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Energy 28 (2003) 929–939
ENERGY
www.elsevier.com/locate/energy

The degree-day method to estimate the residential heating natural gas consumption in Turkey: a case study

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Received 22 February 2002

Abstract

The heating degree-day method was used to determine the natural gas consumption by residential heating in Turkey. Cities located nearby the existing, under construction, and planned natural gas pipelines were chosen for this study. Degree-days, population and resident distribution records obtained for these cities were utilized to estimate the nation-wide natural gas demand. Our study indicates that the potential consumption in Turkey in 2023 could be as high as 14.92 Gm^3 if 100% of residences use natural gas for space heating. The results enable us to locate the distribution of energy demand and pick out the areas where consumption is highest. The predictive method was successfully validated by comparison with real data on natural gas consumption in Turkey for the winter heating of buildings.

1. Introduction

Turkey's demand for energy has been rapidly increasing as a result of factors like industrialization, urbanization and rapid population growth. In an attempt to secure additional energy sources, an intergovernmental agreement was signed in 1984 regarding the supply of natural gas between the governments of Turkey and the former Soviet Union. The first main transmission line, entering from the Bulgarian border and extending to Ankara, was built in 1988. Five cities along the route of the line, Istanbul, Izmit, Bursa, Eskisehir, and Ankara, were linked to the distribution line in a period of 8 years. As of December 2001, natural gas is supplied to about 2.6 million customers in those cities.

Turkey consumed 15.5 Gm^3 of natural gas in 2001, accounting for around 14% of Turkey's

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0360-5442/03/$ - see front matter
doi:10.1016/S0360-5442(03)00035-5

total energy consumption. The residential sector consumes 20% of the natural gas. The power generation sector consumes the biggest share, 55%. According to the projections prepared by BOTAS (Petroleum Pipeline Corporation), Turkey's state-run pipeline company, natural gas demand in Turkey is expected to reach 55 Gm^3 by 2010 and 82 Gm^3 by 2020 [1]. Supply for gas will rise quite steeply over the next 20 years. BOTAS projects that the natural gas demand of the residential sector will be 12% of the total gas consumed in 2020. It will rise from the current 3 to 9.8 Gm^3 in the next 20 years. An extensive natural gas pipeline system is being developed to ensure deliverability of the gas to the customers in 57 cities and is expected to be completed in the next 4 years.

The ability to forecast the evolution of heating energy consumption in residential sector as a function of climatic variations and demographic trends is of considerable economic importance. The degree-day method is widely used in energy consumption to plan and to estimate heating loads and storage requirements. Natural gas is used primarily for space heating, and natural gas consumption in buildings varies throughout the year so that the supply and demand balance must be planned in advance. Variation in space heating needs is measured in degree-days. Degree-day calculations are performed by means of long-term analysis of representative meteorological data. Prediction of the heating natural gas demand in residential and industrial buildings can be based on knowledge of degree-days. Yearly heating degree-hours and degree-days with base temperatures of 15, 17 and 18.3 °C for all cities around Turkey are given in Ref. [2]. The data used in our study are obtained from Ref. [2].

The main purpose of this work is to present a case study for the calculations of residential heating natural gas consumption in Turkey in terms of degree-days. The results are presented in the form of readily usable tables and figures for all transmission lines. They can be used to identify the relative distribution of the potential natural gas demand for winter heating and the geographic areas of Turkey which represent the highest consumption densities. They should be very useful in locating storage facilities and designing distribution grids of natural gas.

2. Results

The fuel consumption for building heating purpose in a heating season can be expressed as

$$Q_{\mathrm{h,yr}} = \frac{\mathrm{UA}}{H\eta_{\mathrm{h}}}\mathrm{HDD}_{\mathrm{y}}, \tag{1}$$

where $Q_{\mathrm{h,yr}}$ is the yearly energy consumption, UA the overall heat transfer coefficient for the building, H the fuel heating value, η_{h} the efficiency of the heating system, and $\mathrm{HDD}_{\mathrm{y}}$ is the yearly heating degree-days [3,4]. Total fuel consumption in a city can be expressed similarly as

$$(Q_{\mathrm{h,yr}})_{\mathrm{c}} = n\frac{\mathrm{UA}}{H\eta_{\mathrm{h}}}\mathrm{HDD}_{\mathrm{y}}, \tag{2}$$

where n is the number of residences (or apartments) in the city and $(Q_{\mathrm{h,yr}})_{\mathrm{c}}$ is the total yearly energy consumption of the city. The fuel consumption in cities supplied by a natural gas transmission pipeline is determined from

$$(Q_{h,yr})_{tp} = \sum_{i=1}^{k} (Q_{h,yr})_c, \qquad (3)$$

where k is the number of cities supplied by the natural gas transmission line and $(Q_{h,yr})_{tp}$ is the total residential energy consumption for the transmission line.

A model apartment having an area of 100 m^2 was assumed to represent a typical residence in this study. The natural gas consumption predictions are made considering UA = 1000 kJ/h °C, $H = 36.8 \times 10^3$ kJ/m^3, and $\eta_h = 0.88$. This value of UA represents an average value for an apartment with 100 m^2 area. Its value is comparable to UA values used in similar studies [5,6]. For practical purposes, the value of η_h is assumed to be 0.88 and also represents an average value for the natural gas burners and utilities. The different values of η_h can be employed in calculations to estimate the natural gas consumption. Refs. [7,8] present the results for $\eta_h = 0.72$ whereas Ref. [5] used $\eta_h = 0.92$ in estimating the natural gas consumption for heating season in Istanbul.

The cities located nearby the existing, under construction and planned natural gas pipelines were chosen. Population and resident distribution records for these cities were obtained from the State Statistical Institute. For each city the number of inhabitants and the number of corresponding households (or residences) registered in the 1990 and 1997 censuses were carefully evaluated to predict the change and trend in the number of residences covering a period from 2000 to 2023(the centennial of the Turkish Republic).

Various pipeline projects are being developed for transporting gas within Turkey. The existing pipeline between the Bulgarian border and Ankara is already serving the northwestern part of Turkey. Following transmission lines are under construction:

- the Iran–Ankara (Eastern Anatolia) transmission line,
- the Samsun–Ankara (Blue Stream) transmission line,
- the Izmir–Bursa (Western Anatolia) transmission line,
- the Can–Canakkale transmission line.

The Turkish government already planned to build the following transmission lines in the next 4–5 years:

- the Kirsehir–Konya (Southern) transmission line,
- the Konya–Izmir transmission line,
- the Dogu Karadeniz (Eastern Black Sea) transmission line,
- the Eregli–Sinop transmission line,
- the Sivas–Gaziantep transmission line,
- the Iraq–Icel (Southeastern) transmission line.

Fig. 1 is a map of Turkey with the transmission lines considered in this study. The routes of the transmission lines are shown in the figure. The number of cities supplied by natural gas for residential heating use will increase from 5 now to 57 in 2005.

Table 1 lists the natural gas transmission pipelines and cities supplied by each pipeline in modeling residential natural gas consumption. Numbers in the first row of Table 1 correspond to the transmission lines shown in Fig. 1. Table 2 gives the data on the number of residences in

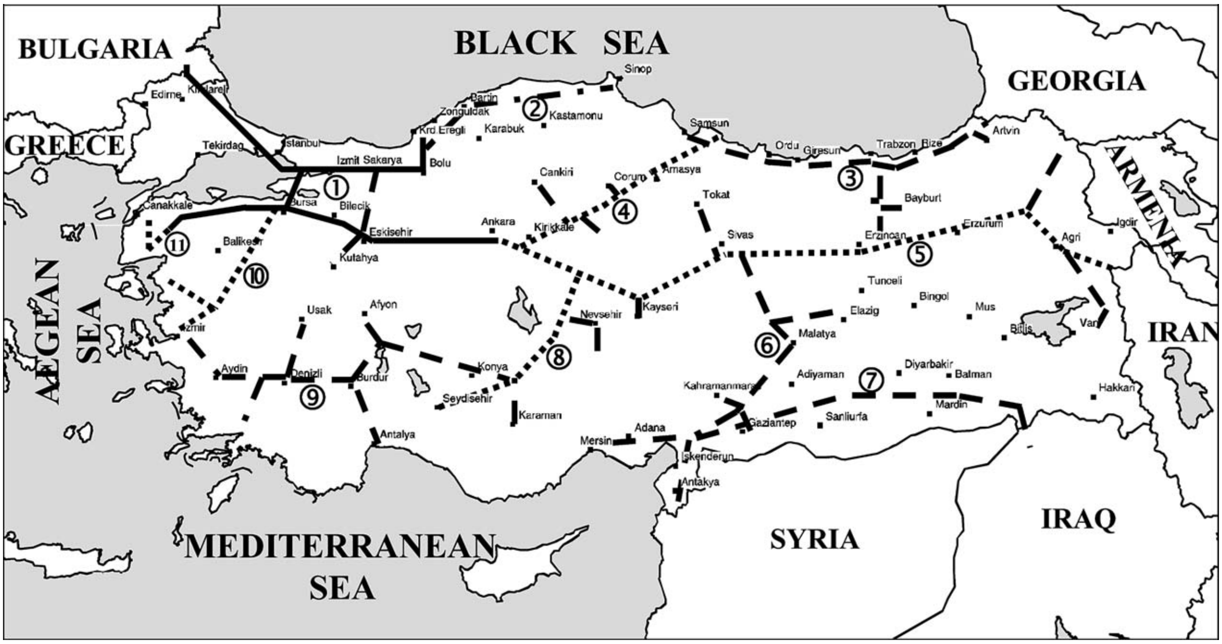

Fig. 1. Map of Turkey with the transmission lines considered in this study.

cities supplied by transmission lines. Numbers in the second column of Table 2 correspond to the registered number of residences in cities supplied by each respective transmission line recorded in the 1997 census. The number of residences covering the period from 2000 to 2023 was determined by considering the change and trend in the number of residences registered in the 1990 and 1997 censuses.

Table 3 summarizes the residential natural gas consumption predictions for transmission lines depending on 18.3, 17 and 15 °C base temperatures until 2023. The natural gas consumption is expressed in standard cubic meters (st m^3; reference conditions: T = 15 °C, p = 101.3 kPa) for each transmission line and each year considered.

Table 3 gives the natural gas consumption forecast under the condition of 100% residence saturation. The residence saturation is defined as the ratio of the number of residences using natural gas to total number of residences multiplied by 100 to express in percent. Consumers will have to decide to what extent they should use natural gas to meet their heating requirements. The costs and policy on natural gas will determine their choice. That is the reason why the potential consumption for each transmission line was calculated in terms of percentages of residences using natural gas for space heating. It represents the number of residences belonging to the particular transmission line which determines the consumption.

The natural gas demand predictions for winter heating in Turkey are shown in Figs. 2 through 4. Fig. 2 illustrates the predicted gas consumptions for transmission lines for 15 °C base temperature and 100% residence saturation. Fig. 3 gives the predicted total consumptions for all transmission lines for 15, 17 and 18.3 °C base temperatures and 100% residence saturation. Finally, Fig. 4 shows the predicted total consumptions for all transmission lines for 15 °C base temperature and 100, 50 and 25% residence saturations.

Table 1
List of the natural gas transmission pipelines and cities supplied by each pipeline

Existing transmission line (1)	Eregi–Sinop transmission line (2)	Dogu Karadeniz transmission line (3)	Samsun–Ankara transmission line (4)	Iran–Ankara transmission line (5)	Sivas–G. Antep transmission line (6)	Iraq–Icel transmission line (7)	Kirsehir–Konya transmission line (8)	Konya–Izmir transmission line (9)	Izmir–Bursa transmission line (10)	Can–Canakkale transmission line (11)
Edime	Zonguldak	Ordu	Samsun	Agri	Elazig	Sirnak	Nevsehir	Afyon	Izmir	Ezine
Kirklareli	Bartin	Giresun	Amasya	Igdir	Malatya	Hakkari	Aksaray	Isparta	Manisa	Canakkale
Luleburgaz	Karabuk	Trabzon	Corum	Kars	K. Maras	Siirt	Nigde	Burdur	Turgutlu	
Tekirdag	Kastamonu	Rize	Yozgat	Ardahan		Batman	Konya	Antalya	Akhisar	
M. Ereglisi	Sinop	Artvin	Cankiri	Van		Mardin	Karaman	Denizli	Balikesir	
Istanbul		Gümüshane	Kirikkale	Erzurum		Diyarbakir		Usak	Yenice	
Kocaeli		Bayburt		Erzincan		Sanli Urfa		Mugla		
Sakarya				Tunceli		Adiyaman		Aydin		
Duzce				Bingol		Gaziantep				
Bolu				Mus		Kilis				
Eregli				Bitlis		Osmaniye				
Yalova				Sivas		Iskenderun				
Bursa				Tokat		Dortyol				
Biga				Kayseri		Hatay				
Can				Kirsehir		Adana				
Bilecik						Icel				
Kutahya										
Eskisehir										
Ankara										

The numbers in parentheses in the first row correspond to transmission lines shown in Fig. 1.

Table 2
Data on the number of residences in cities supplied by the transmission lines (number of residences covering the period from 2000 to 2023 were reduced to three significant digits)

Transmission lines	Number of residences						
	1997	2000	2005	2010	2015	2020	2023
Existing (1)	3,620,181	3,940,000	4,530,000	5,220,000	6,030,000	6,970,000	7,600,000
Eregli–Sinop (2)	76,225	74,400	71,700	69,100	66,700	64,500	63,300
Dogu Karadeniz (3)	113,348	116,000	121,000	127,000	133,000	139,000	143,000
Samsun–Ankara (4)	191,104	198,000	210,000	222,000	236,000	250,000	259,000
Iran–Ankara (5)	407,943	421,000	447,000	476,000	510,000	549,000	577,000
Sivas–G. Antep (6)	184,744	205,000	244,000	291,000	349,000	419,000	468,000
Iraq–Icel (7)	895,879	963,000	1,090,000	1,250,000	1,440,000	1,680,000	1,850,000
Kirsehir–Konya (8)	319,633	333,000	355,000	380,000	406,000	434,000	452,000
Konya–Izmir (9)	340,090	372,000	432,000	503,000	587,000	688,000	758,000
Izmir–Bursa (10)	798,411	846,000	931,000	1,030,000	1,130,000	1,250,000	1,320,000
Can–Canakkale (11)	21,309	22,600	25,000	27,700	30,700	34,000	36,200
Total	6.969×10^6	7.491×10^6	8.457×10^6	9.596×10^6	1.092×10^7	1.248×10^7	1.353×10^7

According to recent data reported by BOTAS, the total natural gas consumption for residential heating in cities located on the routes of the existing transmission line in 1998 and 2000 is 2.08 and 2.68 Gm^3, respectively. The number of residences using natural gas for heating was 1.71 million in 1998 and 2.36 million in 2000. These numbers represent about 46 and 60% of the total residences in cities. Fig. 5 compares the predicted consumption for 15 °C base temperature with the actual natural gas consumptions in 1998 and 2000. The results in Fig. 5 verify that the estimations are in good agreement with the reality and demonstrate that our model provides results of reasonable accuracy.

3. Discussion

The model used to determine predictions is simple and also flexible. For example, if one wants to incorporate the effect of η_h, the results given in Table 3 for $\eta_h = 0.88$ are multiplied by the ratio of $(\eta_h)_{new}/0.88$ to calculate the potential consumption for other η_h values where $(\eta_h)_{new}$ is the new heating efficiency for the case under consideration.

Table 3
The natural gas consumption forecast for transmission lines under the conditions of 18.3, 17 and 15 °C base temperatures and 100% residence saturation for the years 2005, 2010, 2015, 2020 and 2023

Transmission lines	Natural gas consumption (10^6 m^3)														
	2005			2010			2015			2020			2023		
	18.3	17	15	18.3	17	15	18.3	17	15	18.3	17	15	18.3	17	15
Existing	7.568×10^3	6.635×10^3	5.221×10^3	8.669×10^3	7.595×10^3	5.969×10^3	9.945×10^3	8.709×10^3	6.835×10^3	1.143×10^4	1.000×10^4	7.840×10^3	1.243×10^4	1.088×10^4	8.519×10^3
Eregli–Sinop	1.283×10^2	1.122×10^2	8.837×10^1	1.246×10^2	1.089×10^2	8.593×10^1	1.211×10^2	1.060×10^2	8.371×10^1	1.180×10^2	1.033×10^2	8.168×10^1	1.162×10^2	1.018×10^2	8.055×10^1
Dogu Karadeniz	1.896×10^2	1.642×10^2	1.267×10^2	1.960×10^2	1.696×10^2	1.306×10^2	2.034×10^2	1.757×10^2	1.350×10^2	2.116×10^2	1.826×10^2	1.400×10^2	2.169×10^2	1.871×10^2	1.434×10^2
Samsun–Ankara	4.027×10^2	3.564×10^2	2.869×10^2	4.260×10^2	3.769×10^2	3.033×10^2	4.507×10^2	3.987×10^2	3.207×10^2	4.770×10^2	4.219×10^2	3.392×10^2	4.936×10^2	4.365×10^2	3.509×10^2
Iran–Ankara	1.265×10^3	1.156×10^3	9.859×10^2	1.352×10^3	1.236×10^3	1.055×10^3	1.454×10^3	1.329×10^3	1.134×10^3	1.571×10^3	1.437×10^3	1.227×10^3	1.651×10^3	1.511×10^3	1.290×10^3
Sivas–G.Antep	4.590×10^2	4.118×10^2	3.395×10^2	5.497×10^2	4.934×10^2	4.070×10^2	6.602×10^2	5.928×10^2	4.893×10^2	7.952×10^2	7.142×10^2	5.898×10^2	8.902×10^2	7.997×10^2	6.607×10^2
Iraq–Icel	1.298×10^3	1.123×10^3	8.601×10^2	1.506×10^3	1.305×10^3	1.003×10^3	1.763×10^3	1.530×10^3	1.179×10^3	2.082×10^3	1.810×10^3	1.399×10^3	2.310×10^3	2.010×10^3	1.556×10^3
Kirsehir–Konya	8.384×10^2	7.589×10^2	6.342×10^2	8.962×10^2	8.112×10^2	6.779×10^2	9.582×10^2	8.673×10^2	7.247×10^2	1.025×10^3	9.274×10^2	7.749×10^2	1.067×10^3	9.656×10^2	8.067×10^2
Konya–lzmir	5.859×10^2	5.080×10^2	3.902×10^2	6.715×10^2	5.815×10^2	4.453×10^2	7.720×10^2	6.675×10^2	5.096×10^2	8.900×10^2	7.684×10^2	5.848×10^2	9.706×10^2	8.372×10^2	6.360×10^2
Izmir–Bursa	9.755×10^2	8.201×10^2	5.964×10^2	1.073×10^3	9.017×10^2	6.554×10^2	1.180×10^3	9.918×10^2	7.207×10^2	1.299×10^3	1.091×10^3	7.927×10^2	1.376×10^3	1.156×10^3	8.395×10^2
Can–Canakkale	3.489×10^1	3.009×10^1	2.284×10^1	3.861×10^1	3.330×10^1	2.528×10^1	4.279×10^1	3.690×10^1	2.801×10^1	4.747×10^1	4.094×10^1	3.108×10^1	5.054×10^1	4.359×10^1	3.309×10^1
Total	1.375×10^4	1.208×10^4	9.552×10^3	1.550×10^4	1.361×10^4	1.076×10^4	1.755×10^4	1.540×10^4	1.216×10^4	1.994×10^4	1.750×10^4	1.380×10^4	2.157×10^4	1.892×10^4	1.492×10^4

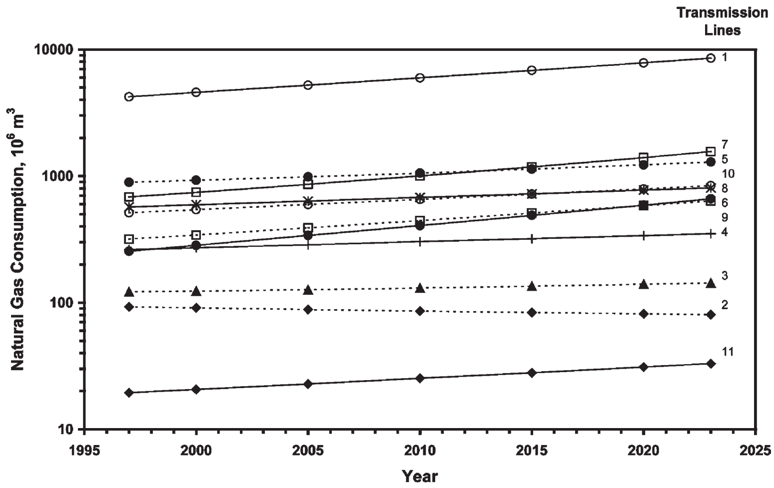

Fig. 2. The natural gas demand forecast for transmission lines for 15 °C base temperature and 100% residence saturation (numbers for transmission lines are listed in Table 1).

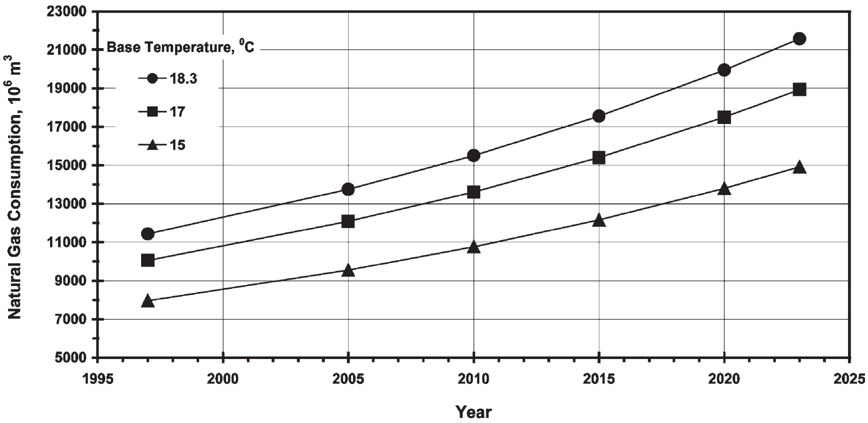

Fig. 3. The natural gas demand forecast for winter heating in Turkey for 15, 17 and 18.3 °C base temperatures and 100% residence saturation.

It is important to point out that if the residence saturations for the cities vary then each city is treated individually to find its consumption using Eq. (2) since HDD_y values for cities also vary. The total consumption for the transmission line is obtained by applying Eq. (3).

Although the results comprise certain assumptions, they nevertheless constitute a concrete indicator of the demand for natural gas and a valuable aid to gas network design. Such an analysis can therefore be extremely helpful in assessing economic and financial profit of network realization, also as an alternative to other solutions and heating techniques. It is moreover possible to develop the calculation on the basis of each single city, thus predicting the consumptions for the extension of the gas network. Consumption predictions made using other energy resources such as coal and fuel oil for a particular city or for the cities supplied by any transmission line can be compared with our results for economic and technical assessments of the relevant heating projects.

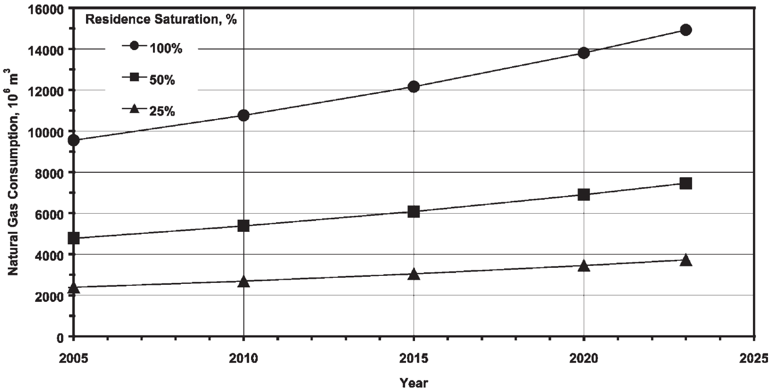

Fig. 4. The natural gas demand forecast for winter heating in Turkey for 15 °C base temperature and 100, 50 and 25% residence saturations.

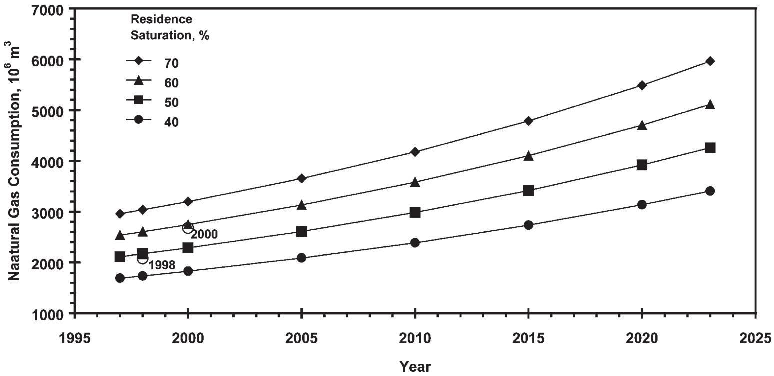

Fig. 5. Comparison of the predicted consumption for existing pipeline for 15 °C base temperature with the actual natural gas consumptions in 1998 and 2000.

Such assessments can be refined through a more exact evaluation of specific annual consumption, by extending the analysis of real consumption data to a larger number of years.

4. Potential use of results

Results in Table 3 can easily be used to make the consumption forecast if the residence saturation is less than 100%. The residence saturation has a linear prorating characteristic. As an example, if one is interested in determining results for 50 and 25% residence saturations, then 100% saturation consumption given in Table 3 is multiplied by 0.5 and 0.25 to obtain the natural gas consumption forecast, respectively.

One can use results given in Table 3 to estimate the potential consumptions for transmission lines as a function of years to come provided that the residence saturations are known. To demonstrate this, let us estimate the consumption for the Iraq–Icel transmission line in 2010 for 15 °C base temperature and 40% residence saturation. Let us also assume that the residence saturations are the same for the cities supplied by that particular transmission line. Starting with Table 3, we find 1 Gm^3 for 100% residence saturation. To obtain the consumption for 40% residence saturation, 1 Gm^3 is multiplied by 0.4, which gives 0.4 Gm^3 as the result.

5. Conclusions

A predictive map of natural gas consumption for the heating of buildings on the basis of the transmission lines and degree-days was constructed. Both the relative distribution of the potential natural gas demand for winter heating and the geographic areas of Turkey which represent the highest consumption densities were identified.

Results enabled us to determine the distribution of potential natural gas demand for winter heating and to define the areas where the consumption is greatest. Such an analysis therefore constitutes a reliable, simple criterion for identifying the zones where energy saving measures are more efficient. It could become useful tool in locating storage facilities and designing distribution grids of natural gas.

Validation of the predictions was developed by comparing the natural gas consumption for winter heating with the actual natural gas demand, obtained from BOTAS data on consumption for the years 1998 and 2000. The comparison showed the substantial reliability of the predictions. The comparison study indicated that the predictions made for 15 °C base temperature and η_h = 0.88 yield the best fit with the actual data.

Our projections for residential heating natural gas demand until 2023 are made on a national basis since the total of the transmission line demands is an estimate of the national demand. Results indicate that the potential residential consumption in Turkey in 2023 could be as high as 14.92 Gm^3 if 100% of residences use natural gas for space heating. It was observed that a large part of the consumption occurs in the cities linked to the existing pipeline. This is an expected conclusion since this area is densely populated, industrialized, and with high degree of urbanization.

We calculated the natural gas consumption for heating that would be created by the construction of a gas network in Turkey. We demonstrated that this kind of analysis would be possible for any area for which degree-days and population distribution are known. Extending the analysis of real consumption data to a larger number of years, in order to obtain a more exact estimate of the annual consumption, would fine-tune the predictive method. We will attempt to improve the accuracy of the predictions by testing them against more real consumption data when they are available.

References

[1] BOTAS (Petroleum Pipeline Corporation)-annual report. Ankara: BOTAS General Directorate; 2000.
[2] Satman A, Yalcinkaya N. Heating and cooling degree-hours for Turkey. Energy 1999;24(10):833–40.
[3] Kreider JF, Rabl A. Heating and cooling of buildings. New York: McGraw-Hill, 1994.
[4] Kreith F, Kreider JF. Principles of solar engineering. New York: McGraw-Hill, 1978.
[5] Durmayaz A, Kadıoglu M, Sen Z. An application of the degree-hours method to estimate the residential heating energy requirement and fuel consumption in Istanbul. Energy 2000;25(12):1245–56.

[6] Agioutantis Z, Bekas A. The potential of district heating using geothermal energy. A case study, Greece. Geothermics 2000;29:51–64.
[7] Karaalioglu H. The need for underground gas storage in Turkey and modeling of the northern Marmara gas field as a storage reservoir. MS thesis. Istanbul: Istanbul Technical University Petroleum and Natural Gas Engineering Department; 1997.
[8] Karaalioglu H, Satman A. Residential natural gas consumption potential for Turkey. Turkish Journal of Oil and Gas 2001;7(2):25–36.