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Farklı Duvar Malzemelerinin Bina Enerji Performansı Üzerindeki Etkilerinin Karşılaştırmalı Analizi

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Öne Çıkanlar

- Çalışma, TS 825 (2024) hedeflerini altı farklı iklim bölgesinde statik ve dinamik yöntemleri kıyaslayarak değerlendirmektedir.
- Yeni standardın zorunlu kıldığı 80 kWh/m^2 enerji hedefinin doğrulanması için dinamik modellemenin şart olduğu belirlenmiştir.
- Statik hesaplar soğuk bölgelerde uygulanamaz duvar kalınlıkları (örn. 341 cm) iken, dinamik simülasyonlar farklı çözümler (örn. 42 cm) sunmaktadır.
- Dinamik simülasyonlar, statik yöntemin genellikle hafife aldığı ısıl kütle ve güneş kazancının kritik önemini ortaya koymaktadır.

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Amaç
Bu çalışmada, Türkiye'nin Adana (Köppen-Geiger: Csa) ve Erzurum (Köppen-Geiger: Dsb) iklimleri ve arasında kalan altı farklı iklim bölgesindeki konut için, farklı duvar malzemelerinin 2024 yılında revize edilen TS 825 standardına göre analitik ve dinamik enerji simülasyon yöntemleriyle karşılaştırması amaçlanmıştır.

Metot
Çalışmada OpenStudio simülasyon programı ve TS 825 (2024) Binalarda Isı Yalıtım Kuralları standardında tarif edilen analitik yöntemler kullanılarak, 103 m2 alana sahip bir evin enerji performansı analiz edilmiştir. Analizde beş farklı ana duvar malzemesi (ahşap, delikli tuğla, gaz beton, kerpiç, perde beton) için yalıtım durumu karşılaştırmalı olarak incelenmiştir.

Sonuçlar
Özellikle soğuk iklim bölgelerinde statik analitik yöntemin güneş kazancı ve malzemenin ısıl kütle etkisini tam olarak modelleyememesi nedeniyle 5. Bölge (Van) gibi illerde kerpiç duvar için 341 cm gibi uygulanabilirliği olmayan kalınlıklar öngördüğünü, buna karşın dinamik simülasyonun (OpenStudio/EnergyPlus) 42 cm gibi makul çözümler sunduğunu ortaya koymaktadır. Ayrıca, düşük ısıl iletkenliğe sahip gaz beton ve ahşap gibi malzemelerin enerji hedeflerine daha ince kesitlerle ulaştığı saptanırken; Erzurum gibi ekstrem iklimlerde hedeflenen enerji limitlerine sadece opak yüzey yalıtımıyla ulaşmanın fiziksel sınırlarına değinilerek, enerji verimliliği optimizasyonunda dinamik simülasyon yöntemlerinin politika ve uygulama süreçlerine entegre edilmesinin kritik önemi vurgulanmaktadır.

Anahtar Kelimeler: TS 825 (2024), Enerji performansı, Duvar malzemeleri, Isı yalıtımı, Dinamik Enerji Simülasyonu.

Comparative Analysis of the Effects of Different Wall Materials on Building Energy Performance

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Highlights

- The study evaluates TS 825 (2024) targets by comparing static and dynamic methods across six climate zones.
- Dynamic modeling is identified as essential for verifying the mandated 80 kWh/m² energy target.
- Dynamic simulations offer feasible wall thicknesses in cold regions, whereas static calculations yield impractical results.
- Dynamic simulation highlights the critical importance of thermal mass and solar gain, which are often underestimated by static methods.

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Abstract

Based on the 80 kWh/m² annual energy consumption target introduced by the revised TS 825 (2024) standard, this study comparatively examines the performance of five different main wall materials (wood, perforated brick, autoclaved aerated concrete, sun-dried earth brick, and shear wall) for residences in six different climate zones of Türkiye using analytical calculation and dynamic energy simulation methods. Research findings reveal that the static analytical method fails to fully model solar heat gain and the thermal mass effect of materials in cold climate regions, leading to impractical thickness predictions such as 341 cm for sun-dried earth brick in provinces like Van (5th Zone); in contrast, dynamic simulation (OpenStudio/EnergyPlus) provides feasible solutions such as 42 cm. Furthermore, while it is observed that materials with lower thermal conductivity, such as autoclaved aerated concrete and wood, reach energy targets with thinner sections, the study highlights the physical limits of reaching targeted energy levels solely through opaque surface insulation in extreme climates like Erzurum. Consequently, the critical importance of integrating dynamic simulation methods into policy and implementation processes for energy efficiency optimization is emphasized.

Keywords: TS 825 (2024), Energy performance, Wall materials, Thermal insulation, Dynamic Energy Simulation.

Nomenclature

Symbol	Definition
λ	Thermal Conductivity (W/mK)
ρ	Density (kg/m³)
Cp	Specific Heat (J/kgK)
U	Thermal Transmittance Coefficient (W/m²K)
U_{wall}	Thermal Transmittance of Wall (W/m²K)
U_{ceil}	Thermal Transmittance of Ceiling (W/m²K)
U_{max}	Maximum Heat Transfer Coefficient (W/m²K)
H_{tot}	Specific Heat Loss Coefficient (Total) (W/K)
H_t	Specific Heat Loss Coefficient due to Transmission (W/K)
H_v	Specific Heat Loss Coefficient due to Ventilation (W/K)
V	Ventilation Volume (m³)
n	Air Infiltration Rate (ACH) (h^{-1})
Ψ	Linear Thermal Transmittance (Thermal Bridge) (W/mK)
L	Length of Thermal Bridge (m)
ρ cp	Heat Capacity of Air per Volume (Constant 0.33) (Wh/m³K)
A_n	Net Floor Area (m²)
A_d	Area of Transparent Component (m²)
Q_g	Monthly Total Heat Gain (kWh)
Q_s	Sky Radiation Loss Rate (W)
Q_w	Solar Gains Through Windows Rate (W)
Q_o	Solar Gain from Opaque Surfaces Rate (W)
Q_i	Internal Heat Gains Rate (W)
$Q_{tr,h}$	Heat Transfer for Heating (kWh)
$Q_{tr,c}$	Heat Transfer for Cooling (kWh)
$Q_{req,h}$	Net Heating Energy Requirement (kWh)
$Q_{req,c}$	Net Cooling Energy Requirement (kWh)
Q_y	Specific Annual Energy Consumption (kWh/m²y)
I_d	Solar Radiation Intensity (Direct) (W/m²)
I_{ort}	Average Solar Radiation Intensity (Opaque) (W/m²)
I_{hor}	Solar Radiation on Horizontal Surface (W/m²)
g_{gl}	Solar Energy Transmittance Factor (0.401) (-)
F_{sh}	Shading Factor (0.8) (-)
F_{fr}	Frame Factor (0.25) (-)
R_{se}	External Surface Thermal Resistance (0.04) (m²K/W)
α	Absorption Coefficient (0.60) (-)
t_m	Time Period of the Month (h)
T_o	Monthly Average Outdoor Temperature (°C)
τ	Time Constant (h)
C_m	Thermal Mass of the Building (J/K)
α_H	Alpha Value (Heating) (-)
γ_H	Gain/Loss Ratio (Heating) (-)
η_H	Usage Factor (Heating) (-)
γ_C	Gain/Loss Ratio (Cooling) (-)
η_C	Usage Factor (Cooling) (-)
COP	Coefficient of Performance (-)

1. Introduction

Today, the sustainable use of energy resources and the reduction of environmental impacts are among the primary agenda items for the entire world. According to International Energy Agency (IEA) data, a very large share of global energy consumption and carbon emissions originates from the building sector [1]. Energy consumption in the building sector accounts for approximately 30% of global total energy consumption [2], and it has been calculated that 80% of energy in buildings is consumed for heating and cooling [3].

The correct determination of thermal insulation thickness is not only a legal necessity but also carries critical importance in terms of national energy policies. Building construction and operational activities accounted for approximately 38% of global energy-related CO_2 emissions in 2019, continuing their critical impact on the environment [5]. Adequate insulation offers an energy saving potential of between 30% and 50% in buildings, thereby reducing operating costs and providing a structural contribution to Turkey's goal of reducing greenhouse gas emissions by up to 41% by 2030 [4]. Thermal insulation in buildings is not limited to external walls; insulation must also be applied to areas such as the roof, floor, ceiling, attic, etc. [3]. The recently updated TS 825 (2024 Revision) standard has introduced more restrictive conditions compared to previous versions. For example, the maximum heat transfer coefficient (U_{max}) value for external walls in the 1st Climate Zone, which is the warmest region, has been reduced to 0.40 W/(m^{2}K), and to 0.25 W/(m^{2}K) in the 6th Climate Zone [5]. These new limits necessitate the updating of insulation thickness calculations and the re-analysis specific to different wall materials.

In literature, research conducted on the effectiveness of insulation and the determination of thickness shows that insulation dramatically reduces energy consumption. Dombaycı (2010) emphasized that the use of optimum insulation thickness not only reduces fuel costs but also directly contributes to environmental sustainability by reducing CO_2 and SO_2 emissions resulting from combustion by over 40% [7]. Bolattürk (2006), in a comprehensive analysis conducted across different degree-day regions of Turkey, determined that insulation thicknesses vary between 2 cm and 17 cm depending on fuel type and climate zone; and if these thicknesses are applied, energy savings occur in the range of 22% to 79% [8]. However, not only the climate zone but also the orientation of the building is effective in determining the insulation thickness. Özel (2011) stated that wall orientation (north, south, etc.) has a decisive effect on insulation thickness and that solar radiation should be included in these calculations [9]. Similarly, scientific research reports that the annual heating energy requirement of an insulated building compliant with TS 825 standards (29.47 kWh/m^3) is reduced to one-third compared to an uninsulated building (91.84 kWh/m^3) [10]. Economic optimization studies, in analyses conducted for provinces in the reconstruction process after earthquakes, emphasize that insulation thickness varies depending on the Degree-Day (DD) value of the region and the fuel type [11]. As the number of degree-days increases (as the climate gets colder), the required insulation thickness increases. As the number of degree-days increases (as the climate gets colder), the required insulation thickness increases. Colder provinces such as Kars and Erzurum require thicker insulation compared to Erzincan [12]. In other words, as the number of degree-days increases, the insulation thickness increases [13].

Although heating loads are generally prioritized in insulation optimization, the importance of cooling loads is gradually increasing with global warming. Studies have emphasized that to correctly determine insulation thickness, the cooling load must also be included in insulation thickness calculations in DD1 and DD2 regions [14]. Insulation provides energy savings not only for heating but also for cooling loads and is effective in reducing costs [15].

Not only insulation thickness but also the thermal mass of the wall, material properties, and architectural configuration directly affect performance. Yüksel et al. (2021) proved that materials with high thermal mass (e.g., cut stone) are much more successful in damping indoor temperature fluctuations compared to modern aerated concrete walls (temperature amplitude difference: 0.18°C vs. 0.59°C) [16]. Elias-Özkan (2006) stated that local materials such as adobe and straw bales provide a more balanced indoor environment compared to reinforced concrete due to their high heat capacities [17]. In another study on traditional materials, Binici et al. (2005) revealed that the thermal insulation properties and mechanical strength of fiber-reinforced adobe can be improved, thus offering a sustainable building material alternative [18]. In contrast, the moisture factor is also important in the application of modern materials. Pehlivanlı (2009) determined that when the mass moisture content of aerated concrete reaches 48%, its thermal conductivity increases approximately 3 times compared to the dry state [19]. Özer and Özgünler (2019) mentioned that thermal insulation materials lose their thermal insulation properties when they absorb water [20]. This is because the thermal conductivity value of water filling the air gaps is 20 times higher than that of air. Regarding wall configuration, it has been reported that the sandwich wall (aerated concrete) model has the lowest heat loss (3300 W/m^2), while uninsulated brick walls yield the highest loss [21].

This study, shaped in the light of existing literature, aims to provide multifaceted contributions to the field of energy efficiency for the Turkish construction sector. The main objective of the study is to determine the required wall thicknesses for five different wall materials (adobe, shear wall concrete, aerated concrete, perforated brick, and wood) to meet the restrictive U_{max} values introduced by the TS 825 standard revised in 2024. The most important element that distinguishes this paper from other studies is that it is not limited to the new static U-value calculations determined according to TS 825 (2024 revision) but also utilizes dynamic energy simulation tools such as OpenStudio. This study aims to provide a guide based on objective data for architects and engineers in choosing the most economically appropriate wall/insulation combination compatible with the new standards.

2. Material and Method

In this study, an energy performance analysis of a typical 2+1 (100 m^2) residence was conducted in order to meet the thermal insulation conditions determined by the latest 2024 revision of the TS 825 standard. For some of the 5 different construction materials (Wood, Perforated Brick, Aerated Concrete, Adobe, Shear Wall Concrete) across the 6 different climate zones revised according to the TS 825 (2024) standard, wall thicknesses that bring the energy performance of the building to the target of 80 kWh/m^2 were calculated by using EPS (Expanded Polystyrene) insulation material. Energy simulations were performed using the OpenStudio and EnergyPlus engines. In the simulations, TMY (Typical Meteorological Year) weather data in EPW format belonging to the city centers of Adana (1st Zone), Izmir (2nd Zone), Istanbul (3rd Zone), Ankara (4th Zone), Van (5th Zone), and Erzurum (6th Zone) were used to represent the 6 climate zones of Turkey, respectively.

2.1. Building Geometry and Enclosure

The external wall area of the reference building was calculated as 105.89 m^2 and the roof area as 100 m^2, and it was modeled as a single-story detached house. The geometry can be seen in Figure 1. In all building types, the ceiling and floor materials were kept constant; insulation thicknesses were adjusted to provide the U-values compliant with TS 825 (2024) standards in the relevant climate zone (Table 1). Although different wall materials (wood, adobe, etc.) were examined in this study, the floor and ceiling systems were assumed to be standard reinforced concrete in all scenarios. Since the high thermal mass formed by these reinforced concrete elements is dominant, the building heat capacity (C_m) was considered constant and classified as 'Heavy Building' for all types in the TS 825 calculations.

The building air infiltration rate was assumed to be at a constant value of 0.3 ACH (air changes per hour). Since the brick used in the 1st and 2nd zones exhibits standard and sufficient thermal performance, it was modeled without insulation. The thermophysical properties of the analyzed construction materials are presented in Table 2, and the insulation thicknesses, whose variation according to climate zones was examined, are presented in Table 3.

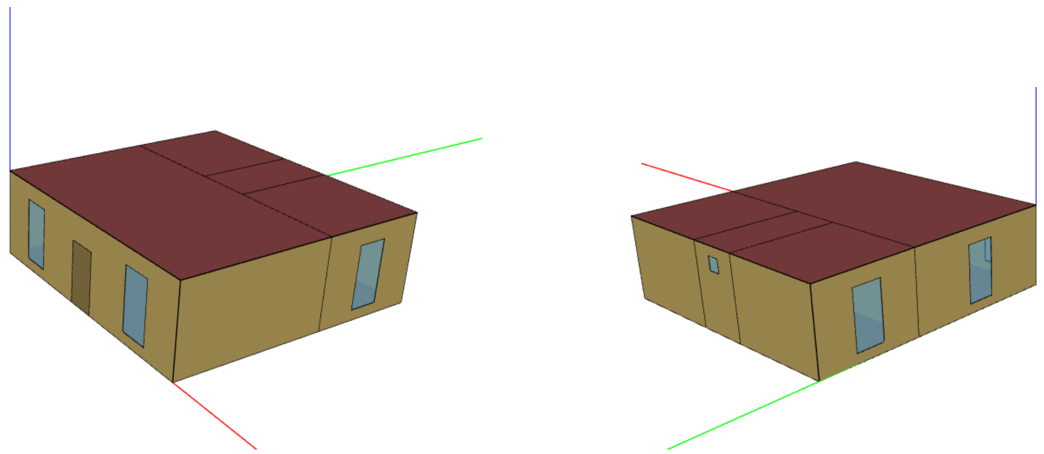

Figure 1. Geometry of the reference building

Table 1. Ceiling and Floor U-values used according to climate zones (W/m^{2}K)

Zones	Ceiling	Floor	Window
Zone 1 (Adana)	0,35	0,4	1,8
Zone 2 (İzmir)	0,3	0,35	1,8
Zone 3 (İstanbul)	0,3	0,35	1,8
Zone 4 (Ankara)	0,25	0,29	1,8
Zone 5 (Van)	0,2	0,24	1,8
Zone 6 (Erzurum)	0,2	0,24	1,8

Table 2. Thermophysical Properties of Building Materials

Material Name	Thermal Conductivity (λ) [W/mK]	Density (ρ) [kg/m³]	Specific Heat (Cp) [J/kgK]
EPS Insulation	0,035	30	1450
Aerated Concrete	0,1	500	1000
Wood (Laminated)	0,13	600	1700
Adobe Block / Mud Plaster	0,2	1000	1000
Perforated Brick	0,29	1000	1000
Interior Plaster (Shear Wall / Aerated Concrete)	1	1800	1000
Exterior Plaster (Brick)	1	1800	1000
Exterior Plaster (Shear Wall / Aerated Concrete)	1,6	2000	1000
Concrete	2,5	2400	1000

Table 3. Thicknesses vary by climate zones according to TS 825 (2024) Standard (m)

Building Type	Variable Layer	Adana (Z1)	İzmir (Z2)	İst. (Z3)	Ankara (Z4)	Van (Z5)	Erzurum (Z6)
Wooden House	Wood Thickness	0,065	0,08	0,11	0,195	0,29	0,7
Brick Wall	EPS Thickness	0	0	0,0025	0,025	0,05	0,17
Shear Wall Concrete	EPS Thickness	0,009	0,014	0,022	0,045	0,069	0,185
Adobe House	Adobe Thickness	0,04	0,078	0,104	0,14	0,37	1
Aerated Concrete	Aerated Concrete Thickness	0,085	0,085	0,085	0,135	0,2	0,54

2.2. Internal Loads and Operating Schedules

The internal gains and usage schedules that determine the energy consumption profile of the residence were established by considering the daily life cycle of an average family. The lighting profile used in the simulations was defined to be off between 08:00-17:00 when daylight is utilized, at full capacity (100%) from 17:00 in the evening until midnight, and at a 10% level during the 00:00-08:00 interval at night. The use of electrical equipment was kept at a minimum 40% load throughout the day, while the usage rate was increased to 100% capacity during the morning (08:00-09:00) and evening (19:00-24:00) hours. While the activity level was kept at a constant value of 70W throughout the simulation, the indoor occupancy hours were structured to intensify in the morning and evening, in harmony with the lighting and equipment profiles.

2.3. Mechanical Systems and Air Conditioning

Constant temperature setpoints were used for the control of air conditioning systems. The indoor design temperature was determined as a constant 20°C for all hours of the day during the winter period (heating) and a constant 26°C for the summer period (cooling). The heating and cooling systems were autosized according to the building dimensions. For the heating system, a combi boiler with a nominal thermal efficiency of 80% and a radiator distribution system were preferred. Furthermore, the boiler water temperature feeding the heating system was kept constant at 67°C. The circulation pump was defined as variable speed with a pressure drop of 60,000 Pa and a motor efficiency of 90%. For cooling requirements, a Packaged Terminal Air Conditioner (PTAC) system with a COP value of 3.0, a fan efficiency of 60%, and a pressure rise of 250 Pa was included in the model. The fan mode was set to operate cyclically, and its heating feature was disabled due to the use of the combi boiler.

2.4. Analytical Calculation Method

The algorithm used in this study is presented in Fig. 2. In these calculations, the "Monthly Calculation Method" defined in the TS 825 (2024) standard was used to determine the energy performance of buildings. Calculations for Zone 3 (Istanbul) are provided as an example. All coefficients and constants used in the equations were taken from Annex C and Annex D of the TS 825 (2024) standard. In the calculations, the thermal transmittance coefficient of the building's opaque component (U_{wall}) was accepted as a variable parameter, while other building components and operating conditions were kept constant.

Fixed Heat Loss (H) Values:

First, the Specific Heat Loss Coefficient (H_{tot}), which consists of transmission (H_t) and ventilation (H_v) heat losses, is defined as follows:

$$H_{tot} = H_t + H_v \qquad (1)$$

The transmission heat loss coefficient (H_t) represents the losses from surfaces and thermal bridges:

$$H_t = \sum(U \times A) + \sum(L + \Psi) \qquad (2)$$

In this study, the effect of thermal bridges (Ψ) was neglected and assumed to be zero in both the analytical calculations and the dynamic simulations to ensure consistency between the two approaches and to focus solely on the performance of the wall materials.

For reference building, the heat loss coefficients of fixed components (excluding external walls) were calculated and summed up to obtain a constant value. These components are detailed in the table below:

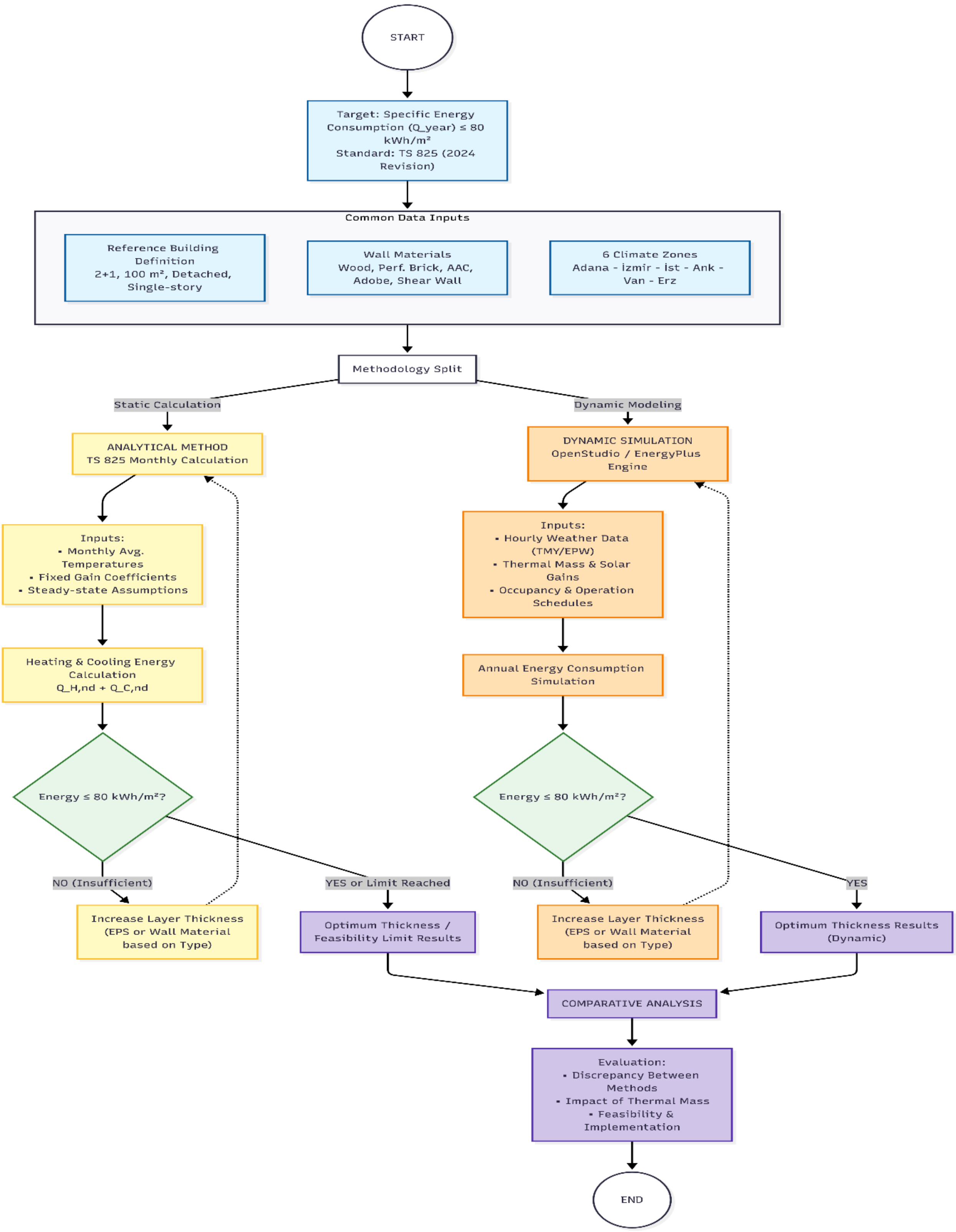

Figure 2. Wall Thickness Analysis Flowchart

Table 4. Fixed heat loss coefficients of the reference building components

Component	Calculation Method	Value (W/K)
Ventilation (H_v)	$0.33 \times A_{net} \times 0.7$ (0.7:m^3/h.m^2 area-based flow rate)	23.10
Ground/Floor(H_g)	Effective U Calculation (($U_{eff} \approx 0.173$)	17.30
Ceiling(H_{ceil})	$100m^2 \times 0.192\, W/m^2\,K$	19.20
Window(H_w)	$11.80m^2 \times 1.801\, W/m^2\,K$	21.25
Door(H_{door})	$2.31m^2 \times 0.870\, W/m^2\,K$	2.01
Fixed Total ($H_{tot/}$)	(Total Excluding Wall)	82.86 W/K

Using this constant value (82.86 W/K), the total Specific Heat Loss Coefficient (H_{tot}) is expressed as a function of the wall thermal transmittance (U_{wall}):

- Specific Heat Loss Coefficient (H):

$$H_{tot} = (U_{wall} \times 105.89) + 82.86 \quad (3)$$

The Total Heat Gains (Q_{gn}) affecting the building's heating and cooling loads were obtained by subtracting sky radiation losses (Q_s) from the sum of solar gains from transparent components (Q_w), solar gains from opaque components (Q_o), and internal heat gains (Q_i). In these calculations, the monthly average solar radiation intensities provided in TS 825 (2024) Annex C (I_d) and outdoor temperature data were used:

- Solar Gains Through Windows (Q_w):

$$Q_w = \sum\left[A_d \times I_d \times g_{gl(0.401)} \times F_{sh(0.8)} \times (1 - F_{fr(0.25)})\right] \quad (4)$$

- Solar Gain from Opaque Surfaces (Q_o):

$$Q_o = R_{se(0.04)} \times \alpha(0.60) \times [(U_{wall} \times 105.89 \times I_{ort}) + (U_{ceil} \times 100 \times I_{hor})] \quad (5)$$

- Sky Radiation Loss (Q_s):

$$Q_s = R_{se(0.04)} \times 4.14 \times 11 \times [(0.5 \times U_{wall} \times 105.89) + (U_{ceil} \times 100 \times I_{hor})] \quad (6)$$

- Internal Gains (Q_i):

$$Q_i = 2.75 \times 100 \quad (7)$$

- Monthly Total Heat Gain (Q_{gn}):

$$Q_{gn} = [(Q_w + Q_o - Q_s) + Q_i] \times t_m \times 0.001 \quad (8)$$

Heating Energy Calculation:

The design indoor temperature for the heating season is assumed to be 20°C. The Heat Transfer for Heating ($Q_{tr,h}$) was calculated using monthly average outdoor temperatures (T_o), and the Time Constant (τ) and Alpha Value (α_H) were determined based on the building's thermal mass (C_m) and specific heat loss:

- Heat Transfer Coefficient for Heating ($Q_{tr,h}$):

$$Q_{tr,h} = [(H_{tot} - 17.30) \times (20 - T_o) + 17.30 \times (20 - (13.54))] \times t_m \times 0.001 \quad (9)$$

- Net Heating Energy Requirement ($Q_{req,h}$):

$$Q_{req,h} = Max\left(0; Q_{tr,h} - (\eta_H \times Q_{gn})\right) \quad (10)$$

Cooling Energy Calculation:

In cooling period calculations, the indoor design temperature is taken as 26°C. Similar to the heating calculation, but considering conditions specific to the cooling period, Heat Transfer for Cooling ($Q_{tr,c}$)is calculated:

- Heat Transfer for Cooling ($Q_{tr,c}$):

$$Q_{tr,c} = [(H_{tot} - 17.30) \times (26 - T_o) + 17.30 \times (26 - (13.54))] \times t_m \times 0.001 \quad (11)$$

The Cooling Gain/Loss Ratio (γ_C) and the Cooling Utilization Factor (η_C) were determined to account for factors that reduce the cooling load. The Net Cooling Energy Requirement ($Q_{req,c}$) was obtained by subtracting the heat transferred out through building elements and ventilation from the total heat gains:

Similar to Net Heating Energy Requirement, Net Cooling Energy Requirement can be calculated by Eq. (12) considering Cooling Gain/Loss ratio.

- Net Cooling Energy Requirement ($Q_{req,c}$):

$$Q_{req,c} = Max(0; Q_{gn} - (\eta_C \times Q_{tr,c})) \quad (12)$$

Optimization:

To achieve the minimum wall insulation value that provides the limit value, which is the main objective of the study, the annual sum of heating and cooling energies is defined as the Specific Energy Consumption (Q_y). The U_{wall} value at the point where this value equals the limit value ($\frac{80kWh}{m^2 \times year}$) was determined separately for each climate zone using an iterative calculation method:

- Specific Energy Consumption (Q_y):

$$Q_y = \frac{\sum Q_{req,h} + \sum Q_{req,c}}{A_n} \quad (13)$$

In the calculations performed according to the TS 825 standard, insulation thickness was not selected as an independent variable; instead, the annual energy consumption limit of 80 kWh/m², introduced by the 2024 update, was set as the objective function. Using the Excel 'Goal Seek' optimization tool, the maximum thermal transmittance coefficient U_{wall} and the corresponding minimum wall thickness required to meet this energy limit were calculated iteratively.

3. Results

In this study, the minimum wall thicknesses and U-values required to ensure energy performance (80 kWh/m^2) in compliance with the TS 825 (2024) standard in provinces representing 6 different climate zones of Turkey were analyzed using the analytical method and the EnergyPlus program.

3.1. Required Thermal Transmittance (U) Values in Different Climate Zones According to the Analytical Calculation Method

As a result of the analytical calculations performed using the TS 825 (2024 revision), the wall U-values that must be provided in the building envelope to avoid exceeding the targeted annual energy consumption limit are presented in Table 4. It was observed that as the climate zones get colder, the required insulation performance (lower U-value) increases significantly to meet the energy performance target.

While a value of 0.432 kW/m^2 is sufficient for the 1st Zone (Adana), this value must decrease to the level of 0.058 kW/m^2 for the

5th Zone (Van). This situation reveals the critical role of the building envelope in preventing heat loss in cold climate zones.

In the calculations for Erzurum (Zone 6), due to the TS 825 standard being based on critical climatic conditions and the resulting increase in constant heat losses (windows and ventilation), the annual energy consumption could not be reduced below the level of 81.65 kWh/m^2, even if the wall thermal transmittance coefficient was lowered to the theoretical lower limit of 0.00 W/m^{2}K Therefore, a wall U-value that achieves the 80 kWh/m^2 target for Erzurum could not be derived with the specified design parameters. While heat losses originating from windows and ventilation appear high in TS 825 calculations because outdoor climatic conditions are fixed based on critical boundary values (the lowest 25th percentile in winter), the hourly dynamic data used by OpenStudio allows for the optimization of these constant loads by reflecting climatic variability more realistically.

3.2. Wall Thicknesses Compliant with U-values Determined According to TS 825

The wall thickness required according to material types to provide the U-values determined by the analytical method are presented in Table 5 and Figure 3. The differences between the thermal conductivity coefficients (λ) of the materials are clearly reflected in the wall thickness, especially in cold climate zones:

Table 5. Wall U-values provide the required energy performance across different climate zones

Zone	Reference City	Required Wall U-Value (W/m^{2}K)
Zone1	Adana	**0.432**
Zone 2	İzmir	**0.383**
Zone 3	İstanbul	**0.338**
Zone 4	Ankara	**0.209**
Zone 5	Van	**0.058**

Table 6. Wall thickness calculated according to climate zones and house types

Zone	Wooden House (cm)	Aerated Concrete (cm)	Adobe (cm)	Shear Wall Concrete (cm)	Brick Wall(cm)
Zone 1 (Adana)	27,88	26,06	42,9	32,09	29,06
Zone 2 (İzmir)	31,73	29,02	48,82	33,13	30,1
Zone 3 (İstanbul)	36,25	32,5	55,77	34,34	31,32
Zone 4 (Ankara)	59,99	50,76	92,29	40,74	37,71
Zone 5 (Van)	221,93	175,33	341,43	84,33	81,31

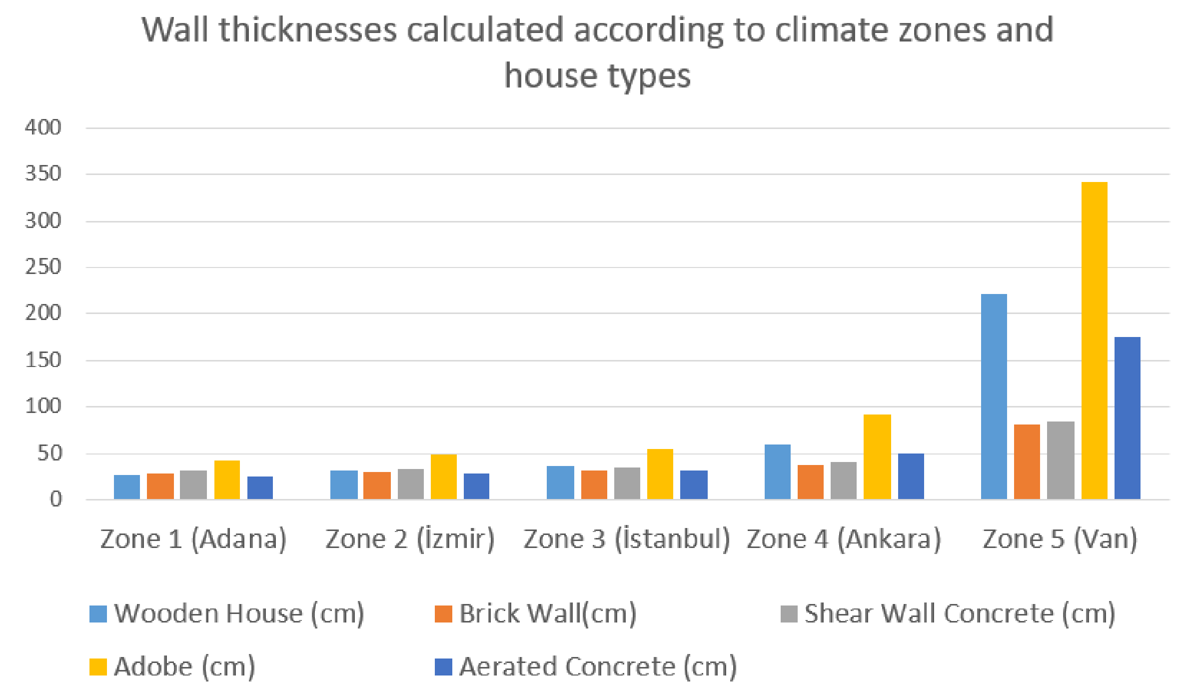

Figure 3. Wall thicknesses calculated with analytically determined wall U-values

3.3. OpenStudio Simulation Results and Thicknesses

The wall thicknesses obtained as a result of OpenStudio simulations, which take dynamic parameters (solar gain, thermal mass, etc.) into account and calculate weather data on an hourly basis, have yielded more feasible results compared to the analytical method (See Table 6 and Figure 4).

- In all regions, materials with better insulation values, such as Aerated Concrete and Wood, achieved the energy target with thinner sections compared to Adobe and Shear Wall Concrete.

- **Erzurum (Zone 6):** According to the simulation results, to meet the energy limit in Erzurum; the wooden wall should be 70 cm, the aerated concrete 59 cm, and the adobe wall 105 cm thick. Although these results are high, they provide a solution set, unlike the analytical method.

- **Comparison of Methods (The Case of Van):** The difference between the methods is seen most clearly in the province of Van. While the analytical method predicts a thickness of 341 cm for the adobe wall, the dynamic simulation calculated this value as 42 cm. This difference demonstrates that dynamic simulation reduces the heating load by using solar gains and the thermal capacity of the building more effectively, and it also highlights the difference between the monthly outdoor temperature data of TS 825 and the outdoor temperatures used in the simulations.

Table 7. Wall thickness obtained because of OpenStudio simulations

Zone	Wood (cm)	Brick (cm)	Shear Wall Concrete (cm)	Adobe (cm)	Aerated Concrete (cm)
Zone 1 (Adana)	6,5	24	25,9	9	13,5
Zone 2 (İzmir)	8	24	26,4	12,8	13,5
Zone 3 (İstanbul)	11	24,25	27,2	15,4	13,5
Zone 4 (Ankara)	19,5	26,5	29,5	19	18,5
Zone 5(Van)	29	29	31,9	42	25
Zone 6 (Erzurum)	70	41	43,5	105	59

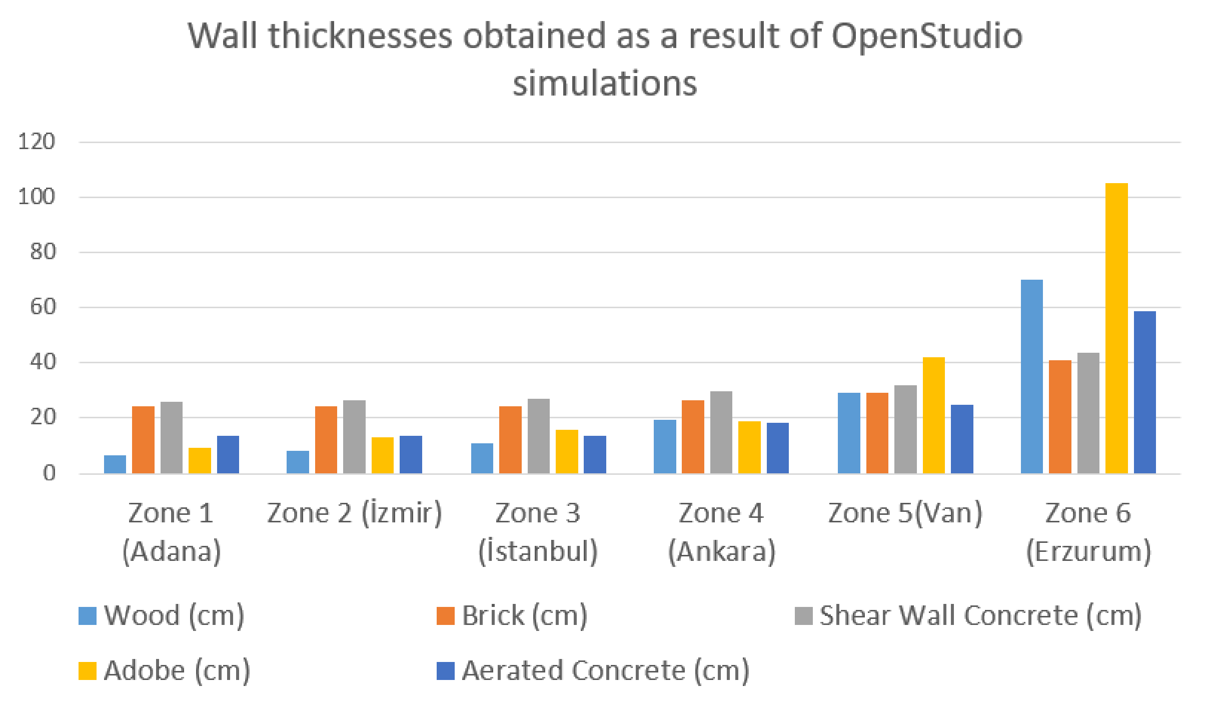

Figure 4. Graphical analysis of the data presented in Table 6.

4. Discussion

The findings obtained in this study reveal significant discrepancies between the analytical calculation method used within the scope of the TS 825 (2024) standard and dynamic energy simulations. Although both approaches confirm that higher wall thicknesses are required to limit heat losses of the building envelopes as climate zones become colder, the quantitative differences between the calculated values are noteworthy. Specifically, the analytical method was observed to predict significantly higher wall thicknesses compared to dynamic simulations across all climate zones and for all construction materials.

This distinction is clear even in temperate climate zones (Zones 1 and 2). In hot-temperate climatic conditions such as Adana and Izmir, it was determined that the wall thicknesses suggested by the analytical method are two to four times greater than the OpenStudio simulation results. For instance, while the analytical method calculated a wall thickness of approximately 28 cm for wooden residences in Adana, dynamic simulations demonstrated that a thickness of approximately 6.5 cm is sufficient in terms of energy performance. This suggests that the analytical approach maintains excessively high safety margins, even in milder climates.

As climatic conditions become more severe, the divergence between the two methods becomes even more pronounced. In the fourth and fifth climate zones, particularly in the province of Van, it was observed that the wall thickness calculated by the analytical method reached values exceeding practical application limits. For Van, the analytical method’s prediction of approximately 222 cm for wooden structures and 341 cm for adobe (mudbrick) structures renders the direct applicability of this method in cold climates controversial. In contrast, dynamic simulations offer reasonable and feasible solutions for the same energy performance target, such as 29 cm for wood and 42 cm for adobe, which are viable in terms of construction techniques.

The basis of this difference lies in the calculation logic of the two approaches. The analytical method based on TS 825 relies on monthly average climate data and steady-state assumptions. In this method, solar gains, internal heat gains, and the time-dependent thermal behavior of structural elements are represented to a limited extent. Conversely, OpenStudio/EnergyPlus-based dynamic simulations provide a modeling approach closer to the actual operating conditions of the building by utilizing hourly climate data.

In particular, the behavior of building materials with high thermal mass plays a crucial role in explaining the difference between the two methods. Materials such as adobe, brick, and concrete can store heat during daylight hours and release it to the interior environment at night, thereby limiting indoor temperature fluctuations. While dynamic simulations account for this "time lag" effect in detail, the analytical method represents this effect largely through fixed coefficients. Consequently, the analytical approach necessitates excessive insulation or wall thickness in most cases to achieve the targeted energy consumption values.

The results obtained for Erzurum, located in the sixth climate zone, clearly demonstrate that merely improving wall insulation is insufficient beyond a certain point. Dynamic simulations revealed that even if the wall heat transfer coefficient is theoretically reduced to near zero, annual energy consumption remains slightly above the 80 kWh/m² target. This finding indicates that heat losses originating from window areas and ventilation become decisive factors in harsh climatic conditions. Nevertheless, dynamic simulations suggest technically feasible wall thicknesses for materials like wood, aerated concrete, and adobe, pointing to the necessity of a holistic design approach.

When evaluated in terms of material type, it was observed that aerated concrete and wooden structures, which possess low thermal conductivity coefficients, can reach energy targets with thinner wall sections compared to materials like adobe and shear wall concrete. For example, a thickness of approximately 25 cm is sufficient for aerated concrete walls in Van, whereas this value increases to 42 cm for adobe walls. This result reconfirms that the direct thermal insulation capacity of the construction material is a determinant for the required wall thickness.

Overall, the results obtained from both analytical and dynamic methods demonstrate that a more robust building envelope is required to meet energy performance targets as climate zones get colder. These findings are consistent with previous studies by Timuralp et al. [10] and Çomaklı and Yüksel [11], supporting the critical role of the building envelope in limiting heat losses in cold climates. However, the results of this study show that dynamic energy simulations have the potential to produce more realistic and applicable design decisions compared to analytical calculation methods, especially under severe climatic conditions.

5. Conclusion

Based on the recently revised TS 825 (2024) standard's Annual Primary Energy Consumption (APEC) target of 80 kWh/m^2, this study analyzed the wall thicknesses of residences in six climate zones of Turkey across five different main wall materials (Wood, Perforated Brick, Aerated Concrete, Adobe, and Shear Wall Concrete) using both the Analytical (Monthly Calculation) Method and Dynamic (OpenStudio/EnergyPlus) Simulation.

The most critical finding of the study is the distinct difference between the two methods. The analytical method predicted wall sections that are too thick to be structurally feasible for achieving energy targets, especially in cold climate zones (Zone 4 and beyond). The most prominent example of this deviation was observed for the Adobe House type in Zone 5 (Van): while the analytical calculation determined a thickness of 341.43 cm (Table 5), the dynamic simulation calculated this value as 42 cm (Table 6). This difference proves that dynamic simulations model the heating load reduction effects of high thermal mass and solar gains more accurately than the analytical method.

For Zone 6 (Erzurum), Turkey's coldest region, the analytical method failed to derive a feasible wall U-value and thickness to meet the targeted 80 kWh/m^2 limit. This is thought to be because heat losses from windows and ventilation appear high in TS 825 calculations—where outdoor climatic conditions are fixed based on critical boundary values (the lowest 25th percentile in winter) whereas the hourly dynamic data used by OpenStudio reflects climatic variability more realistically, allowing for the optimization of these constant loads. In contrast, dynamic simulations were able to offer technically feasible solutions for Wood (70 cm), Aerated Concrete (59 cm), and Adobe (105 cm). According to simulation results, materials with naturally better insulation values, such as Aerated Concrete (λ=0.1W/mK) and Wood (λ=0.13W/mK), achieved the energy target with thinner wall sections.

In conclusion, to reach the 80 kWh/m^2 APEC target set by the TS 825 (2024) standard, the Analytical Calculation Method produces overly cautious results, particularly for high-thermal-mass structures and cold climate zones. The use of Dynamic Energy Simulation methods in energy efficiency optimization is of critical importance for providing applicable and feasible building solutions.

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