	<0
Kırıkkale	0.034	32.30	1.59	0.041	45.46	1.48	0.084	256.33	1.20	0.058	122.54	1.29	-	-	-	0.008	0.69	12.99
Düzce	0.033	29.19	1.61	0.039	41.19	1.51	0.081	234.43	1.20	0.056	111.80	1.30	-	-	-	0.001	<0	<0

Table 8. Optimum insulation layer thickness, energy saving and payback period for SP on roofs

	Heating															Cooling		
	Natural gas			Coal			LPG			Fuel Oil			Geothermal Energy			Electricity		
	x_{opt} m	S $/m²	pp year	x_{opt} m	S $/m²	pp year	x_{opt} m	S $/m²	pp year	x_{opt} m	S $/m²	pp year	x_{opt} m	S $/m²	pp year	x_{opt} m	S $/m²	pp year
Adana	0.024	15.06	1.89	0.028	21.81	1.72	0.061	135.04	1.26	0.042	63.03	1.40	0.030	24.11	1.68	0.022	17.12	1.82
Ankara	0.035	33.67	1.57	0.041	47.35	1.48	0.086	265.99	1.19	0.060	127.28	1.29	0.043	51.96	1.45	0.006	<0	<0
Antalya	0.023	14.08	1.93	0.028	20.46	1.75	0.059	128.14	1.27	0.041	59.65	1.41	-	-	-	0.021	15.51	1.87
Balıkesir	0.032	28.54	1.62	0.038	40.31	1.51	0.080	229.88	1.21	0.055	109.57	1.31	0.040	44.28	1.49	0.007	0.03	320.48
Bilecik	0.035	33.11	1.58	0.041	46.57	1.48	0.085	262.01	1.20	0.059	125.33	1.29	0.043	51.12	1.46	0.000	<0	<0
Bolu	0.039	41.30	1.53	0.046	57.81	1.44	0.094	319.62	1.18	0.066	153.59	1.27	0.048	63.37	1.42	<0	<0	<0
Bursa	0.031	26.36	1.65	0.037	37.31	1.53	0.077	214.55	1.21	0.053	102.04	1.31	0.039	41.02	1.50	0.008	0.47	18.50
Elazığ	0.034	31.75	1.59	0.040	44.70	1.49	0.084	252.44	1.20	0.058	120.63	1.29	0.042	49.08	1.46	0.015	7.24	2.46
Eskişehir	0.036	35.99	1.56	0.043	50.53	1.46	0.089	282.30	1.19	0.062	135.28	1.28	0.045	55.43	1.44	0.000	<0	<0
Gaziantep	0.031	25.86	1.65	0.036	36.63	1.54	0.076	211.06	1.21	0.053	100.33	1.32	-	-	-	0.019	13.46	1.95
Mersin	0.022	12.85	1.99	0.026	18.79	1.79	0.057	119.54	1.28	0.039	55.43	1.43	-	-	-	0.022	17.34	1.81
İstanbul	0.030	24.80	1.67	0.036	35.18	1.55	0.075	203.60	1.22	0.052	96.67	1.32	-	-	-	0.008	0.58	15.22
İzmir	0.025	17.57	1.81	0.030	25.26	1.66	0.065	152.73	1.25	0.044	71.71	1.37	0.032	27.87	1.62	0.019	13.07	1.96
Kayseri	0.038	38.87	1.54	0.045	54.48	1.45	0.092	302.58	1.19	0.064	145.23	1.27	0.047	59.75	1.43	0.001	<0	<0
Kocaeli	0.030	24.46	1.67	0.035	34.70	1.55	0.075	201.16	1.22	0.051	95.47	1.32	0.037	38.17	1.52	0.006	<0	<0
Malatya	0.033	30.40	1.60	0.039	42.85	1.50	0.082	242.95	1.20	0.057	115.98	1.30	-	-	-	0.016	9.52	2.19
Manisa	0.029	22.36	1.70	0.034	31.82	1.58	0.072	186.40	1.23	0.049	88.23	1.34	0.036	35.03	1.55	0.018	11.79	2.03
Sakarya	0.030	24.99	1.66	0.036	35.43	1.55	0.075	204.90	1.22	0.052	97.30	1.32	0.038	38.97	1.52	0.005	<0	<0
Samsun	0.030	25.40	1.66	0.036	36.00	1.54	0.076	207.82	1.21	0.052	98.74	1.32	0.038	39.59	1.51	0.006	<0	<0
Uşak	0.035	33.33	1.58	0.041	46.87	1.48	0.086	263.56	1.20	0.059	126.09	1.29	0.043	51.45	1.45	0.004	<0	<0
Zonguldak	0.032	27.50	1.63	0.038	38.88	1.52	0.078	222.58	1.21	0.054	105.98	1.31	-	-	-	0.000	<0	<0
Kırıkkale	0.034	32.30	1.59	0.041	45.46	1.48	0.084	256.33	1.20	0.058	122.54	1.29	-	-	-	0.008	0.69	12.99
Düzce	0.033	29.19	1.61	0.039	41.19	1.51	0.081	234.43	1.20	0.056	111.80	1.30	-	-	-	0.001	<0	<0

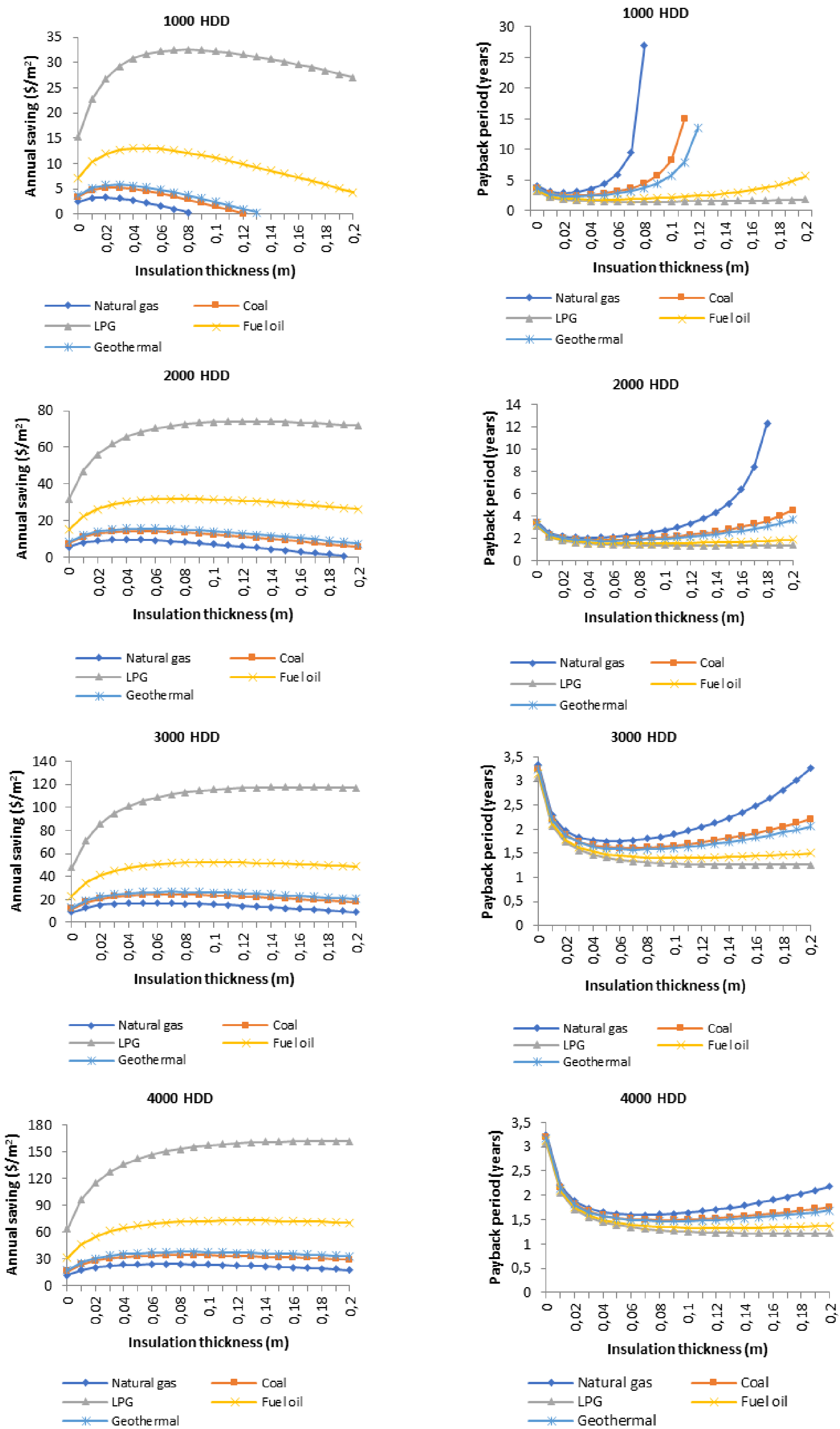

Figure 3. Energy saving and payback period for different HDD in walls (XPS).

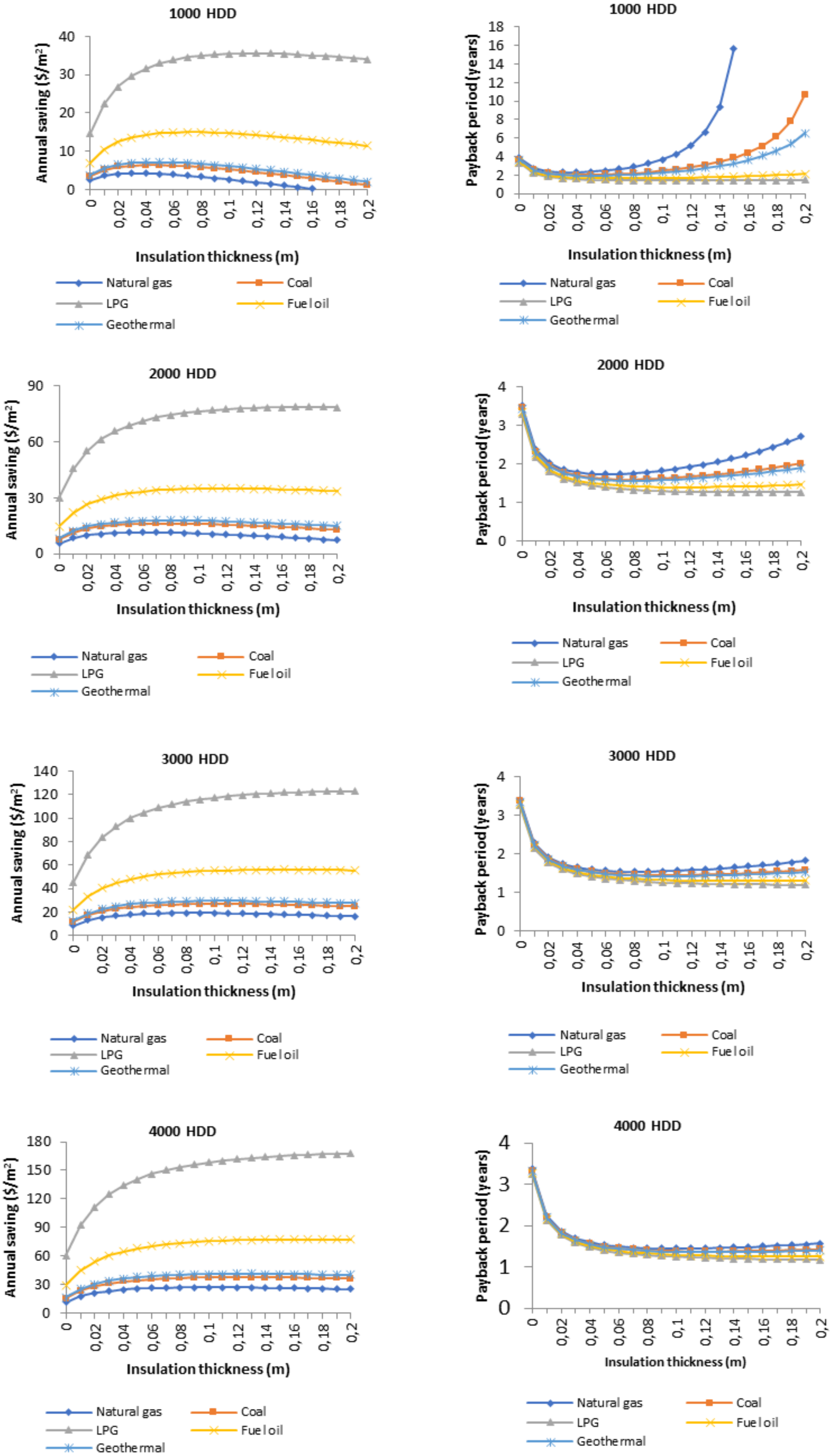

Figure 4. Energy saving and payback period for different HDD in walls (EPS).

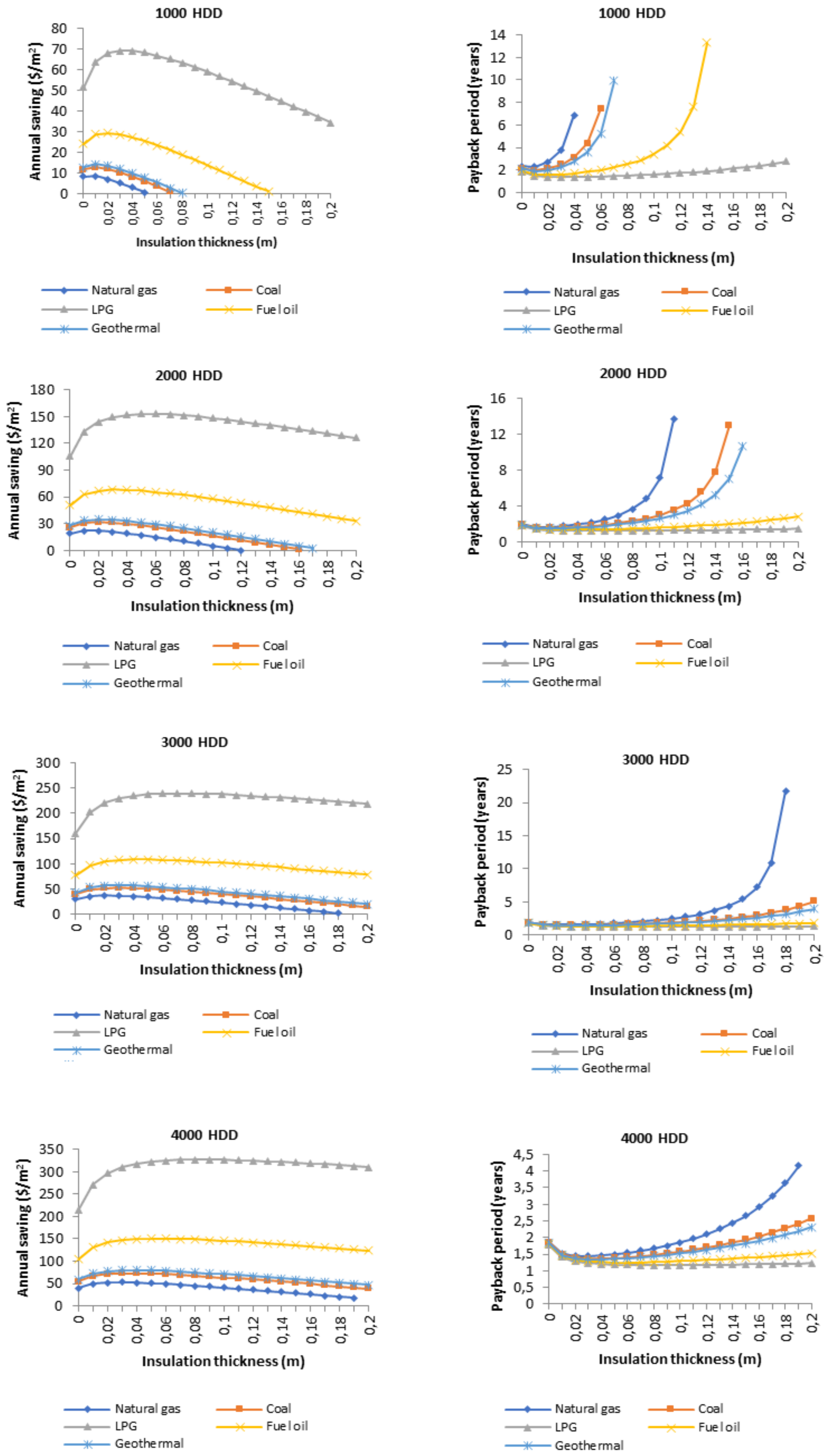

Figure 5. Energy saving and payback period for different HDD in roofs (SP).

Table 9. Fuel consumption and CO_2 amounts for XPS on walls

	Coal		Naturalgas		Fuel-Oil		LPG	
	m_{fA} (kg/m²year)	M_{CO2} (kg/m²year)	m_{fA} (kg/m²year)	M_{CO2} (kg/m²year)	m_{fA} (kg/m²year)	M_{CO2} (kg/m²year)	m_{fA} (kg/m²year)	M_{CO2} (kg/m²year)
Adana	4.20	11.40	2.42	6.42	1.49	4.86	0.87	2.64
Ankara	5.70	15.48	3.31	8.78	2.04	6.64	1.18	3.60
Antalya	4.06	11.03	2.38	6.32	1.47	4.78	0.86	2.61
Balıkesir	5.34	14.49	3.10	8.20	1.92	6.23	1.11	3.38
Bilecik	5.68	15.41	3.30	8.75	2.03	6.60	1.18	3.59
Bolu	6.19	16.79	3.62	9.60	2.23	7.24	1.29	3.93
Bursa	5.16	14.02	3.01	7.98	1.85	6.03	1.07	3.26
Elazığ	5.54	15.03	3.23	8.55	2.00	6.51	1.16	3.52
Eskişehir	5.86	15.91	3.43	9.09	2.10	6.84	1.22	3.72
Gaziantep	5.14	13.96	3.00	7.96	1.84	5.98	1.07	3.24
Mersin	3.98	10.81	2.31	6.13	1.42	4.63	0.82	2.51
İstanbul	5.03	13.65	2.94	7.79	1.81	5.88	1.05	3.19
İzmir	4.40	11.93	2.59	6.86	1.59	5.18	0.92	2.79
Kayseri	6.03	16.38	3.55	9.40	2.17	7.06	1.26	3.84
Kocaeli	5.03	13.65	2.91	7.71	1.80	5.86	1.04	3.18
Malatya	5.45	14.79	3.18	8.44	1.96	6.37	1.14	3.46
Manisa	4.85	13.16	2.82	7.47	1.74	5.65	1.01	3.01
Sakarya	5.06	13.73	2.96	7.84	1.82	5.91	1.05	3.19
Samsun	5.07	13.76	2.96	7.84	1.83	5.95	1.06	3.22
Uşak	5.65	15.35	3.32	8.80	2.04	6.63	1.18	3.59
Zonguldak	5.23	14.20	3.08	8.15	1.89	6.14	1.09	3.32
Kırıkkale	5.62	15.25	3.27	8.67	2.02	6.56	1.17	3.55
Düzce	5.38	14.60	3.12	8.26	1.94	6.30	1.12	3.41

Table 10. Fuel consumption and CO_2 amounts for EPS on walls

	Coal		Naturalgas		Fuel-Oil		LPG	
	m_{fA} (kg/m²year)	M_{CO2} (kg/m²year)	m_{fA} (kg/m²year)	M_{CO2} (kg/m²year)	m_{fA} (kg/m²year)	M_{CO2} (kg/m²year)	m_{fA} (kg/m²year)	M_{CO2} (kg/m²year)
Adana	3.35	9.10	1.95	5.16	1.20	3.90	0.70	2.12
Ankara	4.56	12.39	2.66	7.04	1.64	5.32	0.95	2.89
Antalya	3.26	8.85	1.90	5.04	1.18	3.83	0.68	2.07
Balıkesir	4.25	11.54	2.48	6.57	1.53	4.98	0.89	2.70
Bilecik	4.53	12.59	2.64	7.00	1.63	5.30	0.94	2.87
Bolu	4.97	13.50	2.90	7.69	1.79	5.83	1.04	3.16
Bursa	4.14	11.25	2.41	6.38	1.48	4.83	0.86	2.62
Elazığ	4.44	12.05	2.59	6.87	1.60	5.20	0.93	2.82
Eskişehir	4.69	12.74	2.74	7.27	1.69	5.49	0.98	2.98
Gaziantep	4.08	11.08	2.39	6.34	1.47	4.78	0.85	2.60
Mersin	3.16	8.58	1.85	4.90	1.14	3.71	0.66	2.01
İstanbul	4.04	10.97	2.36	6.25	1.45	4.71	0.84	2.55
İzmir	3.53	9.60	2.06	5.46	1.27	4.13	0.73	2.24
Kayseri	4.85	13.15	2.82	7.47	1.74	5.66	1.01	3.07
Kocaeli	4.00	10.85	2.33	6.18	1.44	4.68	0.83	2.54
Malatya	4.38	11.88	2.54	6.74	1.58	5.13	0.91	2.77
Manisa	3.88	10.54	2.26	5.98	1.39	4.52	0.80	2.45
Sakarya	4.03	10.95	2.35	6.22	1.45	4.73	0.84	2.56
Samsun	4.05	11.01	2.38	6.31	1.46	4.77	0.85	2.58
Uşak	4.56	12.37	2.65	7.04	1.63	5.31	0.94	2.88
Zonguldak	4.19	11.37	2.45	6.48	1.51	4.91	0.87	2.66
Kırıkkale	4.47	12.14	2.61	6.91	1.61	5.25	0.97	2.94
Düzce	4.30	11.67	2.50	6.63	1.55	5.04	0.90	2.73

Table 11. Fuel consumption and CO_2 amounts for SP on roofs

	Coal		Naturalgas		Fuel-Oil		LPG	
	m_{fA} (kg/m²year)	M_{CO2} (kg/m²year)	m_{fA} (kg/m²year)	M_{CO2} (kg/m²year)	m_{fA} (kg/m²year)	M_{CO2} (kg/m²year)	m_{fA} (kg/m²year)	M_{CO2} (kg/m²year)
Adana	6.40	17.36	3.78	10.02	2.31	7.52	1.34	4.08
Ankara	8.73	23.69	5.06	13.40	3.14	10.22	1.83	5.55
Antalya	6.28	17.05	3.61	9.56	2.25	7.33	1.30	3.95
Balıkesir	8.11	22.02	4.75	12.58	2.92	9.48	1.70	5.18
Bilecik	8.60	23.35	5.11	13.53	3.10	10.07	1.80	5.47
Bolu	9.43	25.60	5.50	14.58	3.43	11.15	1.98	6.02
Bursa	7.96	21.60	4.57	12.10	2.82	9.19	1.63	4.97
Elazığ	8.48	23.03	4.93	13.07	3.08	10.03	1.78	5.40
Eskişehir	9.04	24.55	5.23	13.85	3.23	10.49	1.87	5.69
Gaziantep	7.84	21.28	4.62	12.24	2.83	9.20	1.63	4.95
Mersin	6.09	16.52	3.51	9.30	2.16	7.04	1.26	3.83
İstanbul	7.76	21.06	4.47	11.83	2.78	9.05	1.68	5.10
İzmir	6.76	18.35	3.96	10.50	2.43	7.90	1.41	4.30
Kayseri	9.28	25.20	5.46	14.46	3.35	10.89	1.94	5.89
Kocaeli	7.67	20.83	4.54	12.02	2.75	8.95	1.60	4.85
Malatya	8.36	22.69	4.88	12.92	3.02	9.83	1.73	5.27
Manisa	7.51	20.37	4.35	11.52	2.66	8.64	1.54	4.70
Sakarya	7.81	21.19	4.49	11.90	2.80	9.10	1.60	4.88
Samsun	7.73	20.97	4.55	12.06	2.79	9.07	1.63	4.94
Uşak	8.65	23.48	5.14	13.61	3.12	10.13	1.18	5.50
Zonguldak	8.05	21.85	4.73	12.52	2.88	9.35	1.67	5.08
Kırıkkale	8.61	23.36	5.00	13.26	3.08	10.02	1.78	5.42
Düzce	8.26	26.43	4.84	12.81	2.97	9.66	1.71	5.21

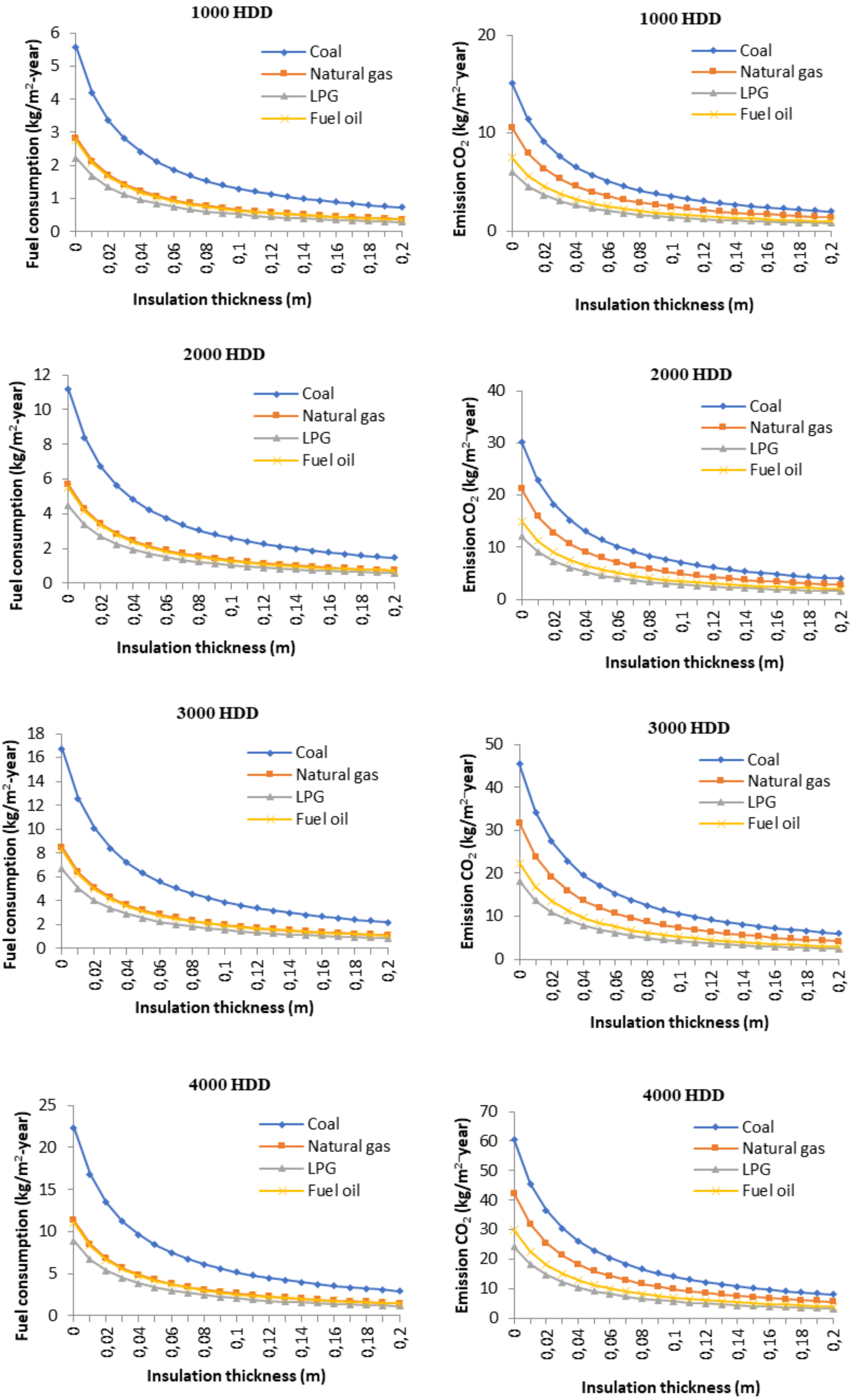

Figure 6. Fuel consumption and CO_2 emissions for different HDD in walls (XPS).

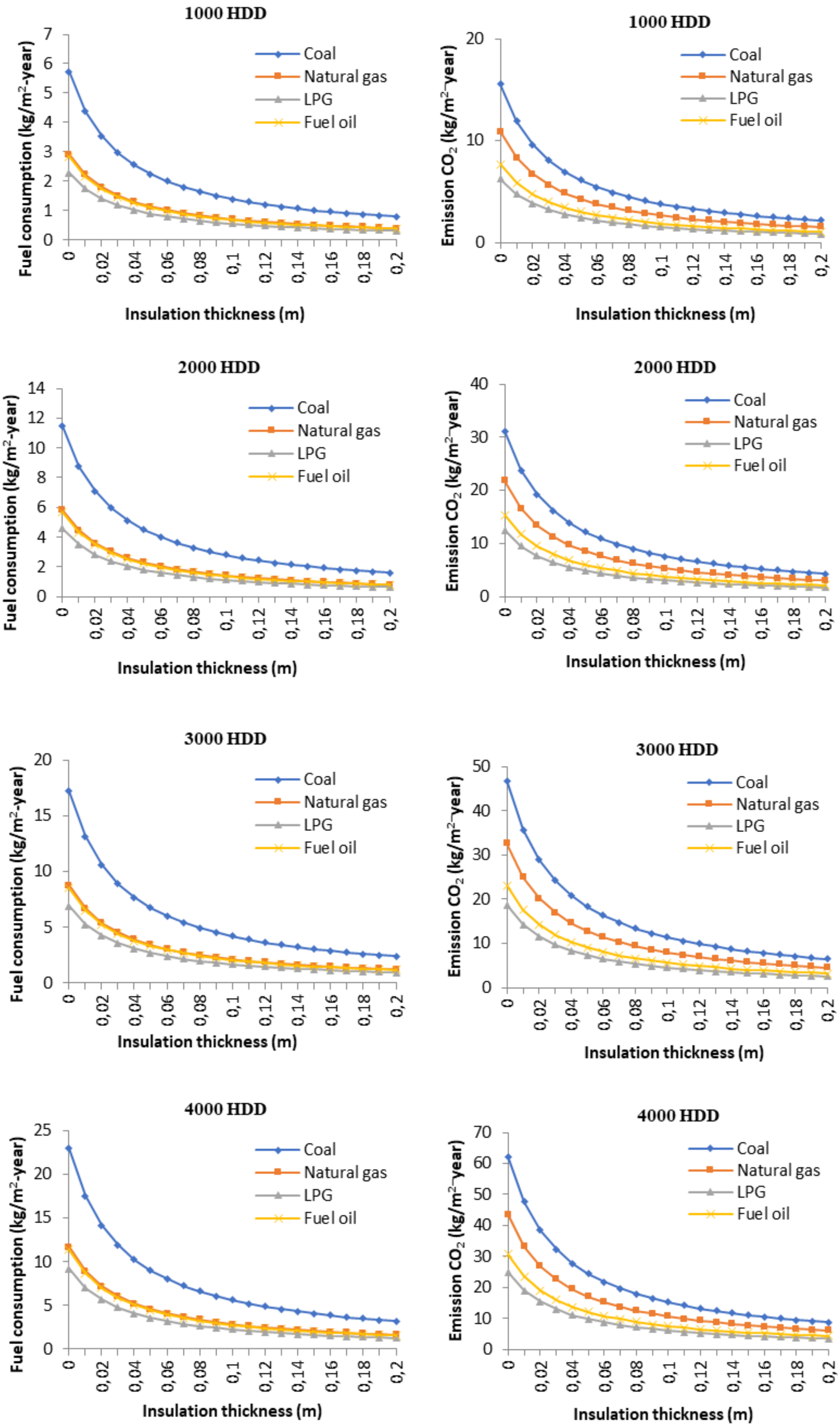

Figure 7. Fuel consumption and CO_2 emissions for different HDD in walls (EPS).

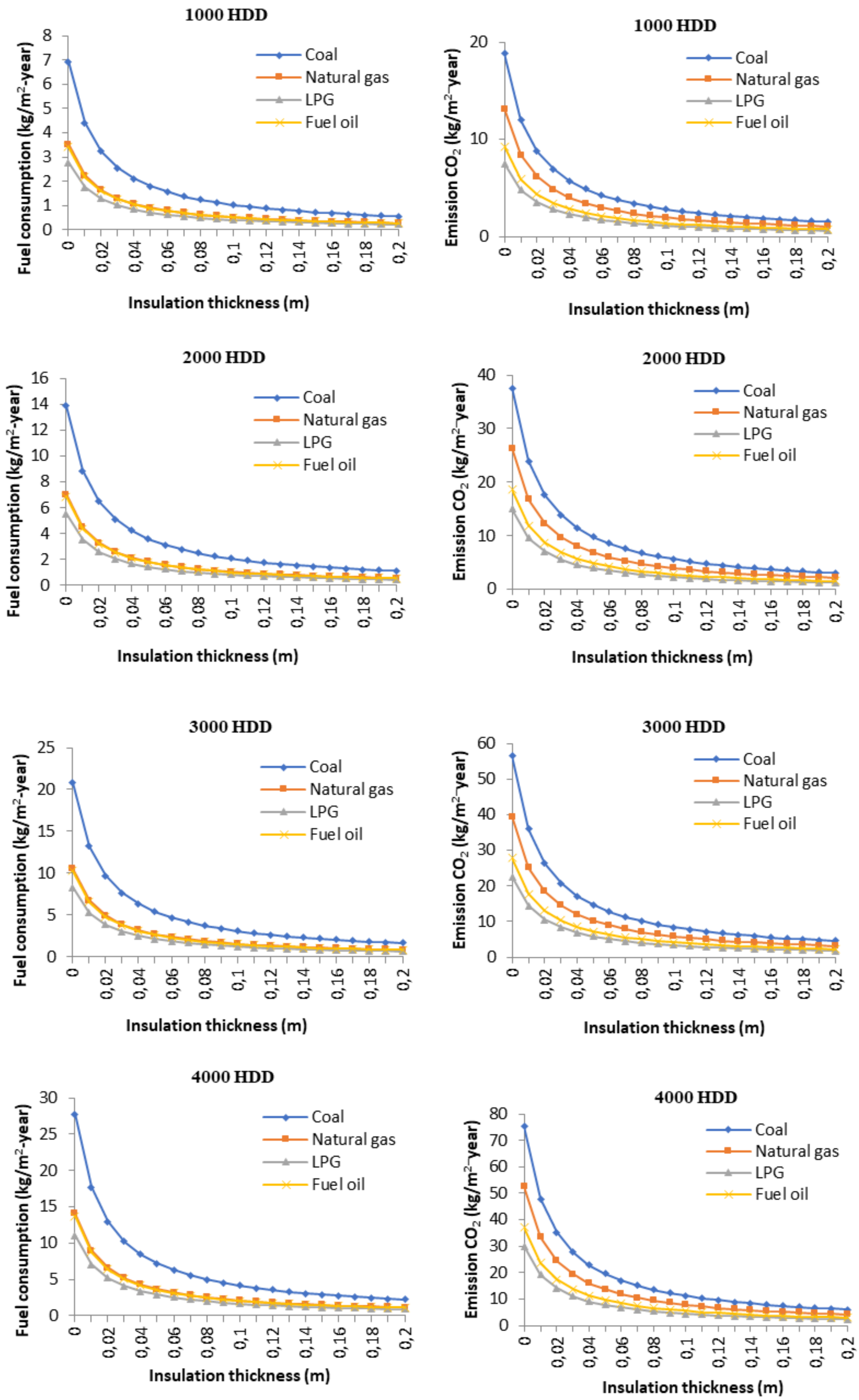

Figure 8. Fuel consumption and CO_2 emissions for different HDD in roofs (SP).

According to the Food and Agriculture Organization of the United Nations (FAO), global poultry meat production was estimated to be 137.8 million tons in 2021 (Gržinić et al., 2023). Türkiye ranks 10th in broiler meat production across the world. Europe produces about 18 million tons of broiler meat. In Europe, Türkiye ranks second in broiler meat production. There are a total of 11,056 enterprises in the poultry farming sector in Türkiye. There are 12,725 commercial poultry houses of these enterprises. It is estimated that the capacity utilization rate in existing enterprises and poultry houses is around 85-90% (Anonymous, 2023b).

Considering the number of poultry farming facilities by provinces in Türkiye, there are 1603 facilities in Manisa (12.6%) and Sakarya (12.6%), 1476 facilities in Balıkesir (11.6%), 1374 facilities in Bolu (10.8%) and 1007 facilities in Mersin (8.7%). In case of applying the optimum insulation layer thickness with XPS on the exterior walls by using natural gas, it was possible to save 13.14 $/m² in Manisa, 14.70 $/m² in Sakarya, 16.80 $/m² in Balıkesir, 24.33 $/m² in Bolu and 7.53 $/m² in Mersin. In case of applying the optimum value for the insulation thickness parameter with sandwich panels on the roofs by using natural gas, it was possible to save 22.36 $/m² in Manisa, 24.99 $/m² in Sakarya, 28.54 $/m² in Balıkesir, 41.30 $/m² in Bolu and $12.85 $/m² in Mersin.

Assuming that poultry farming facilities comply with the relevant insulation standards and considering the floor area as 12x50 m and the wall height as 5 m; in Manisa, it was possible to save approximately 13 million dollars by applying exterior wall insulation with XPS, and 21 million dollars by applying sandwich panels on the roofs in all facilities. Considering that these figures are only obtained for just one province with 12.6% of the total facilities, the amount of savings to be achieved in case of applying insulation to poultry farming facilities throughout Türkiye will be very significant. In addition, there will be a significant reduction in CO_2 emissions as well.

4. Conclusions

In Türkiye, energy consumption increases in parallel with the population growth, and it is crucial to evaluate the potential for savings and reduce losses, especially in sectors with high energy consumption, in order to reduce energy expenditures. As is known, costs of heating and cooling are some of the greatest expense items for establishments in the poultry production sector. Thus, energy savings are of critical importance in poultry farming. The use of insulation systems in closed farm areas in recent years in the poultry farming sector also increases production quality and efficiency by providing suitable physical conditions. In this study, the optimum insulation layer thickness, energy savings, and payback period of the exterior walls of poultry farming facilities in the poultry sector in Türkiye were calculated to ensure efficient energy use in poultry farming facilities. The savings in walls and roofs through insulation vary between 7.53-164.65 $/m² and 12.85-319.62 $/m², respectively, and the payback periods range from 1.19-2.19 years to 1.18-1.99 years, respectively. It is estimated that a 70-80% reduction in CO_2 emissions can be achieved in poultry farming facilities in Türkiye by applying the optimum insulation layer thickness.

Author Contributions

The percentage of the author contributions is presented below. The author reviewed and approved the final version of the manuscript.

	A.A.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

References

Açıkkalp E, Kandemir SY. 2019. A method for determining optimum insulation thickness: Combined economic and environmental method. Therm Sci Eng Prog, 11: 249-253.

Akolgo GA, Uba F, Opoku R, Tweneboah-Koduah S, Alhassan ARM, Anokye EG, Jedaiah AOA, Nunoo E. 2022. Energy analysis of poultry housing in Ghana using artificial neural networks. Sci Afr, 17: 01313.

Akpınar EK, Demir İH. 2018. Calculation of optimum insulation thickness and Energy savings for different climatic regions of Turkey. J Sci Technol, 13(2): 15-22.

Annibaldi V, Cucchiella F, De Berardinis P, Rotilio M, Stornelli V. 2019. Environmental and economic benefits of optimal insulation thickness: A life-cycle cost analysis. Renew Sust Energ Rev, 116: 109441.

Anonymous. 2022a. http://www.canakkalegaz.com.tr/turkish (accessed date: 10 December 2022).

Anonymous. 2022b. http://www.dosider.org, Fuel prices (accessed date: 12 December 2022).

Anonymous. 2022c. http://www.izocam.com.tr, Insulation Unit Prices (accessed date: 10 December 2022).

Anonymous. 2023a. https://www.mta.gov.tr (accessed date:15 October 2023).

Anonymous. 2023b. https://arastirma.tarimorman.gov.tr/tepge (accessed date: 10 October 2023).

Arıtürk E, Ergün A, Yalçın S. 1986. The Relationship Between Poultry and Environmental Temperature. Lalahan Zoot Arast Enst Derg, 26(1-4): 42-52.

Bolattürk A. 2008. Optimum insulation thicknesses for building walls with respect to cooling and heating degree-hours in the warmest zone of Turkey. Build Environ, 43(6): 1055-1064.

Büyükalaca O, Bulut H, Yılmaz T. 2001. Analysis of variable-base heating and cooling degree-days for Turkey. Appl Energy, 69(4): 269-283.

Christenson M, Manz H, Gyalistras D. 2006. Climate warming impact on degree-days and building energy demand in Switzerland. Energy Convers Manag, 47(6): 671-686.

Dağtekin M. 2012. Tecno-ekonomic feasibility analysis of solar energy use in cooling of broiler poultry houses. J Agric Fac ÇÜ, 27(2): 11-20.

De Rosa M, Bianco V, Scarpa F, Tagliafico LA. 2014. Heating and cooling building energy demand evaluation; a simplified model and a modified degree days approach. Appl Energy, 128: 217-229.

Dombaycı ÖA, Atalay Ö, Acar ŞG, Ulu EY, Öztürk HK. 2017. Thermoeconomic method for determination of optimum insulation thickness of external walls for the houses: Case study for Turkey. Sustain Energy Technol Assess, 22: 1-8.

Eto JH. 1988. On using degree-days to account for the effects of weather on annual energy use in office buildings. Energy Build, 12(2): 113-127.

Gržinić G, Piotrowicz-Cieślak A, Klimkowicz-Pawlas A, Górny RL, Ławniczek-Wałczyk A, Piechowicz L, Olkowska E, Potrykus M, Tankiewicz M, Krupka M, Siebielec G, Wolska L. 2023. Intensive poultry farming: A review of the impact on the environment and human health. Sci Total Environ, 858: 160014.

Hou J, Zhang T, Hou C, Fukuda H. 2022. A study on influencing factors of optimum insulation thickness of exterior walls for rural traditional dwellings in northeast of Sichuan hills, China. Case Stud Constr Mater,16: 01033.

Kapica J, Pawlak H, Ścibisz M. 2015. Carbon dioxide emission reduction by heating poultry houses from renewable energy sources in Central Europe. Agric Syst, 139: 238-249.

Lindley JA, Whitaker JH. 1996. Agricultural buildings and structures. American Society of Agricultural Engineers (ASAE), USA, pp 636.

Malka L, Kuriqi A, Haxhimusa A. 2022. Optimum insulation thickness design of exterior walls and overhauling cost to enhance the energy efficiency of Albanian's buildings stock. J Clean Prod, 381: 135160.

Matzarakis A, Balafoutis C. 2004. Heating degree-days over Greece as an index of energy consumption. Int J Climatol, 24(14): 1817-1828.

Özdemir E, Poyraz Ö. 1997. Insulation of poultry houses. Lalahan Zoot. Arast. Enst. Derg, 37(2): 91-108.

Özlü S, Shiranjang R, Elibol O, Karaca A, Türkoğlu M. 2017. Effect of paper waste products as a litter material on broiler performance. J Appl Poult Res, 14(2): 12-17.

Şişman N, Kahya E, Aras N, Aras H. 2007. Determination of optimum insulation thicknesses of the external walls and roof (ceiling) for Turkey's different degree-day regions. Energy Policy, 35(10): 5151-5155.

Ustaoğlu A, Kurtoğlu K, Yaras A. 2020. A comparative study of thermal and fuel performance of an energy-efficient building in different climate regions of Turkey. Sustain Cities Soc, 5: 102163.

Yang Z, Tu Y, Ma H, Yang X, Liang C. 2022. Numerical simulation of a novel double-duct ventilation system in poultry buildings under the winter condition. Build Environ, 207: 108557.