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EVALUATION OF ENERGY CONSUMPTION AND GREENHOUSE GAS EMISSIONS CHANGE OF A BUILDING

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Resesarch Article

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Abstract

The effects of local climatic conditions are evident in the energy consumption and greenhouse gas emissions calculated by considering the boundary conditions defined according to the climatic regions classified by the degree-day method for Turkey. This study aims to investigate the rate of the cities under specified climate regions achieving energy consumption and greenhouse gas emission values below reference indicator values and evaluate the contradictions among the energy consumption and greenhouse gas emissions of a simulated building with two types of outer wall configurations for different cities classified under the same degree-day region with similar climatic conditions by comparing the variation of the results due to reference indicator values defined in the regulation. The variation due to reference indicator values, non-similar for the cities classified under the same degree-day regions, shows the probable deficiency in the existence of these cities under the inappropriate degree-day regions. The primary energy consumption and greenhouse gas emissions of the same building were calculated using BEP-BUY in 38 provinces, where climatic conditions vary in Turkey. The primary energy consumptions and greenhouse gas emissions calculated for the identical structure under the same climate zone classification were above the reference indicator values the "primary energy consumption" and "greenhouse gas emission" in some provinces of all degree-day regions. The study shows that the outcomes were much lower or higher than the RG value for certain cities in the same categorization. Therefore, this shows that it is necessary to evaluate each RG value specified for the degree-day climatic zones.

Keywords: Degree-day zones, Greenhouse gas emissions, Primary energy consumption, REG, BEP-BUY

BİR BİNANIN ENERJİ TÜKETİMİ VE SERA GAZI EMİSYONU DEĞİŞİMİNİN DEĞERLENDİRİLMESİ

Özet

Yerel iklimsel koşulların etkileri, Türkiye için derece-gün yöntemiyle sınıflandırılmış iklim bölgeleri için tanımlı sınır koşullar gözetilerek hesaplanan enerji tüketim ve sera gazı salım miktarlarına yansımaktadır. Aynı derece-gün bölgesi sınıflandırması içerisinde yer alan iller için elde edilen birincil enerji tüketim ve sera gazı salımı miktarlarının yönetmelikte tanımlanan sınır değerler altında olması gerekmektedir. Bu çalışma, enerji tüketimi ve sera gazı emisyon değerlerinin referans gösterge değerlerinin altında elde edildiği belirli iklim bölgesi sınıflandırması altındaki şehir oranlarını belirlemeyi; iki tip dış duvar konfigürasyonu ile simülasyonu gerçekleştirilen bir binanın enerji tüketimi ve sera gazı emisyon sonuçları ile aynı derece-gün bölgeleri altında sınıflandırılan iller için referans gösterge değerlerine göre değişim miktarları arasındaki uyumsuzlukları ortaya koymayı amaçlamaktadır. Aynı derece-gün bölgeleri altında sınıflandırılan iller için elde edilen sonuçların referans gösterge değerlerine göre değişim miktarlarının birbirine benzememesi sınıflandırmada olası bir eksikliğe işaret edebilmektedir. Türkiye'de iklim koşullarının farklılık gösterdiği 38 ilde BEP-BUY ile aynı bina için birincil enerji tüketimi ve sera gazı emisyonları hesaplanmıştır. Hesaplanan birincil enerji tüketim ve sera gazı emisyon miktarları, tüm derece-gün bölgelerinde, bazı illerde "birincil enerji tüketimi" ve "sera gazı emisyonu" referans gösterge değerlerinin üzerinde gerçekleşmiştir. Çalışma, sonuçların aynı kategorideki bazı şehirler için RG değerinden çok daha düşük veya yüksek olduğunu göstermektedir. Dolayısıyla bu durum, derece-gün iklim bölgeleri için belirlenen her bir RG değerinin değerlendirilmesi gerektiğini göstermektedir.

Anahtar Kelimeler: Derece-gün bölgeleri, Sera gazı emisyonu, Birincil enerji tüketimi, REG, BEP-BUY

1. INTRODUCTION

"Climate", considered a natural identity element, has a significant role in the formation of the identity of local architecture and in achieving authenticity at the scale of settlement and structure. Traditional settlement types carried from the past to the present provide rich rexamples of designs suitable for the conditions of hot, cold, temperate, and humid climates in both summer and winter (Ok, Bayraktar & Yasa, 2014).

The architectural structures in these settlements which have managed to survive despite all negative social, economic, or physical conditions, are characterized by the constraints of the local natural environment in terms of protection or benefit from the sun or the wind during summer and winter periods. In addition, these settlements offer optimal solutions that can set an example for today's architecture by reducing energy consumption and providing comfort conditions with traditional approaches such as the optimal orientation of the building to benefit from sun and wind, construction of building envelopes with vernacular materials, and organization of spaces rationally to control heat gains and losses.

In the past, it was a necessity rather than a choice to carry out settlement and structure design processes due to the climate and topographical conditions against abundant resources with limited technology (Bayraktar, 2011). Despite the progress in today's world, approaches to design in light of environmental data such as climate and topography should be carried more effectively due to the pressures and threats such as depletion of energy resources, global warming and the loss of green spaces, climate changes, ozone layer depletion, increasing greenhouse gas emissions, the degradation of fertile lands, the depletion of clean water resources, and environmental pollution resulting from the human needs and activities. While progress in technology can assist in this process, the responsible integration of environmental concerns is essential.

The combined effect of climate elements such as air temperature, wind, and humidity in settlements and buildings determines the level and the quality of factors such as energy efficiency and climatic comfort conditions. Designing buildings with passive heating, cooling, ventilation, and lighting systems tailored to local climatic conditions from the outset ensures minimal energy consumption and greenhouse gas emissions for heating, cooling, ventilation, and lighting, thereby reducing negative environmental impacts. Furthermore, an integrated system that is consistent with the natural environment is ensured while meeting indoor quality criteria. For example, the thickness of thermal insulation materials is determined in line with the typical recurring climatic conditions specific to the region at the design stage of building envelopes (Axaopoulos, Axaopoulos & Gelegenis, 2014). Further, using the lowest outdoor temperature readings which are in line with the worst conditions for the region, instead of average outdoor temperatures, prevent humidity-induced degradation in building envelopes.

The equilibrium temperature range for heating and cooling can be defined as the outdoor temperature range when heating or cooling is not needed in a building (Bulut, Büyükalaca & Yılmaz, 2007). When the outdoor temperature drops below the building equilibrium temperature, it is necessary to heat the environment. Also, when the outdoor temperature rises above the building balance point temperature, it is necessary to cool the environment. Cooling degree-day values are obtained by the cumulative sums of the differences between the daily average temperatures and the balance point temperature where the balance point threshold is exceeded. Heating degree-day values are obtained by the cumulative sums of the differences between the daily average temperatures and the balance point temperature where the equilibrium threshold is not exceeded. According to The Turkish State Meteorological Service (URL-1) HDD (Heating Degree-Day) and CDD (Cooling Degree-Day) calculations for 129 provinces and districts show that temperature values of 15 °C as HDD and 22 °C as CDD are accepted as the equilibrium thresholds for respective calculations.

Depending on the duration of heating or cooling periods for different settlements, limitations imposed by regulations on the average heat transfer coefficient (U-W/m^{2}K) of the components comprising the foundation of building envelopes, require higher values of the CDD and HDD for the city in question to be taken as the basis. Whereas in the TS 825 (1999) standard of thermal insulation rules, only HDD calculation is taken into account. Bayram and Yeşilata (2009) stated that, in some climatic regions, the total of cooling degree days exceeds the total of heating degree days; therefore, the recommended heat transfer coefficients in the regulation might be insufficient for the regions where the cooling requirement is high. The authors developed an approach to change climate zone definitions by also taking cooling loads into account through their calculations performed based on all provinces by the expression of the distribution of non-dimensional values of total cooling degree-days to total heating degree-days ratios instead of increasing the number of climate zones suggested in this regard.

Based on the BEP-TR method, where local climate data entries can be made by experts or organizations authorized by the Ministry of Environment, Urbanization, and Climate, the BEP-BUY Energy Analysis Simulation Tool can calculate annual energy consumption and greenhouse gas emissions.With the evidence of the publications that use the BEP-TR calculation method; it is seen that the evaluations of BEP-BUY and its past versions are aimed at examining and developing usability, program operations, problems encountered in data definitions, the deficiencies of the underlying method and the level of convenience and ease of use features for its users (Aydın & Canım, 2017; Akın & Kaplan, 2019; Yaka, Önal, Koçer & Güngör, 2016; Bilen, Urmamen, Topcu & Solmaz, 2020; İşiler, Yanalak & Selbesoğlu, 2022).

In the study carried out by Aydın and Canım (2017) to obtain information on the usability of the current version of the program, the problems and deficiencies experienced in data entry and definition stages were brought up through the interviews with the Energy Performance Certificate (EKB) experts.

According to the research conducted by Akın and Kaplan (2019), the effects of passive approaches to increase energy efficiency at the design stage were stated to have no meaningful impact on the consumption class in performance calculations. In addition, it was also emphasized that the climatic and topographic characteristics of the region subject to the energy performance processes should be handled in more detail and these documents should be differentiated according to local characteristics. In the study of Yaka et al. (2016), the performance of a 4-story building of 16 flats in terms of heating, cooling, ventilation, and lighting was examined for 5 pilot regions and the changes in consumption classes were brought up based on provinces.

In the study conducted by Bilen et al. (2020), the energy performance of an apartment building, located in Konya was calculated in terms of heating, cooling, hot water, lighting, and greenhouse gas emissions within both insulated and non-insulated conditions through the BEP-BUY simulation tool; and the annual heat energy requirement calculated for the building compared to the maximum value in terms of A/V ratio specified in TS-825 (1999) for the subject region, was found consistent for insulated conditions.

In contrast to earlier research, this study compares the primary energy reference indicator (REG) and greenhouse gas reference indicator (SRG) values specified in the regulation with the outcomes of the simulation process by BEP-BUY to determine total energy consumption and total emission amounts for the same building for both insulated and non-insulated applications of two different wall components for each chosen city within the same climate region classification. The amount of primary energy consumption and greenhouse gas emissions for the cities classified under the same degree-day area must be less than the threshold levels. Additionally, due to the indicator values, it is anticipated that the primary energy consumption and greenhouse gas emissions computed for the same building in the cities with the same climatic zones will vary accordingly. The study aims to determine the ratio of the cities under the same climatic region where the results below these threshold values can be achieved to validate the adequacy of the primary energy reference indicator (REG) and greenhouse gas reference indicator (SRG) ranges defined for different climatic regions in the regulation as the upper limit values to restrict energy consumption and greenhouse gas emissions for various climatic zones. The study also aims to reveal the inconsistencies among the results obtained for the provinces within the same climatic regions by which climate region classification can be validated. The primary energy consumption and greenhouse gas emissions amounts of the building were calculated concerning heat transfer coefficients of building components over the 38 provinces classified under similar conditions within four climate zone distinctions. In the scope of meteorological data provided by the BEP-BUY simulation tool, the provinces where primary energy consumption and greenhouse gas emission amounts of the same building exceed the primary energy reference indicator (REG) and greenhouse gas reference indicator (SRG) thresholds defined in the regulation for all degree-day regions were determined to be set up for querying of province classification made under four climate zones.

2. CONCEPTUAL FRAMEWORK

The developments and regulations aimed at meeting the needs and habits of mankind, particularly for consumption, coupled with the continuous increase in energy usage, have resulted in a significant escalation of environmental damage. This type of damage has also been the triggering factor of global warming and climate change concerns. The negative situation, especially towards the end of the 20th century, which surged at an unprecedented pace, has prompted the world states to come together and propose solutions. The “United Nations Framework Convention on Climate Change”, adopted in 1992 and came into effect in 1994 (Turkey became a signatory party on May 24, 2004) to reduce atmospheric greenhouse gas accumulation and prevent human-induced threats to the climate, is a milestone in this regard (United Nations, 2002). Subsequently, the "Kyoto Protocol" acting as a pledge to reduce CO2 and greenhouse gas emissions of the signatory parties, was signed in 1987 within the "United Nations Framework Convention on Climate Change" and came into effect later in 2005 (Turkey became a party on August 26, 2009), (United Nations, 1998).

However, in Turkey, the Energy Efficiency Law (EVK) No. 5627, which came into force in 2007, is an important step for achieveing energy savings and reducing greenhouse gas emissions at the national level. Upon the law coming into effect with the objective of effective energy usage, prevention of unnecessary energy consumption, alleviation of the burden of energy costs on the economy, and protection of the environment, it has been obligatory to obtain an Energy Performance Certificate for all buildings on May 2, 2017 (Communiqué on National Calculation Method of Energy Performance in Buildings, 2010). "The Regulation on Energy Performance in Buildings" (BEPY, Resmi Gazete, no: 27075, 05.12.2008), which is a statutory regulation of the Energy Efficiency Law No. 5627, came into effect in 2008 to regulate the procedures and principles regarding the prevention of energy waste, protection of the environment, and the effective and efficient usage of energy and energy sources in buildings. As of May 2, 2017, the obligatory Energy Performance Certificate (EKB) enforcement got underway for existing buildings that had received a construction permit before January 1st, 2011, and as of today, obtaining a ministry-approved Energy Performance Certificate which includes information on energy need, energy consumption class, applied insulation type, heating and cooling data as part of the "Regulation on Energy Performance in Buildings" bound to the Energy Efficiency Law No. 5627 in effect, has been obligatory starting from January 1st, 2020 in Turkey. Implementation of the Energy Performance Certificate is expected to be useful in limiting annual energy consumption and greenhouse gas emission amounts of the buildings.

In this framework, moving towards establishing the standards of energy use at the scale of buildings and settlements is an important turning point in the process aimed at minimizing damage to the natural environment. Energy standards play a primary guiding role in the realization of building and settlement designs within the limitations of energy consumption related to climatic conditions or improving energy and comfort conditions of existing buildings concerning their local environment. This ensures that environmental effects on Earth are minimized while ensuring optimal climatic and visual comfort conditions. For example, eight primary climate zone distinctions (hot-humid, hot dry, mixed dry, mixed hot, marine, cold, very cold, and subarctic) are seen in both the ANSI/ASHRAE/IES Standard 100-2018 on existing buildings and the ASHRAE Standard 90.1 on buildings except residential low-rise (ANSI/ASHRAE/IES 100, 2018; ASHRAE 90.1, 2019).

Mandatory TS 825 Thermal Insulation Requirement Standard for Buildings, which is instrumental to limiting energy consumption is not only used for determining the necessary amount of energy required for future buildings and selecting among new building design alternatives for minimum energy consumption but also for determining the insulation thicknesses based on maximum energy consumptions specified for regions in different climatic conditions (TSE 825, 1999). Heat transfer coefficients for building components are also determined relative to the climate zones. According to TS 825 (1999), our country has been divided into four climate zones only by heating degree-day (HDD) values. However, the energy need of cooling periods, based on provinces, therefore the cooling degree-day (CDD) total, was not taken into account for this climate zone classification. Since this approach is insufficient either in execution or fulfilling the goals of "The Regulation on Energy Performance in Buildings", proposals of increasing the number of degree-day zones based on provinces are being discussed (Bayram & Yeşilata, 2009). These changes should also be taken into consideration based on climate change. As a result of global warming affecting the whole world, the known effects of climate on the context of comfort and energy consumption of buildings will also change in our country. For this reason, bringing up building and settlement performance requirements by considering long-term climate change has since become a necessity.

Annual energy consumption and greenhouse gas emissions are calculated using the BEP-TR method with the BEP-BUY simulation tool by experts who have completed the Energy Performance Certificate Specialist Program authorized by the Ministry of Environment, Urbanization, and Climate Change. With the BEP-TR method, annual primary energy consumptions are calculated for heating, cooling, lighting, hot water, and ventilation as per unit area and an appropriate energy class is then designated for the building subject to the Energy Performance Certificate process. According to the energy performance classification which is graded as A, B, C, D, E, F, and G, a building is expected to meet at least the requirements of energy class C. However, in compliance with the amendment of the "Regulation on Energy Performance in Buildings", the buildings having construction sites of 2000 m^2 or more are obliged to be constructed as zero energy structures, and their energy performance class should hold a grade of B or above from the year 2025 (Regulation Amending the Regulation on Energy Performance in Buildings, 2022).

While the current energy regulation includes the BEP-TR method and the BEP-BUY simulation tool, professionals can't easily use the BEP-BUY tool for calculations or to analyze detailed data. This is because the program operates on the ministry's internet service and is only accessible to authorized individuals. The experts exercising the process should have the capacity to perform accurate calculations, be able to interpret the outcomes and have the authority to improve on the existing situations by making suitable propositions. Such short-term training programs are seen as inadequate at delivering the necessary expertise; therefore, specialist applicants who are architects and engineers should essentially have equivalent graduate or post-graduate degrees of knowledge in the field of energy efficiency. In this context, the number of experts and auditors who know how to carry out the process of energy consumption limitation concerning optimal comfort conditions, who have mastered the standards, can determine building energy consumptions by non-destructive test methods and perform current situation analysis. These experts capable to create energy improvement strategies specific to the building, and with the help of building energy modeling methods, and can conduct interdisciplinary studies to reach the optimal solution among different alternatives, should be increased. Members of the construction sector should carry out their training process starting from undergraduate education with this awareness.

3. MATERIALS AND METHOD

Calculations have been performed using the BEP-BUY application based on the BEP-TR method in this study, which conveys information about the scope, content, and objectives of the “Regulation of Energy Performance in Buildings”, the process of obtaining the Energy Performance Certificate, and the content of the BEP-TR method for calculating annual energy consumption and greenhouse gas emission amounts.

As part of this study, a duplex residential building of 100 m^2 integrated with architectural elements of diverse heat transfer rates, such as balconies and overhangs with a southern window area of 10 m^2, is used as a reference to calculate the energy consumption and greenhouse gas emissions of the building through a total of 38 provinces in 4 different degree-day zones for both insulated and non-insulated conditions (Figure 1).

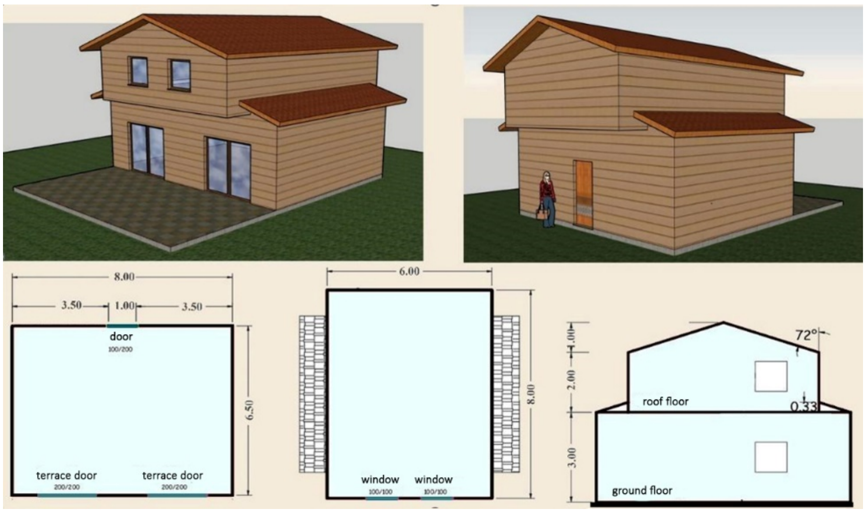

Figure 1. Master Building (Prepared by the authors).

In the TS 825 Standard; wall, floor, and roof layers of building envelope components are defined in the BEP-BUY application relative to suggested heat transfer coefficients in 4 different degree-day zones. Related data for the reference building envelope is displayed in the table (Table 1).

As specified by the BEP-BUY algorithm, mechanical systems, if connected to a single thermal zone, must be defined as local; if connected to more than one thermal zone, must be defined as central. The tool calculates the thermal zones connected to centrally defined systems as if they are supplied from a single source and distributes the source load to the connected thermal zones. In the case of thermal zones that are connected to locally defined systems, the BEP-BUY multiplies the system as much as the number of locally defined thermal zones.

Table 1. Layering data for building envelope components of the master building (Prepared by the authors).

Building Component		Materials	Thickness (m)	Conductivity (W/m-K)	Density (kg/m^3)
Outer Wall	TYPE1	Cement plaster	0.02	1	-
		XPS-extruded polystyrene	0.05	0.034	35
		Brick	0.20	0.81	1800
		Gypsum plaster	0.02	0.7	-
	TYPE2	Cement plaster	0.02	1	-
		XPS-extruded polystyrene	0.05	0.034	35
		Aerated concrete	0.20	0.20	400
		Gypsum plaster	0.02	0.7	-
	TYPE3	Cement plaster	0.02	1	-
		Brick	0.20	0.81	1800
		Gypsum plaster	0.02	0.7	-
	TYPE4	Cement plaster	0.02	1	-
		Aerated concrete	0.20	0.20	400
		Gypsum plaster	0.02	0.7	-
Roof		Concrete flooring	0.12	2.5	2400
		Gypsum plaster	0.015	0.7	-
Mezzanine Floor		Wooden veener	0.012	0.13	-
		Screed	0.05	1.4	
		Concrete flooring	0.12	2.5	2400
		Gypsum plaster	0.015	0.7	-
Ground Floor		Artificial stone	0.01	1.3	-
		Screed	0.05	1.4	-
		Water isolation	0.01	0.19	-
		Lean concrete	0.1	1.65	-
		Slag insulation	0.15	0.23	-
		Blockage(rubble/gravel)	0.15	0.22	-

Regarding the methodology, mechanical and hot water systems are defined as central, mechanical cooling systems are defined as split whereas air conditioning is defined as local. In this case, an advanced condensing combination boiler (combi) of 10 kW for heating and 5 kW for hot water is defined as central. For cooling, split systems of 4 kW are defined as local and included in the calculation as 8 kW since they are connected to two thermal zones. In line with these settings, the changes in total annual energy consumption and greenhouse gas emissions between insulated and non-insulated options based on provinces located in 4 different climate zones in Turkey, were evaluated with the final reports of the licensing phase obtained from the BEP-BUY application based on the BEP-TR calculation method.

In the study, EP, measured in (kWh/m^2-year) is the annual energy consumption converted to primary energy per unit area of the building, and SEG, measured in (kg CO_2/m^2 year) is the annual greenhouse gas emission per unit area of the building. The EP and SEG amount values were obtained from the final reports for 38 provinces to make comparisons against REG and SRG reference indicators. An energy class is designated as a result of Equation (1) related to the energy performance range (Ep) of which the master building falls in between to compare the annual energy consumption per unit area of the master building specified in the BEP-TR with the reference building having the same location and physical attributes as the master building and meeting the minimum requirements on mechanical systems and thermophysical attributes of the current regulations. Ep signifies the energy performance of the building; "a" signifies the master building; "r" signifies the hypothetical (reference) building whereas "EP", signifies the total primary energy consumption (kWh/m^2-year). To form the energy classification range based on the primary energy consumption in Table 2, the Primary Energy Reference Indicator (RG) should also be determined.

$$Ep, EP = 100(EPa/EPr) \quad (1)$$

Table 2. EP: Building energy class related to primary energy consumption (kWh/m^2-year) (Prepared by the authors).

Building Energy Class	Energy Classification Based on Primary Consumptions
A	EP/RG<0.4
B	0.4≤EP/RG<0.8
C	0.8≤EP/RG<1
D	1≤EP/RG<1.2
E	1.2≤EP/RG<1.4
F	1.4≤EP/RG<1.75
G	1.75≤EP/RG

The changes based on different climate zones in the indicator for residential buildings are displayed in Table 3. (BEP-TR Training Manual, 2022). Additionally, CO_2 emissions related to the energy consumption values and the changes in the greenhouse gas emission indicator (SEG) based on different climate zones for residential buildings are calculated with the BEP-BUY application and displayed in Table 4 (BEP-TR Training Manual, 2022). Further, CO_2 emissions related to the energy consumption values are calculated and corresponding (SEG) classifications were displayed. For residential buildings, greenhouse gas emission classifications based on finalized energy consumptions for different climate zones are determined with Equation (2) (Table 4-5), (BEP-TR Training Manual, 2022).

Table 3. Primary energy reference indicator based on building type (kWh/m2-year) (Prepared by the authors).

Building Types	Usage	1st heating zone (RG)	2nd heating zone (RG)	3rd heating zone (RG)	4th heating zone (RG)
Residential	Single and twin-family homes	165	240	285	420

$$Ep, SEG = 100(SEGa/SEGr) \quad (2)$$

Table 4. Reference greenhouse gas indicator based on building type (Prepared by the authors).

Building Types	Usage	1st heating zone (SRG)	2nd heating zone (SRG)	3rd heating zone (SRG)	4th heating zone (SRG)
Residential	Single and twin-family homes	28	40	47	70

Table 5. Greenhouse gas emission classification based on final energy consumptions (Prepared by the authors).

Building Energy Class	Greenhouse Gas Emission Classification Based on Final Energy Consumptions
A	SEG/SRG<0.40
B	0.40≤SEG/SRG<0.80
C	0.80≤SEG/SRG<1.00
D	1.00≤SEG/SRG<1.20
E	1.20≤SEG/SRG<1.40
F	1.40≤SEG/SRG<1.75
G	1.75≤SEG/SRG

4. FINDINGS AND DISCUSSION

Total annual energy consumption and greenhouse gas emission values of the building are compared based on aerated concrete/brick wall alternatives and insulated / non-insulated conditions in different degree-day zones for a total of 38 provinces relative to RG and SRG reference indicators. Ten cities for 1st, 2nd, and 3rd degree-day-zones, and nine cities for 4th degree -zones are selected for the simulation process conducted for the residential building (Figure 2).

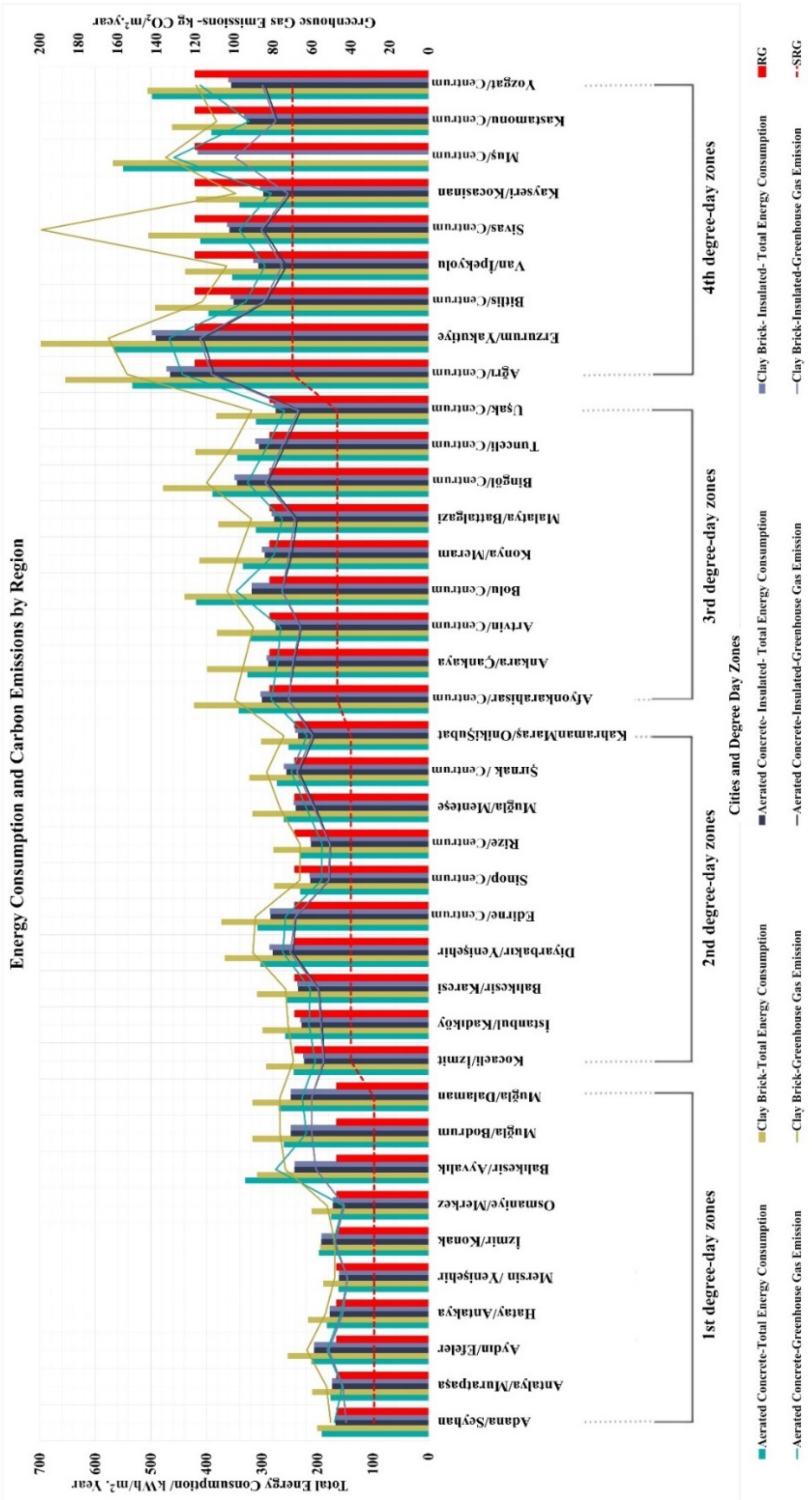

Figure 2. Total energy consumption and greenhouse gas emissions for aerated concrete/clay brick wall based on provinces

4.1. Evaluation Based on the Energy Consumption Reference Indicator

Based on the EP values obtained related to the energy consumption reference indicator for the alternatives in different provinces, percentage ratios of provinces that fell short of the reference indicator are displayed based on 1st, 2nd, 3rd, and 4th degree-day zones in Table 6. Comparing the non-insulated wall options within itself, it is seen that the energy consumption in Mersin which falls under the 1st zone is below the reference indicator for the aerated concrete option even in the non-insulated condition. Again when an insulation layer is applied, the brick wall option has formed a value below the reference indicator only in Mersin.

Table 6. The percentage ratio of provinces equal to or below the energy consumption reference indicator in different degree-day zones.

	1st degree-day zone		2nd degree-day zone		3rd degree-day zone		4th degree-day zone	
Aerated Concrete Wall	Mersin-Yenişehir	10%	Sinop- Centrum, Rize- Centrum	20%	0	0	Sivas- Centrum, Kayseri-Kocasinan, Kastamonu- Centrum Bitlis- Centrum Van-İpekyolu	56%
Clay Brick Wall	0	0	0	0	0	0	Kayseri-Kocasinan	11%
Aerated Concrete Wall-Insulated	Mersin-Yenişehir	10%	Kocaeli-İzmit, İstanbul-Kadıköy, Balıkesir-Karesi, Sinop-Merkez, Rize-Merkez, Muğla-Menteşe Kahramanmaraş-Onikişubat	70%	Artvin- Centrum, Malatya-Battalgazi, Uşak- Centrum	33%	Bitlis- Centrum, Van-İpekyolu, Sivas- Centrum, Kayseri-Kocasinan Muş-Centrum Kastamonu- Centrum, Yozgat- Centrum	77%
Clay Brick Wall-Insulated	Mersin-Yenişehir	10%	Kocaeli-İzmit, İstanbul-Kadıköy, Balıkesir-Karesi, Sinop- Centrum, Rize- Centrum Kahramanmaraş-Onikişubat	60%	Artvin- Centrum, Malatya-Battalgazi, Uşak- Centrum	33%	Bitlis- Centrum, Van-İpekyolu, Sivas- Centrum, Kayseri-Kocasinan Muş-Centrum Kastamonu- Centrum, Yozgat- Centrum	77%

It has been observed that there are provinces despite being in the same climate region where the total energy consumptions are either below or above the reference indicator. Such a variation especially reveals itself on both the aerated concrete and brick wall alternatives in the 1st, 4th-degree-day zones.

In Mersin-Yenişehir, classified under the first-degree-day region, even in the absence of insulation on the aerated concrete wall, energy consumption is provided below the RG limit value, while a similar situation does not occur in any other province in this region with the option of the uninsulated brick-wall building envelope. With the insulated wall options in the first-degree-day zone, only in Mersin-Yenişehir, energy consumption below RG (165 kWh/m^2.year) could be achieved with both alternatives in the cities. In other provinces, there were a slight excess above the Rg value. In Balıkesir-Ayvalık, Muğla-Bodrum, and Muğla-Dalaman, the total energy consumption amounts, which are well above the RG limit value, have been calculated even under-insulated wall conditions.

In Sinop-Centrum and Rize-Centrum, classified in the second-degree-day region, calculated values were below the RG with a “240 kWh/m^2.year” threshold value with the non-insulated aerated concrete wall option. The same situation did not occur with the brick wall option. Values below RG were calculated with the insulated gas concrete wall in the provinces except for Diyarbakır-Yenişehir, Edirne-Centrum, and Şırnak-Centrum. The RG value was exceeded slightly in Muğla-Menteşe than in Diyarbakır-Yenişehir, Edirne-Centrum, and Şırnak-Centrum with insulated brick walls. The values are far above RG compared to the non-insulated aerated concrete wall option with the non-insulated brick walls in all the second regional provinces. Even with both insulated wall options, Diyarbakır-Yenişehir and Edirne-Centrum stand out as the provinces where the RG value exceeded rate is the highest.

In the context of degree-day analysis, the total energy consumption values were computed for any cities below RG (285 kWh/m^2.year), specifically for the non-insulated brick and gas concrete wall configurations for the third degree-day region. However, cities including Artvin-Centrum, Malatya-Battalgazi, and Uşak-Centrum had values below RG, with insulated aerated concrete and brick wall alternatives. The most substantial values exceeding RG were calculated with insulated aerated concrete and brick wall alternatives for the cities such as Bingöl-Centrum and Bolu-Centrum. Interestingly, markedly elevated values beyond the RG benchmark were recorded across all provinces by the uninsulated aerated walls after brick walls in the third-degree-day region. The highest deviations from the RG threshold were observed predominantly in Bolu-Centrum and Bingöl-Centrum, particularly in scenarios where non-insulated aerated concrete and brick walls were employed.

The aerated concrete wall provided values below RG (420 kWh/m^2.year) even with the uninsulated condition in Bitlis-Centrum, Van-Ipekyolu, Sivas-Centrum, Kayseri-Kocasinan, and Kastamonu-Centrum, classified under the fourth degree-day Region. However, in Ağrı-Centrum and Erzurum-Yakutiye, on the contrary, total energy consumption amounts above RG were calculated even in the insulated condition. The energy consumption values below RG are achieved only in Kayseri-Kocasinan with the uninsulated brick wall alternative. The highest difference over RG occurred in the provinces of Ağrı-Centrum, Erzurum-Yakutiye, and Muş-Centrum with the same. Values close to each other were obtained below the RG in all provinces except Ağrı-Centrum and Erzurum-Yakutiye with the insulated aerated concrete and brick wall options. However, for Muş-Centrum, the insulated aerated concrete wall generated less energy consumption than the insulated brick wall.

For 4 alternative conditions and 4 different degree-day zones, differences based on provinces were observed either through insulated conditions. In terms of ensuring energy consumption below the reference indicator, the insulated aerated concrete wall option and the insulated brick wall option showed similar results, except for Muş-Centrum, which is in the 4th-degree-day region. In Muş-Centrum, the amount of energy consumption was found below the reference indicator within the insulated brick wall option.

In line with the acceptances within the scope of this study, two of the nine provinces (Ağrı-Center-Erzurum-Yakutiye) considered in the fourth region gave quite different results from the others. It reveals the need for a re-evaluation regarding the classification of these provinces under the fourth climate zone classification. A similar situation for three under the primary zone classification (Balıkesir-Ayvalık, Bodrum-Muğla, Muğla-Dalaman), two in the second-degree day-wise (Diyarbakır-Yenişehir, Edirne-Centrum), two provinces in the third-degree day zone (Bolu-Centrum, Bingöl-Centrum) is also in question. It would be appropriate to re-evaluate the degree-day region classification in these provinces. The fact that the results obtained for the other seven cities in the fourth-degree day region are well below the RG value indicates a necessity to lower the RG value in this climate region.

Insulation application to the brick and aerated concrete walls in the four-degree-day region has significantly contributed to reaching the defined RG values. In particular, the insulated aerated concrete wall's performance was better than other wall configurations in all provinces. Although mostly insulated brick wall produces closer results to an insulated aerated concrete wall, a situation where it provides a lower total energy consumption value has not occurred within the scope of this study. The smallness of the difference has changed only in Muş-Centrum, which is under the fourth region classification, and for this province, both being below the RG value, it has provided a considerably lower energy consumption compared to the insulated concrete insulated brick wall.

With an aerated concrete wall, Mersin Yenişehir in the first-degree-day region, Kocaeli-İzmit, Sinop-Center, Rize-Center in the Second Degree day region; values below RG were obtained even in uninsulated condition in the provinces of Bitlis-Center, Van-İpekyolu, Sivas-centrum, Kayseri-Kocasinan, Kastamonu-Centrum in the fourth-degree day region. The same situation was valid only for the Kayseri-Kocasinan province in the fourth-degree day region with the uninsulated tube wall option.

4.2. Evaluation Based on the Greenhouse Gas Emission Indicator

No provinces have greenhouse gas emissions below the reference indicator in different degree-day zones based on alternative conditions. The brick wall option produces higher greenhouse gas emissions in all degree-day zones compared to other alternatives; but the most unfavorable conditions are seen to occur in the 4th zone, especially in the provinces and districts such as Sivas-Centrum, Erzurum-Yakutiye, and Ağrı-Centrum. Among these provinces, the highest total energy consumption was observed for Erzurum-Yakutiye within the same alternative. The alternatives of insulated brick walls and aerated concrete walls; produced results closer to the greenhouse gas emission indicator in all degree-day zones compared to the non-insulated conditions. The SRG Value on a degree-day region basis is approached with Van-İpekyolu and Kayseri-Kocasinan cities in the 4th Day region with the insulated brick and gas concrete wall options but not with lower values.

5. CONCLUSIONS AND RECOMMENDATIONS

In this study, the negative effects of designs created without considering the effects of the climate component which is one of the physical environmental factors, are emphasized. In this context, with the aid of the BEP-BUY application based on the BEP-TR calculation method; the total amount of annual energy consumption and greenhouse gas emissions were evaluated within insulated and non-insulated conditions and aerated concrete and brick wall alternatives based on 38 provinces located in 4 different degree-day zones. Although similar results are expected in primary energy consumption and greenhouse gas emissions for a single reference building design used in different provinces located in similar climatic zones, findings indicate the presence of provinces having results exceeding the threshold. Therefore, it was observed that the classification within the current climate zones for these provinces should be revised.

Despite being located in the same degree-day zones, there were provinces with varying conditions based on both energy consumption and greenhouse gas emission indicators. The EP and SEG results from the BEP-BUY program were analyzed to understand these discrepancies, considering both insulated and non-insulated scenarios as well as aerated concrete and brick wall alternatives. It was observed that the aerated concrete wall provided less energy consumption than the brick wall option in the non-insulated condition. However, it was found that this difference was not reflected in the results obtained with the insulated alternative. For this reason, despite making evaluations over the provinces below reference indicators which are in the minority, distinctions made based on the degree-day zones specified in TS 825 Standards are seen as insufficient. For example, while Balıkesir-Ayvalık, Muğla-Bodrum, and Muğla-Dalaman were classified under the first-degree-day zone, results were consistent with the energy consumption reference indicator values of the second-degree-day zone. Similarly, for Diyarbakır-Yenişehir and Edirne-Centrum located in the second-degree-day zone, the results were consistent with the energy consumption reference indicator values of the third-degree-day zone. In all alternative conditions with or without insulation for aerated and brick wall alternatives, values for all below the energy consumption reference indicator could be found only for Kayseri-Kocasinan in the 4th- degree-day climatic zone. The results were well below or upper the RG value unsimilar for some cities under the same classification. Therefore, this indicates a necessity for the evaluation of each RG value defined for the degree degree-day climatic zones.

Furthermore, the obtained results demonstrate that it is not sufficient to only increase the thermal transfer coefficients to the required levels; passive design strategies such as correct material selection in coordination with climatic data, the location and size of window openings, and the orientation and form of the building should also be taken into consideration to improve the energy performance and lower greenhouse emissions.

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in the study do not require ethical committee approval and/or legal-specific permission.

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