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The Prediction of Fuel and Energy Consumption by Using Degree-days Method for Residential Buildings in Denizli

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Abstract: Energy analysis has an important role on optimum design of HVAC systems of buildings. Although there are different energy analysis methods, degree-days method is the easiest and the most reliable one for energy analysis of residential buildings. The main objective of this paper is to present case study for the prediction of total coal and energy consumption by using degree-days method for Denizli, Turkey. On degree-days method, hourly temperature values were used in order to obtain more definite results. This paper is considered at two steps. In the first step, depending on the number of residences, total coal and energy consumptions for uninsulated buildings were predicted for 16, 18, 20, and 22°C base temperatures in 2010, 2015, 2020 and 2023. For the second step, assuming the buildings are insulated (polystyrene for external wall and glass wool for roof), total coal and energy consumptions were predicted for the same base temperatures in the same years. The total coal consumption of insulated buildings for 22°C base temperatures in 2010 is 29% lower than the prediction of the total coal consumption of uninsulated buildings for 16°C base temperatures in the same year.

Keywords: Degree-days, Residential Buildings, Coal Consumption

1. Introduction

With its geographic situation extending from Asia to Europe, Turkey is next to the countries having rich energy sources like Ukrayna, Rusya, Azerbeycan, Iran and Iraq. However, Turkey isn't a rich country in terms of energy sources. Although this great country has a population of about 78.44 million and the Gross National Product of about 798 billion dollars, it hasn't enough energy sources and this causes significant dangers in respect to energy reliability [1].

In Turkey, the most used energy sources coal, oil, natural gas and hydro. The primary domestic energy sources are hydro and lignite. Hydro sources and lignite basins are in the eastern and southeastern part of the country respectively; but Turkey has no big oil and gas reserves, almost all oil and natural gas are imported [2]. While energy production was at the level of 22.48 Mtoe (million tons of oil equivalents) in 1990, it was at the level of 25.17 Mtoe in 2001. In 2001, 51.1% of total energy production from primary energy sources was provided from coal (lignite and hard coal), 11.7% from oil and natural gas, 8.2% from hydraulic and 24.7% from non-commercial sources [3]. In 2008, about 50% of electricity produced by thermal power with natural gas.

The total energy consumption can be divided into four main sectors: industrial, building (residential), transportation, and agriculture. Table 1 shows the sectoral distribution of the general energy consumption according to years [3]. It is clear that the largest energy consumer is the industrial sector; the second one is the residential sector. The prediction of energy requirements and fuel consumption in residential buildings has been reported in several studies [4, 5, 6, 7]. Several ways can be used to decrease the energy consumption in the building sector. It was investigated the effect of insulation material on energy saving in the building sector by using different insulation materials [8, 9, 10, 11, 12, 13].

Table 1. *Distribution of energy consumption in different sectors in Turkey (Mtoe).*

Year	1999	Share %	2000	Share %	2001	Share %
Industry	19873	26.7	24501	30.4	21324	28.2
Buildings	18978	24.5	20058	25	18122	24
Transportation	11351	15.2	12008	15	12.000	16
Agriculture	2923	3.93	3073	3.81	2964	3.93
Other	1881	2.53	1915	2.37	1638	2.17
Total	55006	100	61555	100	56048	100

The main objective of this paper is to present case study for the prediction of coal and energy consumption for residential space heating with insulated and uninsulated in terms of degree-days calculated by hourly mean temperature values obtained from Meterological Service for Denizli, Turkey [14].

2. Construction of Buildings

Denizli is located in the inner part of West Anatolia. Buildings have the average surface area of 130 m^2 in Denizli. Turkey has four climatic regions and Denizli is in the 3rd region [15]. In this region heating is employed for five months of a year. Maximum and minimum temperatures values versus the months in 2005 are given in Table 2 [15].

The materials used in the construction of buildings consist of stones, concrete, bricks, and reinforcement iron bars. The external walls are built as composite structure which consists of horizontal hallow bricks in outside, insulation at the middle and plaster layers on both sides. The ceiling structure of the buildings consists of a plaster layer on bottom, reinforced concrete, and insulation on top.

Table 2. *Climate in Denizli, maximum and minimum temperatures (°C) in 2005.*

Month	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Avarage Max.	10.5	12.1	15.8	20.7	26.3	31.2	34.4	34.4	29.9	23.7	17.3	12.2
Avarage Min	2.3	2.8	5.2	9.0	13.2	17.3	20.0	19.7	15.7	11.3	7.0	4.0
Max	22.6	25.9	30.8	35.8	37.0	42.4	43.9	44.4	41.6	34.4	29.9	26.6
Min	-10.5	-11.4	-7.0	-2.0	2.7	7.9	12.6	11.6	6.6	-0.8	-4.5	-10.4

In the calculations, expanded polystyrene (ρ>20kg/m^3, k =0.032W/mK) and glass wool (k =0.040 W/m K) were chosen as the insulation material for external wall and ceiling, respectively.

3. Degree-days Method

Energy analysis has an important role on optimum design of HVAC (Heating, Ventilating and Air –Conditioning) systems of buildings. Although there are energy analysis methods at different difficulty, degree-days method is the easiest and the most reliable one for energy analysis of residential buildings, inner temperature and inner heat gains of which are relatively constant. Degree-days value is a measure to show energy requirements of residences for heating and cooling. Monthly or/and yearly heating or cooling energy requirements of specific buildings in different zones are predictable by degree-days method. On degree-days method, it is accepted that residences energy requirement is proportional to difference between daily mean temperature and base temperature. Base temperature is the temperature that is higher or lower than outdoor temperature according to heating or cooling requirements.

For heating, heating degree-days (HDD) can be calculated using following expression [16];

$$\mathrm{HDD} = (1\,\mathrm{day})\sum_{\mathrm{days}} (T_b - T_m)^+ \tag{1}$$

in which, T_b is the base temperature and T_m is the daily mean outdoor temperature. The plus sign above the parentheses of Eq. (1) indicates that only positive values are to be considered.

On degree-days method, hourly temperature values were used in order to obtain more definite results. The temperature values of 52560 hours were used from Turkish State Meterological Service for Denizli, Turkey. Table 3 shows the information for the province, periods of the data considered, and the annual heating degree days with 16, 18, 20, and 22°C base temperatures.

Table 3. *Information for the province considered and the yearly heating-degree-days.*

Province	Longitude	Latitude	Elevation (m)	Total hours
Denizli	29.05	37.47	428	52560
	Base temperature (°C)			
	16	18	20	22
Heating degree-days	1347	1732	2163	2642

4. Calculations of Fuel and Energy Consumptions

The coal and energy consumption in a building for heating purpose in a heating season can be seen as following [4],

$$Q_{cc,y} = \frac{UA}{H \cdot \eta} \cdot HDD_y \cdot \frac{24}{1000}, \; Q_{ec,y} = \frac{UA}{\eta} \cdot HDD_y \cdot \frac{24}{1000} \quad (2)$$

Where $Q_{,cc,y}$ and $Q_{,ec,,y}$ are the yearly coal and energy consumption in a building, respectively. UA is the total heat transfer coefficient for the building, H is the fuel heating value, η is the efficiency of the heating system, and HDD_y is the yearly heating degree-days.

Total coal and energy consumption in a city for heating purpose in a heating season can be seen similarly as,

$$Q_{cc,t} = n \cdot \frac{UA}{H \cdot \eta} \cdot HDD_y \cdot \frac{24}{1000},$$

$$Q_{ec,t} = n \cdot \frac{UA}{\eta} \cdot HDD_y \cdot \frac{24}{1000} \quad (3)$$

Where n is the number of residences (or buildings) in the city. $Q_{cc,\ t}$ and $Q_{,ec,\ t}$ are the total yearly coal and energy consumption of the city, respectively.

5. Results

A model building has an area of 130 m^2 was assumed to present a typical residence in this study. The total heat transfer coefficient (UA) for the uninsulated and the insulated building are 1764 kJ/h °C and 636 kJ/h °C, respectively. The coal heating value (H) is 18,834.75 kJ/kg and the efficiency of the heating system (η) is 65%. For practical purpose, the value of η is assumed to be 65%. The different values of η can be employed in calculations to estimate the coal consumption. Ref. [8] presents the results for η=70% whereas Ref. [13] used η=65% to calculate the optimum insulation thickness of external walls.

The number of residences and population of Denizli in 1984 and 2000 were obtained from the Republic of Turkey Turkish Statistics Institution [17] and by using these data, the number of residences in 2010, 2015, 2020 and 2023 years were predicted. This paper is considered at two steps. In the first step, depending on the number of residences, total coal and energy consumptions for uninsulated buildings were predicted for 16, 18, 20, and 22°C base temperatures in 2010, 2015, 2020 and 2023. And in the second step, assuming the buildings are insulated (polystyrene for external wall and glass wool for roof), total coal and energy consumptions were predicted for the same base temperatures in the same years.

Figs.1 and 2 show the predicted total coal and energy consumptions for uninsulated buildings for 16, 18, 20, and 22°C base temperatures in a heating season until 2023.

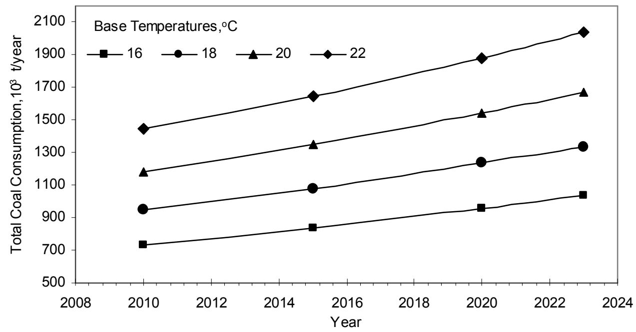

Fig. 1. The predicted total coal consumptions for uninsulated buildings for different base temperatures in a heating season.

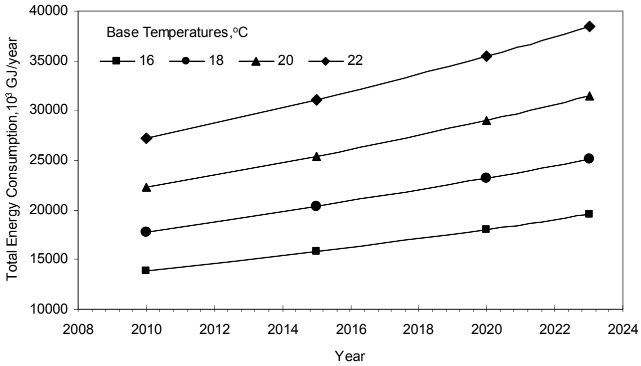

Fig. 2. The predicted total energy consumption for uninsulated buildings for different base temperatures in a heating season.

Figs. 3 and 4 show the predicted total coal and energy consumptions for insulated buildings for the same base temperatures in the same years. As seen in the Figures, coal and energy consumptions linearly increase by increasing base temperature. It is obvious that by insulating buildings, coal consumption remarkably decrease. For example, as the coal consumption for uninsulated buildings was approximately 735,000 t/year for 16°C base temperatures in 2010, the coal consumption for insulated buildings was predicted as 265,000 t/year for the same base temperature in the same year.

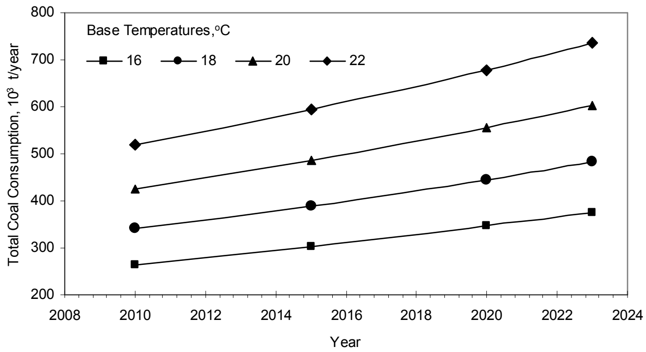

Fig. 3. The predicted total coal consumption for insulated buildings for different base temperatures in a heating season.

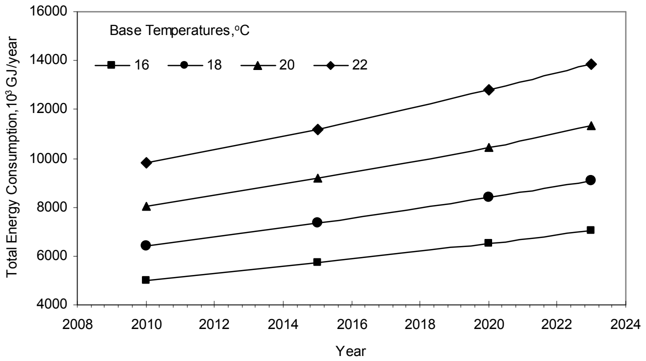

Fig. 4. The predicted total energy consumption for insulated buildings or different base temperatures in a heating season.

The prediction of the total coal consumption of insulated buildings for 22°C base temperatures in 2010 is lower 29% lower than the prediction of the total coal consumption of uninsulated buildings for 16°C base temperatures in the same year. So, to maintain less energy consumption in buildings, base temperature value should be kept as low as possible. This is possible by applying double-glazed window, minimizing air infiltration, and designing residences which can utilize from solar radiation at maximum level in addition to insulating of external walls and roofs.

6. Conclusions

This paper presents a case study for the prediction of coal and energy consumption for residential buildings with insulated and uninsulated by using degree-days calculated by hourly mean temperature values obtained from Turkish Meteorological Service for Denizli, Turkey. In calculations, coal was used as the energy source. Polystyrene and glass wool were chosen for external wall and roof insulation, respectively. By insulating the buildings, savings of 64% were obtained on coal and energy consumption for Denizli.

Although coal is used for energy requirement in building and industry sectors in Denizli, it is considered that total energy consumption to be provided from natural gas for the next five years. As the natural gas and oil sources are extremely inadequate and nearly depends on imports, Turkey should provide its energy requirement from domestic energy source. It's vital. For this reason, the project of energy consumption depending on natural gas should be abandoned and we should go on using coal as it's a reliable national source in terms of reserve. In addition, coal qualifying technologies which decrease the harmful gas emissions like CO_2 and SO_2 which occur when coal is burnt should be developed. In the process of constructing buildings, insulation should be obligatory.

Nomenclature

HVAC	Heating, Ventilating and Air –Conditioning
$Q_{cc,y}$	Coal consumption in a building (t/year)
$Q_{ec,y}$	Energy consumption in a building (GJ/year)
$Q_{cc,t}$	Total coal consumption of the city (t/year)
$Q_{ec,t}$	Total energy consumption of the city (GJ/year)
UA	Total heat transfer coefficient (kJ /h °C)
HDD	Heating degree-days (°Cdays)
η	Efficiency of space-heating system
H	Heating value (kJ/kg)
n	number of residences (or buildings)
Mtoe	Million tons of oil equivalents

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