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A practical methodology for predicting electricity consumption of urban residential buildings

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Abstract

It is a challenging task for determining the emissions and energy-saving options for counties and countries. In order to overcome this issue, two new concepts are introduced in this study. These are residential base electricity consumption and residential base natural gas consumption. A new model that estimates the total energy consumption of urban residential buildings from the available electricity consumption data is developed. The model employs heating degree days (HDD) and cooling degree days (CDD) parameters to predict the energy consumption for heating and cooling purposes. A month with zero or almost zero values of both HDD and CDD is considered as "base month." These months when there is neither heating nor cooling, plays a key role in this study.

The proposed model is applied to a county with a population of over 62,000 located in Southern Turkey, and the total electricity consumption is calculated with 1.24% accuracy. The validity and accuracy of the model are tested by theoretical electricity calculations, coal, and wood consumption. Accordingly, while annual electrical heating is equal to 2618 kWh/year for an average house of 96 m^2, for the coal and wood burning households, the annual energy consumption values are 2190 and 2616 kWh/year, respectively.

KEYWORDS
energy efficiency, greenhouse gas, sustainability

1 | INTRODUCTION

Knowing greenhouse gas (GHG) emissions of a county or city gives valuable information for sustainable urban planning, especially for the municipalities and law enforcement.[1,2] Several specifications and protocols have been launched for calculating the carbon footprint of countries, cities, and even counties. Table 1 summarizes these standards along with the institution that has developed the standard and the year it was enacted. The most recent standard is the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC Protocol).

GPC offers a powerful and clear framework that builds on existing methodologies for calculating and reporting city-wide GHG emissions. GPC requires cities to measure and disclose a comprehensive inventory of GHG emissions. Inventory methods that cities have been using to this date vary significantly. This inconsistency makes comparisons between cities challenging, raises questions around data quality and limits the ability to aggregate local, subnational, and national government GHG emissions data. In order to reach greater consistency, more reliable and meaningful reporting in GHG accounting is required.

GPC defines three GHG emissions categories referred to as scopes. Scope 1 represents the direct emissions from the sources located within the city boundary. Scope 2 represents the indirect emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam, and/or cooling within the city boundary. Finally, Scope 3 is other indirect emissions that occur outside the city boundary as a result of activities taking place within the city boundary. GPC is designed to account for GHG emissions from city activities that are classified into six main sectors[3]: Stationary energy, transportation, waste, industrial processes and industrial product use, agriculture, forestry and land use and other Scope 3 emission sources. The most difficult emissions to calculate are the major sub-sectors in the stationary energy sector because the emissions from residential, commercial, and industrial buildings, and facilities with a vast number of variations, exceed all the other emission sources combined. Residential buildings include high-rise buildings, landed buildings, farm-houses covering all residential units in agricultural farms and all other homes within the region.

The most important philosophy of the protocols given in Table 1, is to identify and introduce applicable emission reduction plans for all sectors. In other words, urban carbon footprint reports should not be a one-time-only job. However, when most if not all, the available urban GHG footprint reports are examined in detail there are no satisfying follow up studies once the original footprint report was published. The stationary energy sector, especially residential buildings, is one of the main reasons why we do not see follow-up reports.There are several studies on urban GHG footprint. A study of GHG footprint for the eight US cities has conducted on average energy, water, material use, travel demand, and associated GHG emissions.[4] Another study was performed in six Indian cities, including the emissions from energy, domestic, transportation, industrial, waste, agricultural, and livestock sectors. The major sectors contributing to the GHG footprint were found to be transportation, domestic and industrial sectors.[5] However, the paper falls short on answering several important emission factors such as residential heating, residential cooling, commercial heating, and cooling.

Instead of comparing some cities, there are studies conducted basically on just one city, such as the one conducted in Xiamen, China. The authors used a hybrid method combining the environmental input–output analysis, bottom-up based on process analysis, and life cycle analysis to evaluate this city's carbon footprint. Energy usage has the biggest share in the city's carbon footprint, whereas the industrial, commercial and public sectors, and household sectors were the top three in the energy-use emissions.[6] Apart from calculating the greenhouse gas emissions of the whole city, there are studies concentrating on a single activity of the energy source such as emissions from industrial production,[7–10] building energy consumption,[11–15] or transportation energy.[16–20]

TABLE 1 Standards for the urban carbon footprint

Name of the standard	Institution(s)	Year
Baseline Emission Inventory (BEI)	European Commission (EC)	2010
International Standard for Reporting GHG Emissions for Cities (ISC)	World Bank (WB), United Nations-Habitat (UN-H) and United Nations Environmental Program (UNEP)	2010
Specification for the Assessment of GHG Emissions of a City (PAS 2070)	British Standard Institution (BSI)	2013
Global Protocol for Community-scale GHG Emissions (GPC)	WRI, C40, ICLEI	2014

A study conducted in the United States focused on developing a residential energy use prediction methodology. The variables including location, household, housing, appliance use and climatic characteristics have been used to estimate the energy usage.[21] Consequently, energy consumption due to a building's heating and cooling load mainly depends on the climate conditions, energy performance of the building, and internal gains. In a study conducted in Greece, a detailed estimation of heating degree days (HDD) and cooling degree days (CDD) values based on hourly air temperature data has been used to examine the influence of urbanization on energy demand between neighboring locations of a hypothetical specific residential building.[22] In another study conducted in European cities, while linear relationship between energy consumption and degree days is maintained, the important role of solar irradiation on CDD has been taken into consideration.[23] Additionally, a similar study has been conducted for educational buildings, including various weather parameters and highlighting the importance of variation of base temperatures.[24] The potential impact of global warming on building energy requirements in eight major Indian cities has been investigated. In this study, using the time series analysis of historical weather records and general circulation model outputs, they quantified the historical (1969–2017) and future (2018–2100) trends in annual mean temperatures.[25] Heating and cooling in the housing sector have the biggest share in energy consumption. Hence, to decrease the energy consumption and CO_2 emissions, the heating and cooling loads must be calculated while considering the local building structure and climate parameters.[26] Several engineering, statistical and artificial intelligence methods have been developed to predict the energy demand of a building. HDD is one method that depends on the climate conditions.[27–29] The difference between mean daily temperature and a given reference temperature, which is the human comfort temperature, is defined as a "degree day."[30] The term degree day shows that the daily average outside temperature was one degree higher or lower than some comfortable baseline temperatures on that day. The sum of HDD and CDD over a year is proportional to the annual amount of energy demand to heat or cool a building in that particular location.[31] Domestic heating energy consumption or energy demand can be estimated by using the degree days' information.[32] In a study conducted in Greece, it has been found that as the HDD increases, the fuel consumption increases as well.[33]

In sustainable energy project developments, the decision-makers must comprehend the current situation and provide a baseline for future scenarios to improve environmental sustainability. The lignite power plants are getting more popular in Turkey, and over 70% of Turkish electricity generation is based on fossil fuels.[34] Since the lignite power plants release GHG emissions or other environmental burdens, electricity consumption will become more critical for GHG emission calculations. It is a challenging task for local governments such as counties to determine emission mitigation and energy-saving options. Residential buildings share a considerable portion of energy consumption in counties.[35] It is an important task to identify the details of energy consumption for taking necessary actions. The total electricity consumption figures are easy to obtain from the electrical utility companies. On the other hand, it is a difficult step to calculate the distribution of the consumed electricity into the processes or equipment. In this manner, 173 carbon emission reports of 106 cities available in the literature were investigated, and it is observed that the energy consumption details were not given in any of the reports. Almost all carbon emission reports rely on the total electricity consumption figures provided by utilities for residences, commercial and public buildings, and industrial buildings. Since there are no separate electricity meters for heating, cooling, and other usages, it is almost impossible to differentiate between the processes. Heating and cooling sectors should be included in energy supply and energy efficiency studies to provide better insight to support sustainable energy transition.[36] Data obtained from natural gas supply companies give a similar type of distribution among residential, commercial, and industrial buildings. Again, how much natural gas is used for heating, hot water production, cooking in a residence, or industrial processes warrants separate gas meters or a reliable distribution model. Because there is usually one utility or natural gas supplier in a specific region or neighborhood, the data is relatively easy to collect. However, if coal and wood are used, there will be multiple suppliers with different calorific values and there will be a need for long-term storage. Due to the difficulties cited above, there are truly no follow-up carbon emission reports as well that give prioritization of energy-saving measures in residences.

In order to reveal the ecological impact of a country, it is important to calculate the GHG emissions accurately. It is an essential first step to propose reliable models for urban energy consumption to calculate the GHG emissions of a country. Calculation of GHG emissions according to the GPC Protocol involves significant data collection and highly complex calculations. In this context, instead of applying time and labor consuming processes repeatedly, it becomes important to use practical, repeatable models. The latest GPC Protocol version was used for the carbon footprint study of Seydikemer Municipality in Mugla province in Turkey in 2019. In order to calculate the carbon emissions, from the energy consumption of a typical residential building, a new method based on HDD and CDD parameters of the region is proposed. In this context, in order to calculate the ecological impact of an urban unit, not only the human activities but also the local seasonal temperature fluctuations must be taken into account. The aim of this study is to develop a model that estimates the annual energy consumption of urban residential buildings. In order to predict energy consumption, readily available HDD and CDD data of a specific location are to be used. Using HDD and CDD data to calculate heating and cooling loads proposes a practical approach for energy consumption calculations. Thus, the primary objective is to be able to accurately predict the annual heating and cooling consumption in order to calculate and mitigate household carbon emissions. The model's validity and accuracy are tested with the data obtained from Seydikemer county, with a population of over 62,000 located in Southern Turkey based on HDD, CDD, and electricity consumption data set of a typical year.

2 | METHODOLOGY

GHG emissions calculation of a building is highly related to heating and cooling processes together with other electricity and fuel consumptions. Thus, it is necessary to know the distribution of energy consumption within the building. When calculating the heat loss or gain for a building, all the energy transfers through the walls, floors, ceilings, doors, and windows (building envelope) should be known. Once the building is completed and years go by, it would be impossible to get hold of the original heat transfer calculations, identify the construction materials used originally, and calculate the relevant heat transfer coefficients and actual heating/cooling requirements. Additionally, the heating equipment may lose its effectiveness and might even be entirely changed over the years.

Clearly, the degree days method would be a more practical approach to estimate the heat loads and losses. In this method, the overall heat transfer coefficient is used together with the number of degree days to predict how much space heating a building might need in different geographical locations. The heat loss from a building is proportional to the average temperature difference between the interior and the outside air. The experience has shown that if on a given day, the average external temperature drops to or below 15°C, then heating will be needed.[31] In a study conducted for Ethiopian cities, classification of climatic zones to understand building energy consumption prediction using degree days has been proposed.[37] The climate zones in Turkey, that signifies the spatial variations in temperatures, have been used in this study.

The HDD and CDD data used in this model are taken from the Turkish State Meteorological Service databank, and the minimum temperature for HDD is set at 15°C of outdoors temperature. Similarly, the threshold for the need of cooling is the ambient temperature being above 22°C.[38] Turkey is divided into four heating zones.[38] When HDD are calculated by the ASHRAE method, it varies between 500 and 4700 degree-days (Figure 1).[39] Depending on what region the residential, commercial, or institutional building is located in, heating can be achieved by different fuel types. However, electricity is mainly used for the first heating zone. Wherever the natural gas is available, in the other heating zones, it is preferred for heating purposes. If there is no natural gas distribution in that locality, then diesel oil takes second place, and the coal runs a distant third for heating purposes. In rural areas, wood is also one of the viable options.

As mentioned above, electricity and natural gas data are more dependable due to the fact that there is no intermediate storage. Old conventional fuels such as wood, coal, or diesel represent many problems in calculating the fuel used for heating purposes; because they are bought in bulk amounts and stored somewhere close to the building. Thus, it is a difficult task to assess daily and monthly consumptions. Furthermore, calorific values and thermal efficiencies may

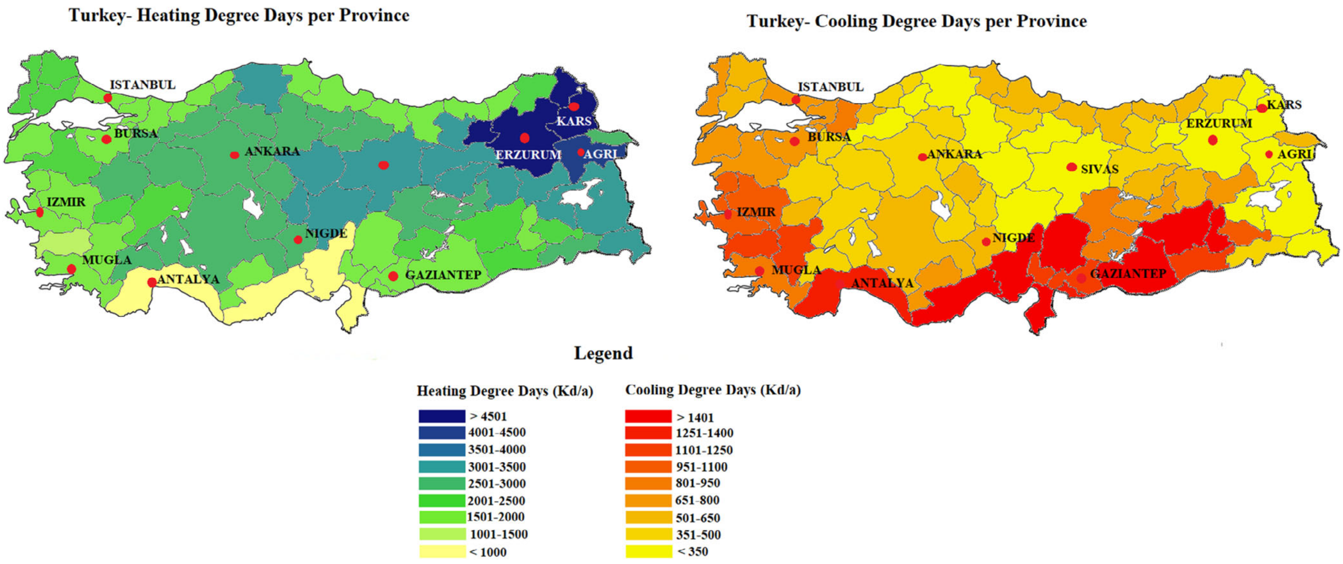

FIGURE 1 Maps of heating and cooling degree days of Turkey (adopted from ECOFYS)[39]

TABLE 2 Major heating fuels used in Turkey.

Type of heating fuel	Supply method	Storage capability	Other major uses in addition to heating	Alternative fuel if not available
Electricity	As it is consumed	None for heating purposes	All electrical and electronic appliances and devices, lighting, water heating	Electricity production with a generator
Natural gas	As it is consumed	None for heating purposes except the use of LNG for special applications	Cooking, water heating	LPG with some modifications to the system
Diesel oil	In bulk	Yes	Generators	-
Coal	In bulk	Yes	-	-
Wood	In bulk	Yes	-	-
LPG	In bulk or bottles	Yes	Water heating, cooking and other uses	-

change in time due to the variations of stored fuel's water content and other losses caused by improper storage. Diesel oil may represent a big problem if it is also used for generators from the same storage tank. Table 2 gives information on major heating fuels used in Turkey.

HDD and CDD values have great importance in the proposed model. If the residential area does not have HDD or CDD information, then HDD or CDD information of the location geographically closest to that residential area, provided that the altitudes are comparable, can be used to estimate the energy requirement. Within the model's framework, in months with HDD values, heating-induced consumption, in months with CDD values, cooling-induced consumption is calculated. It is assumed that for heating purposes, electricity, natural gas, diesel, fuel oil, coal, geothermal, and even solar energies are utilized, whereas cooling is achieved by electricity consumption only. In addition, the months which have zero or almost zero values of both HDD and CDD are considered to be "base months." Therefore, in the base months, there is neither heating nor cooling. Base consumption includes durable consumer goods, lighting, and other electricity consumption within the residence.

Consequently, in this article, two new concepts are introduced. They are residential base electricity consumption and residential base natural gas consumption. For the month m, without heating and cooling, Equation (1) gives the single residence's base electricity consumption ($RBEC_{ms}$), whereas Equation (2) represents the single residence's base natural gas consumption ($RBNGC_{ms}$). It should be noted that when there is more than 1 month with no heating or cooling, then the month with minimum electricity or natural gas consumption should be chosen for the calculation.

$$RBEC_{ms} = E_{consumption}\,(\mathrm{kWh}) \tag{1}$$

$$RBNGC_{ms} = NG_{consumption}\,(\mathrm{kWh}) \tag{2}$$

If the total number of residences in a sample is taken, then residential base electricity consumption and residential base natural gas consumption of the base month is calculated as Equations (3) and (4), respectively.

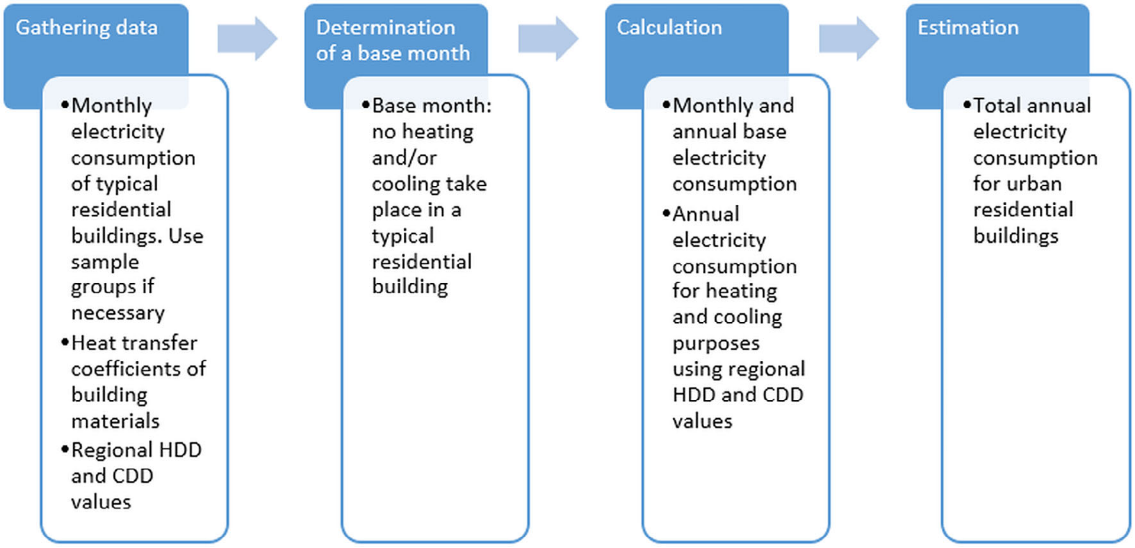

FIGURE 2 Calculation steps of the proposed methodology.

$$\mathrm{RBEC}_m = \left(\frac{\sum_{\text{no. of residences}} E_{\text{consumption}}}{\text{Number of residences}}\right) \quad (3)$$

$$\mathrm{RBNGC}_m = \left(\frac{\sum_{\text{no. of residences}} NG_{\text{consumption}}}{\text{Number of residences}}\right) \quad (4)$$

Because Seydikemer has no natural gas, only RBEC is discussed in this article. The amount of electricity consumed in heating and cooling is calculated with Equations (5) and (6), respectively.

$$Q_{\mathrm{HEATING}} = \sum_{i=1}^{n} Q_i - (\mathrm{NOS}_h \times \mathrm{RBEC}_m) \quad (5)$$

$$Q_{\mathrm{COOLING}} = \sum_{j=1}^{k} Q_j - (\mathrm{NOS}_c \times \mathrm{RBEC}_m) \quad (6)$$

where;

Q_{HEATING}: Annual electricity consumption for heating (kWh/year).

Qi: Total electricity consumption of the sample for the month i (kWh/month).

NOS_h: Number of residences in sample heated by electricity.

RBEC_m: Residential base electricity consumption of the base month (kWh/month).

i: Heating months in a year.

n: Total number of heating months.

Q_{COOLING}: Annual electricity consumption for cooling (kWh/year).

Qj: Total electricity consumption of the sample for the month j (kWh/month).

NOS_c: Number of residences in sample cooled by electricity.

j: Cooling months in a year.

k: Total number of cooling months.

Using these new concepts makes it possible to calculate the electricity consumption of a building for heating and cooling purposes. Finally, total annual electricity consumption (Q_{TOTAL}) is calculated by the Equation (7) in kWh/year.

$$Q_{\mathrm{TOTAL}} = (12 \times \mathrm{RBEC}_m) + Q_{\mathrm{HEATING}} + Q_{\mathrm{COOLING}} \quad (7)$$

Figure 2 demonstrates the steps of the calculation methodology proposed in this study. The methodology's power lies in the reliability of data provided by local sources such as electric and/or natural gas utilities. If HDD or CDD data for the target location is not available, HDD or CDD data of a similar location can be used. Determination of base month might not be straightforward for particular cases in which temperature variations are skewed; nonetheless, base month plays the central role in this methodology. Not only estimating total annual electricity consumption but also the base, heating and cooling distinction plays important role for proceeding energy efficiency studies.

Essentially, HDD and CDD values of a residential area allows typical heating cooling load calculations practically. In the calculations, the typical buildings and their materials must be considered in the calculations. Since HDD and CDD values are based on long years' data, once calculated this method provide results on solid bases. Hence, typical domestic energy consumptions do not vary considerably over the years.

3 | RESULTS AND DISCUSSION

The province of Mugla is located at the south western tip of Turkey with 13 counties, the newest of which is Seydikemer. Table 3 summarizes the essentials of Seydikemer county.

Long-term average meteorological data for Seydikemer (1960–2015) is presented in Table 4. Seydikemer county, the most eastern county of Mugla province, that truly represents the Mediterranean climate. Table 4 also gives the HDD and CDD information for the year 2017.

Since the heating loads are not extremely high, both heating and cooling in Seydikemer county are mostly carried out with air conditioners. It has been decided, that the amount of electricity consumed for basic (base) electricity consumption in a typical residence can be calculated with the degree-day method for electricity consumed for heating and cooling purposes with high reliability. The annual electricity consumption data for all residential, commercial, and other stationary consumers were available. However, information on how much electricity is used for heating and/or cooling purposes, average square meter area, the average number of floors of multiple-story buildings, whether the buildings are attached or detached, and the common construction materials used were not readily available.

TABLE 3 Information on Seydikemer county

Country	Turkey
Geographical boundaries	North—Burdur province East—Kas county, Antalya province South—Aegean sea West—Fethiye, Mugla province
Coordinates	Latitude: 36.64 Longitude: 29.36
Land area (Km^2)	2208
Population (2017)	61,000
GDP (US Dollars-2014)	738,832,000
Structure of the economy	Agriculture, livestock, tourism
Climate	Mediterranean climate, winters rainy not so cold, summers dry, and hot
HDD and CDD zones	Zone 1 in Turkey
Other	Rich historical and archeological heritage

According to the information obtained from AYDEM, the electrical utility company serving to Mugla, Aydin, and Denizli provinces, it is reported that a total of 36,913 residential tariff users were in Seydikemer for the year 2017. Twenty-eight thousand residences were within the boundaries of Seydikemer, 8558 were small-scale commercial establishments, and 355 were large-scale commercial entities. As can be seen, most commercial customers are also on residential tariffs. Because of privacy concerns, a detailed breakdown of the residential customers was not provided by AYDEM. For this reason, it was decided that to carry out a detailed survey within the county. The information obtained from the survey results and face-to-face interviews is given in Table 5. Accordingly, the use of fuel type for heating purposes within the county seat and other locations differ vastly for the residences. Also, based on the survey results, it is assumed that 50 percent of the residences have electrical cooling available.

Similarly, coal and wood consumption per residence or commercial entity are gathered and given in Table 6. In addition to wood consumption in large commercial entities (such as bakeries), there is a wood consumption in the residential stoves, and it is reported to be 1380 tons in total for the year 2017 (22.3 kg/capita-year).

Considering the distribution of HDD and CDD and verifying it with local people, it was predicted that residential buildings are cooled for 5 months, May, June, July, August, and September. The buildings are heated for a period of 6 months, from November to April. However, in the survey, a large part respondent (87%) claimed that in most parts of March, they would occasionally use the air conditioner, and in April, they do not need heating. Thus, even though there is 10 HDD in April, heating is considered for only 5 months. Based on Tables 4 and 5, it can be stated that the month of October will have neither

TABLE 4 Meteorological data for Seydikemer

Months	1	2	3	4	5	6	7	8	9	10	11	12	Annual
Average temp. (°C)	10.1	10.8	12.9	16.1	20.4	25.0	27.7	27.6	23.9	19.2	14.4	11.4	18.3
Average max. temp. (°C)	16.0	16.5	19.0	22.1	26.4	31.4	34.4	34.6	31.4	26.6	21.4	17.4	24.8
Average minimum temp. (°C)	5.3	5.8	7.3	10.1	13.8	17.6	20.2	20.3	16.9	13.2	9.8	6.2	12.2
Average sunshine (h)	4.4	5.3	6.6	7.5	9.4	10.5	11.2	11.3	11.1	9.5	7.4	5.3	8.9
Average RH (%)	70.1	67.5	67.0	67.1	65.1	58.9	57.3	59.1	61.9	67.2	71.0	72.2	65.4
Average rainy days	13.0	11.0	9.0	8.0	6.0	3.0	1.0	0	2.0	5.0	8.0	12.0	6.4[b]
Average precipitation	170.4	134.4	77.9	48.8	26.5	3	1.2	1.5	16.7	66.4	119.9	197.5	864.2[a]
Maximum/minimum values attained in the period (1960–2015)													
Max. temp. (°C)	25.0	27.4	33.0	35.7	39.0	42.7	44.3	43.0	40.6	38.6	32	26.5	44.3
Minimum temp. (°C)	−6.6	−4.4	−1.9	0.2	5.5	10.4	13.4	13.8	8.1	3.6	−2.4	−3.5	−6.6
Heating degree days (HDD) and cooling degree days (CDD) (2017)													
HDD	268	168	86	10							80	155	-
CDD					21	146	253	223	124				-

[a]Total precipitation.
[b]Average rainy days have been rounded up to nearest digit.

TABLE 5 Survey and interview results—Heating and cooling percentages in Seydikemer

Consumer type	Number of total residential customers	Heating by fuel type %			Cooling %
		Electricity	Coal	Wood	Electricity
Residences					
Seydikemer town (county seat)	1,130	68	12	20	50
Other neighborhoods and villages	26,870	38	12	50	50
Commercial entities					
Large	355	68	12	20	75
Small	8,558	68	12	20	68

TABLE 6 Survey and interview results—Amount of wood and coal consumption per consumer.

Consumer type	Annual coal consumption per consumer (tons/year)	Annual wood consumption per consumer (tons/year)
Residences		
Seydikemer town (county seat)	0.75	1.0
Other neighborhoods and villages	0.75	1.0
Commercial entities		
Large (more than 10 employees)	0.8	1.0
Small (less than or equal to 10 employees)	0.4	0.5

heating nor cooling. Thus, October is chosen as the base month. AYDEM provided a selected data in detail. Table 7 shows the monthly electricity consumption of the data provided by AYDEM along with the HDD and CDD information.

When we consider the monthly total distribution of electricity consumption of 86 residences, it was observed that the month of October was indeed the lowest month with 12,715 kWh, which was decided as the base month. The base-month electricity value was calculated as 147.85 kWh/month per residence (12,715 kWh/86). Thus, annual base electricity consumption per residence was 1773.6 kWh/year.

In electrically heated residences, electricity consumption should be relatively higher in months of heating, and similarly, electricity consumption should be relatively higher in months of cooling. Criteria for electrically heated residences and criteria for electrically cooled residences, which are obtained from statistical analysis, are given by Equations (8) and (9), respectively.

$$\frac{E_{\text{consumption, month with highest HDD}}}{\text{RBEC}_{\text{ms}}} \geq 1.18 \tag{8}$$

$$\frac{E_{\text{consumption,month with highest CDD}}}{\text{RBEC}_{\text{ms}}} \geq 1.18 \tag{9}$$

where,

$E_{\text{consumption, month with highest HDD}}$: Electricity consumption of the month with the highest HDD.

$E_{\text{consumption, month with highest CDD}}$: Electricity consumption of the month with the highest CDD.

RBEC_{ms}: Single residence's base electricity of the month m with neither heating nor cooling.

For the sample group, if the electricity consumption of the highest HDD month (January), divided by the electricity consumption of the base month (October), is over 1.18, then it is assumed that those residences are heated by electricity, whereas the rest are heated by wood or coal. There are 52 residences, and the base month calculations were made based on. The value 1.18 was chosen from the statistical analysis of the data. If there is no electrical heating, then the electricity consumption of the month of the highest HDD month divided with the base month load should give a value of around 1. When all the residential consumptions in the sample group were listed, then the breakpoint is found to be 1.18.

From the CDD values given in Table 6, cooling is needed for the period from the beginning of May to the end of September. For the sample group, if the electricity consumption of the highest CDD month (July), divided by the electricity consumption of the base month (October), is over 1.18, it is assumed that those residences are cooled by electricity whereas the rest do not have any cooling system. There are 61 such residences, and cooling calculations were made based on them. A summary of the results is given in Table 8.

The total monthly electricity consumption, base electricity consumption, and electricity consumption for heating and cooling purposes of the 86 sample residences are shown in Figure 3.

The total electricity consumption for the 86 residences was 203,530 kWh in 2017 as demonstrated in Table 8. By using the proposed method, the total electricity consumption is calculated as 206,054 kWh/year with 1.24% accuracy.

In order to check the results of this approach, an inquiry was made to the department of housing of Seydikemer Municipality concerning the average residence dimensions. With the data provided by the Municipality, the average area of a typical house was calculated to be approximately 96 m^2, which corresponds to an apartment flat of a 4-story-8 flats apartment building. Since Seydikemer is a new county, almost all air conditioners used are type-A air conditioners.

TABLE 7 Monthly electricity consumption of sample residences provided by AYDEM

			Monthly electricity consumption provided by AYDEM for the year 2017 (kWh)	
Month	HDD	CDD	Seydikemer county (223 samples)	Seydikemer town (86 samples)
1	268	-	35,075	25,106
2	168	-	35,859	24,173
3	86	-	26,280	16,137
4	10	-	28,083	14,755
5	-	21	26,651	14,063
6	-	146	26,556	15,185
7	-	253	41,947	17,571
8	-	223	35,938	15,442
9	-	124	33,459	16,063
10	-	-	25,004	12,715
11	80	-	29,158	13,718
12	155	-	33,592	18,602
Total			342,527	203,530

TABLE 8 Summary of the results

Total number of residences (provided by AYDEM)	86
Residences heated by electricity (NOS_h)	52
Residences cooled with electricity (NOS_c)	61
Heating months for Seydikemer (i)	January, February, March–November–December
Cooling months for Seydikemer (j)	May, June, July, August, September
Monthly residential base electricity consumption ($RBEC_m$)	147.85 kWh/month
Annual electricity consumed in heating ($Q_{HEATING}$)	38,894 kWh/year
Annual electricity consumed in cooling ($Q_{COOLING}$)	14,580 kWh/year
Annual electricity consumption in heating per heated residence	748.0 kWh/year-residence
Annual electricity consumption in cooling per cooled residence	239.0 kWh/year-residence

The majority of the apartments are stand-alone types with two apartment flats on each floor. A four-story building with two flats on each floor is shown in Figure 4.

Most of the buildings in the county are relatively new. They are assumed to be complying with the latest residential building insulation guidelines standards of the country. The standard, which was enacted in May 2008, recommends the total heat transfer coefficient (*U* values) for residential buildings for all the HDD regions in Turkey, as shown in Table 9.[38]

Once the *U* values are known, then heat loss calculations can be made by using Equation (10).

$$Q_{\text{heat loss}} = \sum_i (U_i A_i) \times \Delta T \,(W) \tag{10}$$

where U_i represents the heat transfer coefficient for the surface area of element *i* (such as external walls), and A_i represents the total heat transfer area of that element. Overall heat transfer coefficient U_{overall} is given by Equation (11).

$$U_{\text{overall}} = \frac{Q_{\text{heat loss}}}{\Delta T} = \sum_i (U_i A_i) \,(W/K) \tag{11}$$

The calculations shown in Table 10 holds for the apartment buildings on each floor. In addition, because the two flats are adjacent, it is assumed that there is no heat transfer between the two apartments, and the gross height of each flat is approximately 3.00 m. As can be seen from the table, window areas are deducted from the outside wall area.

Although $U_{\text{overall},i}$ is calculated, it will need another variable to calculate the total heat transfer coefficient U_{total}. The ventilation heat loss must also be included for the apartment flat, which has a gross volume of approximately 288 m^3. Ventilation heat loss is given by Equation (12).

$$Q_{\text{ventilation heat loss}} = 0.33 \times n \times V \times \Delta T \,(W) \tag{12}$$

where *n* is the number of air changes per hour (ACH), and *V* is the volume of the house (m^3). In this equation, *n* represents the number of air changes in 1 h, and the thermal insulation requirements for buildings standard describes typical ACH value as 0.8.[38] The constant value of 0.33 $\frac{Wh}{m^3}$ is the heat capacity of the air representing the thermal

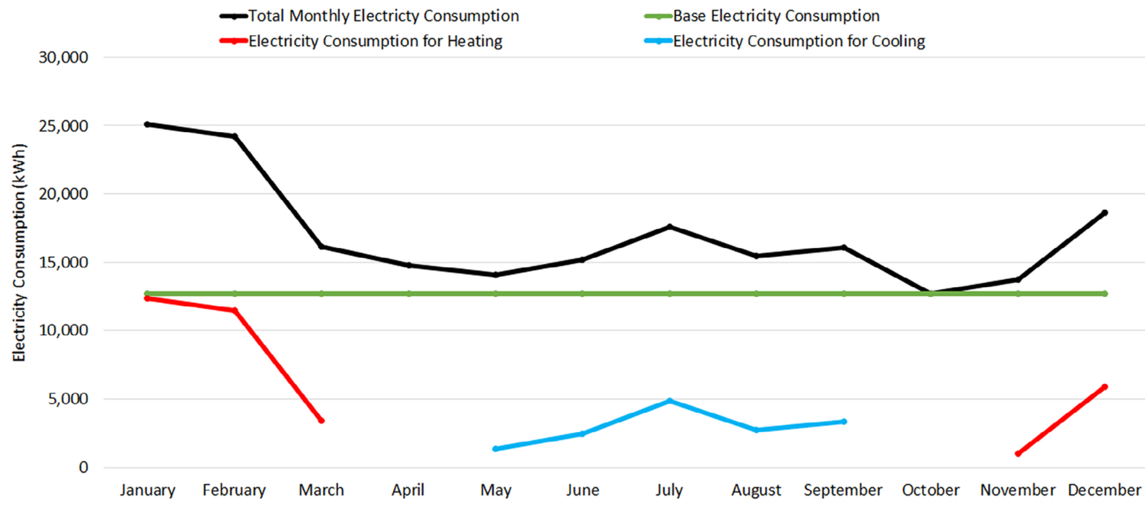

FIGURE 3 Electricity consumption (kWh) distribution of the sample group

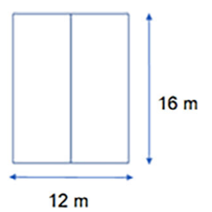

FIGURE 4 Average apartment size and number of apartments in one floor in Seydikemer town

energy required to raise its temperature by 1 K. It is equal to the specific heat of the air multiplied by its mass and the temperature change.

Thus, like the previous equation, ventilation heat loss contribution to the overall heat transfer coefficient is obtained from Equation (13).

$$U_{\text{ventilation}} = \frac{Q_{\text{ventilation heat loss}}}{\Delta T} = 0.33 \times 0.8 \times 288 = 76\, {}^{W}\!/_{K} \quad (13)$$

Total heat loss coefficient for the average house in Seydikemer becomes as in Equation (14).

$$U_{\text{total}} = U_{\text{overall,average}} + U_{\text{ventilation}} = 123.4 + 76.0 = 199.4\, {}^{W}\!/_{K} \quad (14)$$

If the total HDD is known, annual consumption of energy for heating purposes can easily be determined, which is given by Equation (15).

$$\text{Annual energy consumption for heating in kWh} = \frac{(U_{\text{total}} \times \text{HDD} \times 24)}{1000} = \frac{199.4 \times 767 \times 24}{1000} = 3671\,\text{kWh/year} \quad (15)$$

As it is mentioned above, most of the heating is done by air conditioners. The Chamber of Mechanical Engineers of Turkey gives the coefficient of performance (COP) and energy efficiency rate (EER) values of the air conditioners used in Turkey as 3.5 and 3.0, respectively.[40] The actual values are obtained using these values for the total heating and cooling, as in Table 11.

There are more than 1130 residences in the town. It has been observed that variations of the residences in terms of size, building materials, degree of insulation, single/double glazed windows pose an important challenge in energy calculations. On the other hand, it has been observed that there is a good agreement between Equation (15) and the annual electricity consumption per heated residence given in Table 11.

When applying the proposed model for Seydikemer town, it is found that the monthly base electricity consumption for a typical house is 147.85 kWh/month. Afterward, the annual electricity consumed in heating per heated residence is found 748.0 kWh/year. In addition, it is found that the annual electricity consumed in cooling per cooled residence is 239.0 kWh/year. By using this method, the total electricity consumption for the 86 residences in Seydikemer is calculated as 206,054 kWh/year with 1.24% accuracy. The total heat loss coefficient and the annual energy consumption in terms of HDD for the average apartment flat in Seydikemer was calculated as 199.4 W/K, and annual energy consumption for heating was calculated as 3671 kWh/year. According to the model results given in Table 11, annual electricity consumption in heating per heated residence is found as 2618 kWh/year, whereas annual electricity consumption in cooling per cooled residence is found as 717 kWh/year.

Considering the diversity of the residences in terms of size, building materials, degree of insulation, single all double-glazed windows, and all the other factors and remembering that there are over 1130 residences, it is believed that there is a good agreement between the two results. Naturally, heating is not done 100% of the time. Indeed, in the survey and face to face interviews, almost everyone (87%) said that in most parts of the month of March they would occasionally use the air conditioner and in April they will have no heating. The value obtained for energy consumed in heating corresponds to 72% of the time, which is in line with the survey results. The results gave the Municipality the priority actions to be taken in residences for reducing the carbon footprint, and it is all related to heating, as shown in

TABLE 9 U values as given by the thermal insulation requirements for buildings standard.

Region	U_{wall} (W/m² K)	U_{floor} (W/m² K)	$U_{ceiling}$ (W/m² K)	U_{window} (W/m² K)[a]
I	0.70	0.45	0.70	2.4
II	0.60	0.40	0.60	2.4
III	0.50	0.30	0.45	2.4
IV	0.40	0.25	0.40	2.4

[a]It is assumed that apartment flats open to the hallway, and their loss can be neglected.

TABLE 10 Calculation methods by floor

Floor	A_{wall}	A_{floor}	$A_{ceiling}$	$A_{windows}$	$A_{main\ door}$	
U (W/m² K)	0.70	0.45	0.70	2.4	2.4	
Floor number (i)						$U_{overall,i}$ (W/K)
1	84–20 = 64	96	-	20	5	148
2	84–20 = 64	-	-	20	-	92.8
3	84–20 = 64	-	-	20	-	92.8
4	84–20 = 64	-	96	20	-	160.0
$\sum_{1}^{4} U_{overall,i}$						493.6
$U_{overall,average}$						123.4

TABLE 11 Annual equivalent electricity consumption in a typical residence in Seydikemer town, 2017

Fuel and consumption type	Energy consumed by air conditioner (kWh/year-residence)	Multipliers COP and EER	Electricity equivalent (kWh/year)
Annual electricity consumption in heating per heated residence	748	3.5	2,618
Annual electricity consumption in cooling per cooled residence	239	3.0	717

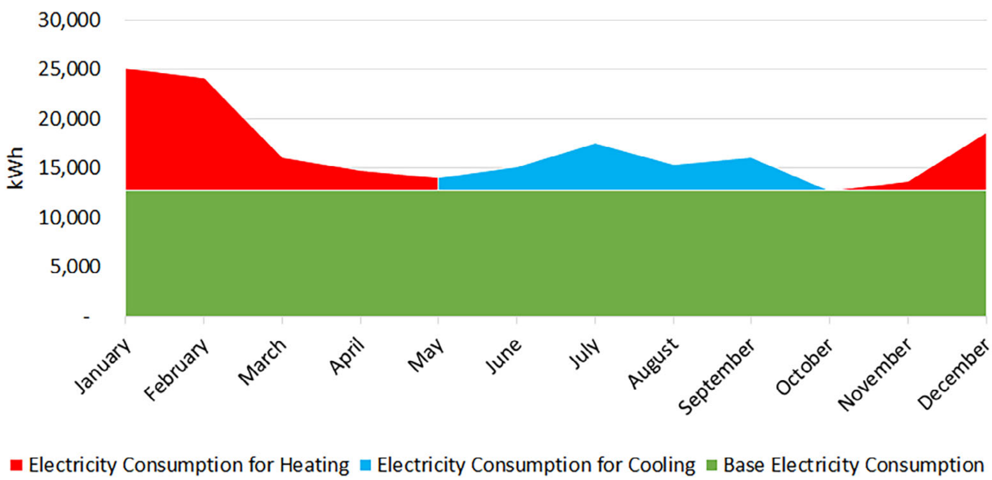

FIGURE 5 Distribution of electricity consumption in Seydikemer town

TABLE 12 Annual coal and wood consumption in a typical residence in Seydikemer town, 2017

Fuel and consumption type	Supply method	Calorific value (kWh/kg)	Average efficiency (%)	Amount consumed per residence (kg/year)	Total energy consumed (kWh/year)
Coal	In bulk	4,185	0.6	750	2,190
Wood	In bulk	4,500	0.5	1,000	2,616

Figure 5. The viable alternatives would be additional insulation, double glazed windows usage, and more passive solar heating whenever possible.

Another validation method could be to compare it with coal and wood consumption. Face-to-face interviews indicated that only 68% used electricity for heating, and 32% used either wood or coal. Thus, their consumption should be similar to each other. Table 12 gives the results for these two options. Accordingly, for coal, it is found 2190 kWh/year, and wood 2616 kWh/year and they both are similar quantitatively to what the model developed predicts for annual heating.

Besides the theoretical electricity calculations for heating purposes, the results are validated by using the coal and wood consumption of Seydikemer county as well.

Since the method proposed in this study is based on the HDD, CDD, and electricity consumption data set of the previous years, it can easily be implemented in another geographical location as well, as long as there are HDD and CDD data available. In order to implement the model, the energy sources available for heating and cooling in that region are to be considered. Also, in a typical residential building, the construction and thermal insulation materials are taken into account to calculate the overall heat transfer coefficient value. First, using the HDD and CDD data set, the base electricity consumption is calculated. Second, annual electricity consumption for heating and cooling purposes are calculated. Finally, the total annual electricity consumption of a typical residential building is determined by segregating the base, heating, and cooling electricity consumptions.

Although the HDD and CDD data could be easily found, in case HDD and/or CDD data is not available, then HDD or CDD information of the location geographically closest to that residential area, provided that the altitudes are comparable, can be used to estimate the energy requirement. In addition, although the proposed model is reasonably practical, there might be some setbacks in the application. The initial problem one may encounter in achieving the electricity consumption and heating energy type data. Electricity supplying companies do not want to share the data in most districts due to privacy issues. Second, the variation of structural properties may complicate defining a typical residential building representing the geographical district.

4 | CONCLUSION

Increasing concentrations of greenhouse gases in the atmosphere are regarded as the main cause of global warming, which has become one of the most discussed topics not only in the scientific environment only but also in our daily lives as well. In order to calculate the greenhouse gas emissions of a building, it is essential to know the energy consumption, which is basically the sum of energy consumed for heating and cooling processes together with other electricity and fuel consumptions. Thus, it is necessary to know the distribution of energy consumption within the building. When the study like the carbon footprint of a region is considered, then the number of residences will be in thousands. Additionally, with almost as many variations in terms of size, the material used, area, and other variables for the residences in question. Thus, it becomes a difficult task to estimate the building's energy consumption and especially identify the energy-saving measures with appropriate priorities.

The model uses the residential base electricity consumption and residential base natural gas consumption concepts. It basically employs HDD and CDD parameters for predicting the energy consumed for heating and cooling purposes. Because Seydikemer is located in Region 1 of Turkey, dominantly with a typical Mediterranean climate, both heating and cooling are achieved by air conditioning units. Thus, the months with zero or almost zero values of both HDD and CDD are "base electricity months". Hence, in the base months, there is neither heating nor cooling. Base consumption includes durable consumer goods, lighting appliances, and other electricity consumption within the residence.

Overall extracted results from this research can be summarized under the three main categories:

- A model that predicts total energy consumption for heating of urban residential buildings from the available electricity consumption data is developed. The base electricity consumption concept is introduced for residential buildings. Additionally, the proposed model distinguishes between electricity used for base consumption, heating, and cooling.
- The proposed model is applied to a county with a population of over 62,000 located in Southern Turkey, and the total electricity consumption is calculated with 1.24% accuracy.
- The validity and accuracy of the model are tested by theoretical electricity calculations, coal and wood consumption. Accordingly, while annual electrical heating is equal to 2618 kWh/year for an average house of 96 m^2, for the coal and wood burning households, the annual energy consumption values are 2190 and 2616 kWh/year, respectively.

Thus, an original methodology supported by the simple calculations has been developed for the residential buildings to calculate their electricity consumption and also determine the priorities they have to give for lowering their total consumption. The model constructed in this study differs from the literature. The proposed model uses the heating and CDD method for calculation of the energy consumption used for heating and cooling purposes, especially in Region I. For the other regions, using $RBNGC_m$ values, if any, may be more appropriate. Especially when the architectural drawings and wall layer structures are not known, this approach gives much better and quicker results once the HDD and CDD values are known.

Carbon footprint calculations do not deal with a single residence but a vast number of residences. Basically, HDD and CDD values are good parameters indicating whether or not there is a need for heating or cooling. They also provide excellent data for defining the base load for electricity or natural gas consumption for a neighborhood. This unique property of HDD and CDD values is fully utilized in this study.

Emerging studies provide daily or hourly HDD and CDD calculations. While the trade-off between practicality and computational load is considered, to improve the accuracy, the data for the shorter time intervals can be implemented as a future work.

DATA AVAILABILITY STATEMENT

Author elects to not share data

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