Comparative Thermal Performance of Recycled Plastic Bricks: A Property-Based Analysis for Energy-Efficient Housing

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Abstract: *This study addresses the growing need for energy-efficient and low-impact building materials in Turkey by evaluating the energy performance of innovative recycled-plastic bricks. Although plastic bricks have demonstrated promising thermal properties in international research, the research gap lies in the absence of a systematic, climate-specific assessment for Istanbul's mild-humid conditions and a lack of comparative simulations against commonly used Turkish masonry. The aim of this study is to conduct a comprehensive performance evaluation of recycled-plastic bricks and the objective is to determine which formulations offer the greatest potential for reducing building energy demand in Turkey. The methods used in this study involves twenty years of meteorological data from the Turkish State Meteorological Service and dynamic energy simulations conducted in DesignBuilder/EnergyPlus. A U-shaped residential building typology previously identified as the most energy-efficient form for Istanbul was modeled. Seventeen recycled-plastic brick types (B1–B17) sourced from existing literature were analyzed based on thermal conductivity, specific heat capacity, density, moisture resistance, and fire resistance, and were benchmarked against Turkish hollow clay bricks. The key findings of this study show that several plastic brick types significantly outperform the traditional masonry. In particular, Brick B15, composed of recycled PET and sand, achieved the highest overall energy savings of 13.89%, driven by a 26.24% reduction in heating load with only a minimal rise in cooling demand. This superior performance stems from its optimal combination of low thermal conductivity, moderate density, and high specific heat capacity. Furthermore, eight additional plastic bricks demonstrated substantial efficiency gains, underscoring the role of recycled thermoplastics and stabilizing additives (e.g., fly ash, quarry dust) in improving thermal inertia and indoor comfort. The key implication of these findings is that plastic composite bricks can substantially reduce operational energy consumption, particularly in low- and middle-income housing where insulation levels are often inadequate. By integrating long-term climate data, material science insights, and high-resolution simulation, this study provides a scalable and evidence-based framework for the adoption of eco-friendly plastic bricks in temperate climates. The results offer actionable guidance for architects, engineers, policymakers, and housing agencies aiming to lower energy use and carbon emissions in Turkey's residential construction sector.*

Keywords: *recycled plastic bricks, energy efficiency in buildings, thermal performance of masonry, sustainable building materials, affordable housing design.*

Geri Dönüştürülmüş Plastik Tuğlalarin Karşilaştirmali Termal Performansi: Enerji Verimli Konutlar İçin Özellik Temelli Bir Analiz

Özet: *Bu çalışma, Türkiye'de enerji verimli ve çevresel etkisi düşük yapı malzemelerine yönelik artan gereksinime yanıt olarak, yenilikçi geri dönüştürülmüş plastik tuğlaların enerji performansını değerlendirmektedir. Plastik tuğlalar, uluslararası literatürde umut verici ısıl özellikler sergilemiş olsa da, İstanbul'un ılıman ve nemli iklim koşullarına özgü sistematik değerlendirmelerin sınırlı olması ve Türkiye'de yaygın olarak kullanılan geleneksel yığma duvar malzemeleriyle karşılaştırmalı simülasyon çalışmalarının bulunmaması önemli bir araştırma boşluğu oluşturmaktadır. Bu bağlamda çalışmanın amacı, geri dönüştürülmüş plastik tuğlaların kapsamlı bir performans analizini gerçekleştirmek; temel hedefi ise Türkiye'de bina enerji talebini azaltma potansiyeli en yüksek tuğla* *formülasyonlarını belirlemektir. Çalışmada, Türk Devlet Meteoroloji İşleri'nden elde edilen yirmi yıllık meteorolojik veriler kullanılarak DesignBuilder ve EnergyPlus yazılımları aracılığıyla dinamik enerji simülasyonları gerçekleştirilmiştir. İstanbul için daha önce en enerji verimli yapı formu olarak tanımlanan U-şekilli konut tipolojisi modellenmiştir. Literatürden derlenen on yedi geri dönüştürülmüş plastik tuğla türü (B1–B17), ısıl iletkenlik, özgül ısı kapasitesi, yoğunluk, neme dayanım ve yangın dayanımı kriterleri doğrultusunda analiz edilmiş ve Türkiye'de yaygın olarak kullanılan delikli kil tuğlaları ile karşılaştırılmıştır. Elde edilen bulgular, birçok plastik tuğla türünün geleneksel yığma duvar malzemelerine kıyasla belirgin biçimde daha yüksek enerji performansı sunduğunu göstermektedir. Özellikle geri dönüştürülmüş PET ve kumdan üretilen B15 tuğlası, ısıtma yükünde %26,24'lük bir azalma ve soğutma talebinde yalnızca sınırlı bir artış ile toplamda %13,89 oranında en yüksek enerji tasarrufunu sağlamıştır. Bu üstün performans, düşük ısıl iletkenlik, orta düzey yoğunluk ve yüksek özgül ısı kapasitesi arasında kurulan dengeli bileşimden kaynaklanmaktadır. Ayrıca sekiz plastik tuğla türü daha kayda değer verimlilik artışları göstermiş; geri dönüştürülmüş termoplastikler ile uçucu kül ve ocak tozu gibi dengeleyici katkı maddelerinin, ısıl ataletin artırılması ve iç mekân konforunun iyileştirilmesindeki rolünü ortaya koymuştur. Bu çalışmanın temel çıkarımı, plastik kompozit tuğlaların özellikle yalıtım seviyelerinin yetersiz olduğu düşük ve orta gelirli konutlarda işletme enerjisi tüketimini anlamlı ölçüde azaltabileceğidir. Uzun dönemli iklim verileri, malzeme bilimi temelli analizler ve yüksek çözünürlüklü simülasyonların bütüncül biçimde kullanılmasıyla bu çalışma, ılıman iklim koşullarında çevre dostu plastik tuğlaların benimsenmesine yönelik ölçeklenebilir ve kanıta dayalı bir çerçeve sunmaktadır. Elde edilen sonuçlar, Türkiye'nin konut sektöründe enerji kullanımını ve karbon emisyonlarını azaltmayı hedefleyen mimarlar, mühendisler, politika yapıcılar ve konut kurumları için uygulanabilir nitelikte yol gösterici bulgular sağlamaktadır.*

***Anahtar Kelimeler**: geri dönüştürülmüş plastik tuğlalar, binalarda enerji verimliliği, duvar malzemelerinin ısıl performansı, sürdürülebilir yapı malzemeleri, uygun maliyetli konut tasarımı.*

1. INTRODUCTION

Preservation can be defined as safeguarding assets from threats [1]. The energy efficiency of construction materials is essential for minimizing overall energy consumption and the environmental effect of residential structures. In the Turkish residential construction sector, this significance is heightened by other interrelated elements, including the nation's climatic diversity, escalating urbanization, and rising energy demand. Turkey's climate exhibits considerable regional variation, spanning from arid continental zones to humid coastal areas. Istanbul and its district, Esenyurt, are situated in a temperate-humid climate zone, marked by hot, humid summers and mild, rainy winters. This climate unpredictability requires construction materials that can efficiently regulate indoor temperatures by decreasing heat loss in cold conditions and limiting heat gain in warm conditions. Bricks, as a fundamental element of building envelopes, are crucial for thermal control.

Conventional bricks prevalent in Turkey, including the Turkish hollow clay brick and burned clay brick, have elevated thermal conductivity values (surpassing 0.50 W/m·K) and high density, facilitating swift heat movement through construction walls. This leads to heightened heating requirements in winter and cooling needs in summer, resulting in elevated operating energy consumption and related expenses. Considering that residential structures represent a considerable segment of Turkey's construction inventory, enhancing the thermal efficiency of bricks can significantly diminish national energy usage and carbon emissions. Furthermore, energy efficiency in construction materials corresponds with Turkey's overarching energy policy objectives and international obligations for sustainability and climate change mitigation. The energy consumption of the residential sector significantly contributes to Turkey's total energy demand, and improving the thermal characteristics of bricks can diminish dependence on mechanical heating and cooling systems, which are frequently energy-intensive and expensive for low- and middle-income homes. The implementation of energy-efficient bricks not only conserves energy but also enhances occupant comfort by regulating indoor temperatures and minimizing swings. This is especially crucial in areas such as Istanbul, where seasonal temperature fluctuations necessitate materials that offer both insulation and thermal mass. The research underscores the promise of novel materials like recycled plastic bricks, which exhibit enhanced thermal characteristics relative to conventional clay bricks. These materials are noted for their reduced thermal conductivity, moderate density, and elevated specific heat capacity, allowing them to function as efficient thermal buffers that substantially decrease heating loads while ensuring satisfactory cooling performance. This idea enhances energy efficiency and promotes environmental sustainability through the use of repurposed waste materials.

Aside the core concept of energy efficiency, the demand for affordable and sustainable housing has reached unprecedented levels in recent decades, particularly in rapidly urbanizing regions where population growth, migration, and economic pressures converge to exacerbate housing deficits. According to the United Nations, nearly 3 billion people will require access to adequate housing by 2030, underscoring the urgency of adopting innovative construction materials and methods that are both cost-effective and environmentally responsible [2]. Conventional construction practices, which remain heavily dependent on resource-intensive materials such as cement, fired clay bricks, and steel, contribute significantly to global greenhouse gas emissions, accounting for approximately 37% of energy-related carbon dioxide emissions worldwide [3]. The dual challenge of reducing the environmental impact of the building sector while ensuring the affordability of housing necessitates the exploration of alternative building materials that can deliver high energy performance without escalating costs. Among the potential solutions gaining momentum in recent years is the use of recycled plastic bricks. Globally, plastic waste has emerged as one of the most critical environmental challenges of the 21st century, with over 350 million tons produced annually and less than 10% effectively recycled [4]. Integrating recycled plastics into the construction sector not only provides a pathway for reducing environmental pollution but also offers a potential substitute for traditional masonry units in low- and middle-income housing projects. Several studies have highlighted the advantages of plastic-based construction materials, including their lightweight nature, high durability, moisture resistance, and potential for thermal insulation [5]. However, despite growing interest, there remains a significant gap in understanding how variations in thermal and physical properties across different recycled plastic brick designs affect their real-world energy performance in buildings.

Previous research into the thermal behavior of masonry units has demonstrated that properties such as thermal conductivity, density, and specific heat capacity play decisive roles in determining building energy demand [6]. Traditional Turkish hollow clay bricks, widely used in affordable housing across Turkey and similar contexts, offer moderate thermal insulation but are limited by their relatively high thermal conductivity and susceptibility to moisture ingress. In contrast, plastic bricks offer opportunities to customize these thermal parameters through disparities in composition, geometry, and manufacturing processes. Yet, while scattered case studies exist on the performance of individual plastic brick designs in different countries, comparative analyses that systematically evaluate multiple prototypes under consistent climatic conditions remain scarce. Such analyses are vital for identifying which design attributes most strongly influence energy efficiency and for providing a scientific basis for the commercialization of plastic brick technology. To address this gap, this study conducts a comparative evaluation of seventeen bricks which includes 17 recycled plastic brick prototypes documented in the international literature and two widely used brick types in the Turkish construction industry, all of which were subjected to dynamic energy performance simulations using EnergyPlus through DesignBuilder, calibrated with twenty years of climatic data for Istanbul. Istanbul was selected as a representative context due to its dense urban population, diverse socio-economic composition, and significant reliance on mid-rise residential buildings constructed with hollow clay bricks. The study systematically assesses thermal conductivity, density, specific heat capacity, moisture absorption, compressive strength, and fire resistance, correlating these material properties with simulated energy demand. By doing so, it seeks not only to determine which prototypes outperform conventional Turkish hollow bricks but also to explain *why* certain designs excel while others fall short.

The novelty of this research lies in its property-performance linkage, offering a scientific explanation of the mechanisms through which recycled plastic bricks achieve or fail to achieve superior energy efficiency. Whereas much of the existing literature reports performance outcomes without probing the causal factors, this study emphasizes the material and structural determinants of success, thereby providing actionable insights for both academia and industry. Notably, the analysis identifies two brick prototypes that demonstrate markedly better thermal performance, attributable to their optimal balance of low thermal conductivity, moderate density, and effective heat storage capacity. These findings are particularly relevant to policymakers and developers in Turkey and comparable contexts, where housing affordability and energy efficiency are pressing national concerns.

Beyond its technical contributions, the study also aligns with broader global agendas, including the United Nations Sustainable Development Goals (SDGs), particularly SDG 11 (Sustainable Cities and Communities) and SDG 12 (Responsible Consumption and Production). By valorizing plastic waste into high-performing construction materials, the research supports circular economy principles while addressing the twin challenges of waste management and housing affordability. The implications extend to informing material selection criteria for large-scale housing programs, particularly in regions where resource constraints and environmental pressures necessitate innovative yet practical building solutions. In summary, this paper seeks to expand the discourse on sustainable construction by delivering a comprehensive, property-based analysis of recycled plastic bricks in the context of affordable housing. It argues that while not all plastic bricks are inherently superior to conventional masonry, strategic optimization of thermal and physical properties can produce designs that significantly enhance building energy efficiency. In doing so, it establishes a framework for both academic inquiry and practical implementation, bridging the gap between laboratory research and real-world housing policy. Furthermore, showing that energy efficiency in bricks is a vital consideration in the Turkish residential construction sector due to climatic demands, energy policy objectives, economic factors, and occupant comfort. Advancements in brick materials, particularly through the integration of recycled plastics and optimized composites, present promising pathways to enhance building performance, reduce energy consumption, and support sustainable development goals in Turkey. This contextual foundation underscores the significance of the study's focus on evaluating and simulating the energy performance of various brick types under Turkish climatic conditions.

2. LITERATURE REVIEW

2.1 The global housing challenge and sustainable materials

Sustaining a place requires fostering meaningful connections between individuals and their environment [7] therefore, the priorities of majority should be considered for instance the need of a person for affordable options in housing. The global demand for affordable and sustainable housing has intensified over the past two decades, particularly in rapidly urbanizing regions of Asia, Africa, and Latin America. [8] projects that nearly 96,000 new affordable housing units will be needed daily to accommodate urban population growth by 2030. Traditional masonry units such as fired clay bricks and concrete blocks remain the dominant materials due to their availability and established construction practices. However, their production processes are energy-intensive and environmentally damaging. Clay brick manufacturing, for example, contributes significantly to deforestation and air pollution in South Asia, while cement production is estimated to account for nearly 8% of global CO_2 emissions [3]. This environmental burden has prompted the construction industry to explore alternative materials that minimize both embodied energy and operational energy consumption.

The mismanagement of plastic waste presents an urgent environmental challenge, with the [4] reporting that only 9% of the 353 million tons of plastic generated annually is recycled. Researchers have increasingly investigated the incorporation of plastic waste into construction materials as a dual strategy for addressing housing affordability and environmental sustainability. Studies in India [9] and Nigeria [10] highlight the potential of plastic bricks to reduce material costs while offering enhanced durability and water resistance. Similarly, research in Kenya demonstrated that interlocking plastic bricks reduced construction time and costs by eliminating mortar use while providing competitive compressive strength. Latin American initiatives, particularly in Colombia and Mexico, have shown the feasibility of large-scale applications, where modular plastic brick systems were used to construct low-cost housing for vulnerable communities [11]. These findings collectively suggest that recycled plastic bricks can serve as viable alternatives, but performance varies significantly depending on composition and design.

2.2. Thermal performance of masonry units

Thermal performance is a critical determinant of a building material's contribution to energy efficiency. Parameters such as thermal conductivity, density, and specific heat capacity govern heat transfer through the building envelope, directly influencing cooling and heating loads. [12] demonstrated that walls constructed from materials with lower thermal conductivity reduced cooling energy demand in Indian climates by up to 20%. Similar results were reported in Mediterranean regions, where lightweight bricks with optimized density improved thermal comfort and reduced reliance on mechanical cooling. In Turkey, hollow clay bricks remain the conventional choice for affordable housing due to their moderate insulation properties; however, studies confirm their limitations under increasing cooling demands, particularly in urban centers such as Istanbul. These findings highlight the need for masonry units with superior thermal efficiency, especially as climate change intensifies energy consumption for cooling.

Although a growing body of literature documents the use of recycled plastics in construction, comparative studies focusing on their thermal performance remain limited. Several compared plastic-sand composite bricks with concrete blocks, reporting improved thermal insulation but variable compressive strength. In South Africa, [13] found that PET-based bricks offered lower thermal conductivity but required reinforcement to meet structural safety standards. In India, [9] demonstrated that polypropylene bricks reduced wall U-values by 25% compared to traditional clay bricks, significantly lowering cooling loads in hot climates. Conversely, a study in Brazil cautioned that some plastic bricks, when manufactured with high-density polymer mixes, exhibited higher thermal conductivity than conventional materials, leading to less favorable energy outcomes. These contrasting results underscore the importance of analyzing not only performance outcomes but also the material properties that drive them.

Although the use of plastics in construction raises legitimate concerns particularly regarding the emission of harmful gases during high-temperature processing and the historical environmental burden associated with virgin polymer production these impacts are substantially reduced when recycled plastics are used instead of new materials. Recycling diverts waste from landfills and incineration, reduces demand for fossil-based virgin plastics, and enables the creation of durable building components with lower embodied carbon compared to fired-clay masonry. Studies consistently show that recycled plastic composites can achieve strong mechanical and thermal performance while repurposing waste polymers that would otherwise persist in the environment. In Turkey, while there is currently no large-scale producer of recycled-plastic bricks, existing recyclers such as Birlik Geri Dönüşüm supply LDPE, HDPE, and PP feedstock that could support future brick manufacturing, and local initiatives inspired by global models like Precious Plastic demonstrate the feasibility of small-scale community production [14]. Thus, although environmental risks during processing must be acknowledged, the overall life-cycle benefits of reusing waste plastics such as lower emissions, reduced waste, and affordable low-carbon construction provide a compelling justification for continued research and adoption of recycled-plastic bricks.

The reviewed literature establishes that recycled plastic bricks hold significant potential for contributing to affordable, energy-efficient housing worldwide. However, most studies remain fragmented, often limited to single prototypes or regional case-specific trials without comprehensive, cross-comparative analysis. Furthermore, while previous work confirms that material properties strongly influence building energy performance, little effort has been made to systematically test a wide spectrum of plastic brick designs under uniform climatic conditions. To address this gap, the present study evaluates seventeen recycled plastic brick prototypes, each modeled through dynamic energy simulations using EnergyPlus via DesignBuilder under Istanbul's climatic context. This comprehensive approach enables both broad benchmarking and detailed analysis of performance differences. The findings not only identify which prototypes surpass conventional Turkish hollow clay bricks but also provide property-based explanations for why the best-performing bricks achieved superior results. This dual emphasis on breadth and causal analysis distinguishes the study from existing literature and delivers actionable insights for sustainable housing design and policy.

3. METHODS AND MATERIALS

This study employs a comprehensive, multi-step methodology integrating climate data analysis, material property characterization, building typology selection, and advanced energy simulation to evaluate the thermal performance and energy efficiency of various plastic bricks compared to traditional masonry materials in residential construction. The methodology is designed to ensure robust, replicable, and contextually relevant results for the Istanbul region, specifically the Esenyurt district, within the mild-humid climate zone of Turkey.

3.1 Climate data collection and processing

Accurate climatic inputs are critical for realistic building energy simulations. For this purpose, long-term weather data spanning 20 years (2004–2024) were obtained from the Turkish State Meteorological Service (MGM). The dataset includes monthly averages of key climatic parameters such as ambient temperature, relative humidity, solar radiation, wind speed, cloud cover, precipitation, and the frequency of rain and frost days. These parameters were specifically extracted for Istanbul, classified under Climate Zone 2 (Mild-Humid), which is representative of the study area, Esenyurt. The data were formatted and processed to be compatible with the DesignBuilder/EnergyPlus simulation environment, ensuring temporal consistency and eliminating short-term anomalies to reflect typical climatic pressures on residential buildings.

Table 1. Marmara region- Istanbul. Average data over the past 20 years 2004-2024

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.
Avg daily temp(^{0}c)	6.6	6.9	8.9	12.2	17.0	21.8	24.4	24.8	21.4	16.9	12.8	8.7
Humidity (%)	75%	75%	74%	75%	75%	72%	70%	70%	69%	72%	74%	75%
Wind speed(mph)	12.4	12.5	11.5	9.8	9.1	9.3	11.4	12.5	11.5	11.8	11.9	12.4
Sun hours(hrs.)	4.6	5.6	7.4	9.5	11.0	12.2	12.1	11.0	9.2	6.5	5.2	4.6
Cloud cover (%)	51%	52%	48%	44%	33%	17%	4%	6%	19%	38%	48%	54%
Precipitation(mm)	75	73	67	45	34	24	17	13	39	80	73	97
Rain\Frost days	8	8	8	5	5	3	2	2	4	6	7	10

3.2 Building typology and brick selection and modeling

The study focuses on a U-shaped residential building typology, identified through preliminary analyses as the most energy-efficient form for the local climate. This typology was selected due to its favorable passive design characteristics, including natural ventilation facilitation, self-shading, and optimized surface-area-to-volume ratio. The building model represents a 20-floor structure with a total floor area of approximately 940 m², located in the Zafer neighborhood of Esenyurt. (ZAFER Mah. TONGUÇ BABA Cadde, "gate" Kapı No: 69C). Detailed architectural plans, including site and floor layouts, were developed to accurately represent the spatial configuration and envelope characteristics of the U-shaped form as seen below. Figure 1 and figure 2 below show the spatial arrangement of the U-shaped building, figure 2 shows the site plan and building height.

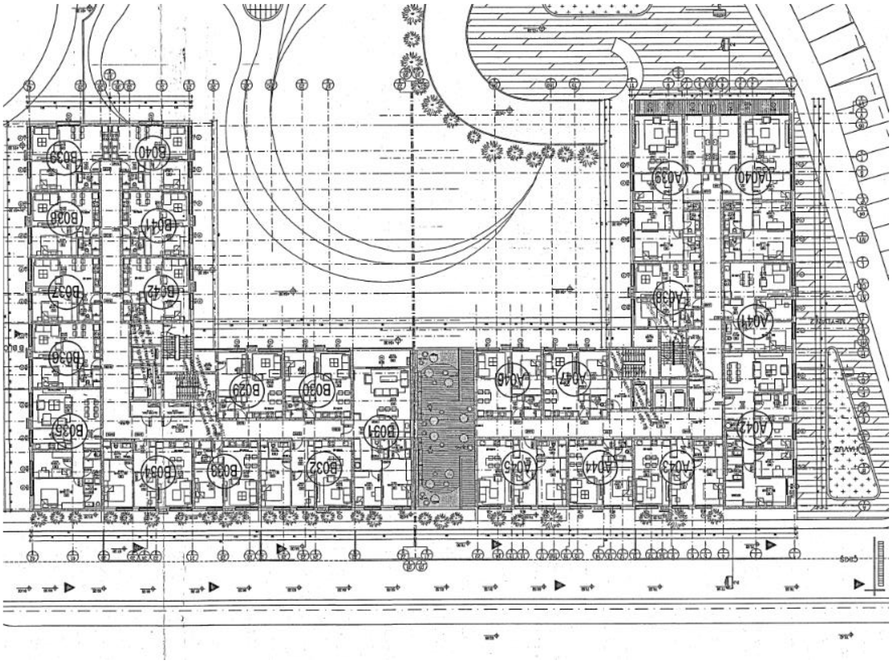

***Figure 1**. Floor Plan showing the U-shaped building used to run the simulation*

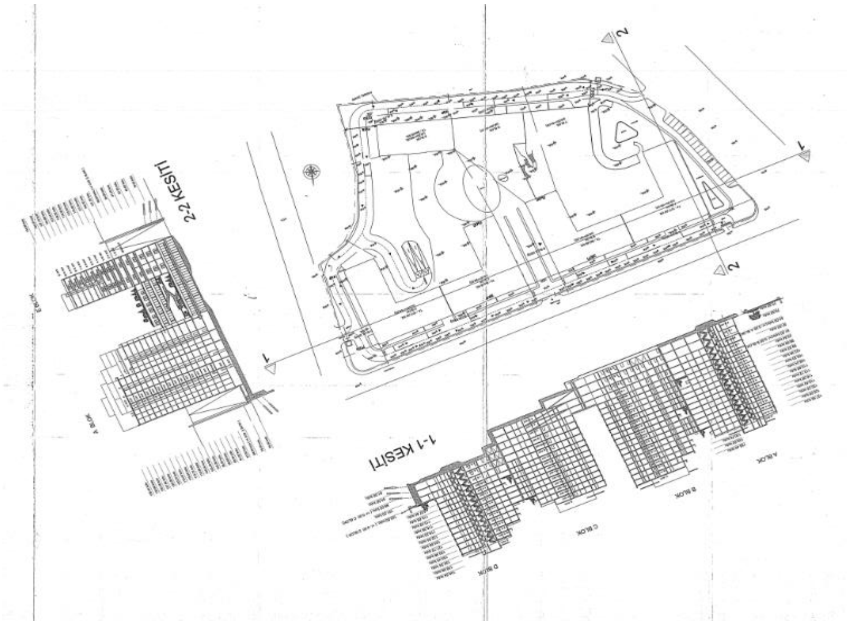

***Figure 2**. Site Plan showing the U-shaped building used to run the simulation*

A critical component of the methodology involved the selection and detailed characterization of 17 types of bricks including 15 plastic bricks sourced from peer-reviewed literature. These bricks vary in polymer composition, filler materials, density, thermal conductivity, specific heat capacity, moisture resistance, fire resistance, and compressive strength. The properties of these bricks were compiled into a comprehensive database to facilitate comparative analysis. The Turkish hollow clay brick and traditional burned clay brick were included as baseline benchmarks due to their widespread use in Turkish residential construction. The characterization data were used to parameterize the building envelope materials in the simulation models Some brick pictures are seen below in the picture table for visual understanding of the tested bricks simulated in the study in figure 3 below:

Sample photographs of some of the bricks included in the simulation testing

Brick name: B2

Brick name: B3

Brick name: B5

***Figure 3**. brick pictures for visual understanding*

3.3 Energy simulation setup and data analysis and performance metrics

Energy performance simulations were conducted using the DesignBuilder interface coupled with the EnergyPlus simulation engine. The U-shaped building model was constructed within the software, with all physical and operational parameters standardized across simulations to isolate the effect of brick material properties on energy demand. The climatic data for Istanbul were applied uniformly to all models. Each brick type was assigned to the external wall construction layer, with its thermal and physical properties inputted according to the compiled database. The simulations calculated annual heating load, cooling load, and total electrical energy consumption for each material scenario.

Simulation outputs were analyzed to quantify the energy savings or penalties associated with each brick type relative to the burned clay brick benchmark. Key performance indicators included total annual electrical energy consumption (kWh), heating load (kWh), and cooling load (kWh). Differences (Δ) and percentage changes (% Δ) were computed to facilitate direct comparison. The analysis emphasized the balance between heating and cooling demands, considering Istanbul's climate where heating predominates. The thermal behavior of bricks was interpreted in terms of their conductivity, density, and specific heat capacity to explain observed energy performance trends.

While direct experimental validation was beyond the scope of this study, the methodology incorporated peer-reviewed material property data and standardized simulation protocols to ensure reliability. Sensitivity to climatic variability was mitigated by using long-term averaged weather data. The choice of a single, well-documented building typology further controlled for architectural variability. Future work may include empirical validation and exploration of additional building forms and climate zones archived in the dataset.

3.3.1 Steps Undertaken to Achieve the Results

1. Seventeen brick types were selected, including fifteen recycled plastic bricks from peer-reviewed literature and two conventional clay-based bricks (Turkish hollow clay and burned clay) used as benchmarks. Relevant physical and thermal properties were extracted and compiled into a unified material database.
2. A U-shaped residential building model was developed in DesignBuilder, with all geometric, operational, and construction parameters standardized except for the external wall material.
3. Long-term averaged climatic data for Istanbul were applied consistently across all simulations.
4. Each brick type was individually assigned to the external wall layer, with material properties input directly from the compiled database.
5. Energy simulations were conducted using the DesignBuilder–EnergyPlus platform to calculate annual heating load, cooling load, and total electrical energy consumption for each scenario.
6. Simulation outputs were analyzed relative to the burned clay brick benchmark by calculating absolute and percentage differences in energy demand. Performance trends were interpreted based on material thermal properties, with emphasis on heating-dominated conditions in Istanbul.

4. RESULTS

4.1 Material properties analysis

This section of the material properties analysis provides an outlined comparison between various plastic bricks and the Turkish hollow brick, focusing on key physical and thermal properties critical for building energy performance. This comparison is based on data compiled from 17 literature studies and summarized in the Tables 2, 3, and 4 below:

Table 2. Brick Properties

Properties	**Turkish hollow brick**	**B1**	**B2**	**B3**	**B4**	**B5**
Type/Name of Brick	Hollow clay brick	polypropylene (PP) waste fibers, fly ash, cement, and M sand.	as PET, HDPE, PP, sometimes mixed with sand, clay, or brick powder.	Sand-Plastic (SP) bricks	Plastic-bonded sand interlocking blocks	Lego-like bricks
Composition Ratio of Brick	60–70% clay, 10–20% silt, 5–15% sand.	Fly ash 40%, M sand 40%, Cement 10%, PP waste 10%	70% PET +sand, clay, or brick powder	25% plastic, 75% sand	plastic waste binder:25% Sand 75%	40% plastic, 60% sand
Density of Brick	800 kg/m³	1665 kg/m³	1660 kg/m³	1998 kg/m³	1600 kg/m³	1640 kg/m³
Thermal Conductivity of Brick	0.38 W/m·K	0.28 W/m·K	0.15-0.4 W/m·K	0.45-0.52 W/m·K	0.3 to 0.5 W/m·K	0.8 and 1.06 W/(m·K)
Specific Heat Capacity of Brick	840 J/kg·K	902 J/kg·K	1200 - 1350 J/kg·K	1900 J/kg·K	1200 J/kg·K	830 to 1720 J/m³K
Thickness/Size/Dimensions of Brick (L.W.H)	13.5x19x29 cm and 19x19x39	230 mm × 110 mm × 90 mm	3D modeling 230 mm × 110 mm × 90 mm	230 mm × 115 mm × 75 mm	356 mm × 152 mm × 127 mm	20 mm (steel mold)
Solar Absorptance of Brick	0.8	Not specified	Not specified	Not specified	0.5 to 0.7	Not specified
Thermal Absorptance of Brick	0.8	Not specified	Not specified	Not specified	0.5 to 0.7	Not specified
Color of Brick	Redish brown	Dark brownish grey	brownish grey	Grey	brownish grey	Grey
Moisture Resistance of Brick	15–20% by weight	7.89%	Very High	High	Very high	Water absorption between 0% and 0.35%
Thermal Diffusivity (α) of Brick	~5.65 × 10^{-7} m²/s	Not specified	Not specified	Not specified	Not specified	Between 0.56 and 1.06 mm²/s
Fire Resistance of Brick	2–4 hours (A1 fire class, non-combustible)	Polypropylene melting point: 160 °C- Ignition point: 590 °C-	Not specified	700 °C, held for 15 minutes	250–300 °C	Operating temp. during production: 200 ± 20 °C
Compressive strength (N/mm²)	3.5N/mm2	16.85	>11.9	133mpa	14.8	38.65 MPa

Source or paper	Site visit	[15]	[16]	[17]	[18]	[19]
Journal	------	Discover Civil Engineering (2024), Volume 1, Article 43	Vojnotehnički Glasnik / Military Technical Courier, 2024, Vol. 72, Issue 3	Journal of Engineering Science and Technology Review, Vol. 13 (2)	Sustainability (2023), Volume 15, Article 16602	Sustainability, 2024, Volume 16, Article 8567
location	Turkey	India	Algeria	India	Ghana	Egypt

Table 3. Brick Properties

Properties	**B6**	**B7**	**B8**	**B9**	**B10**	**B11**
Type/Name of Brick	High-Density Polyethylene (HDPE), quartz sand, and bitumen	Eco-friendly bricks polypropylene (PP) bumper waste mixed with sand and bitumen	Recycled plastic bricks produced from Scrap Plastic Waste (SPW) and Foundry Sand.	Plastic-sand bricks	Eco-friendly plastic sand bricks	Compressed Earth Bricks (CEB)
Composition Ratio of Brick	plastic-to-sand ratio of 3:2 + 2% bitumen	50% PP, 50% sand, 5% bitumen	70% Foundry Sand (FS) and 30% Scrap Plastic Waste (SPW)	60% plastic waste and 2% bitumen+ sand+ fly ash	75% sand:25% plastic with 5% Kaolin	1% shredded waste plastic + soil
Density of Brick	941–967 kg/m^3	1200 to 1600 kg/m^3	2200 to 2400 kg/m^3	1105 kg/m^3	1700 kg/m^3	1710 kg/m^3
Thermal Conductivity of Brick	0.4 to 1.0 W/m·K	0.2 to 0.6 W/m·K	0.15-0.4 W/m·K	0.1-0.22 W/m·K	0.45-0.52 W/m·K	0.15-0.4 W/m·K
Specific Heat Capacity of Brick	1500 J/kg·K	1300 to 1500 J/kg·K	1200 - 1350 J/kg·K	1700-1900 J/kg·K	1900 J/kg·K	1200 - 1350 J/kg·K
Thickness/Size/Dimensions of Brick (L.W.H)	230 mm × 120 mm × 150 mm	210 mm × 100 mm × 75 mm	222 mm length x 106 mm depth x 73 mm	23 cm × 10 cm × 8 cm	190 mm × 90 mm × 50 mm	230 mm × 110 mm × 90 mm
Solar Absorptance of Brick	Not specified	Not specified	Not specified	Not specified	Not specified	Not specified
Thermal Absorptance of Brick	Not specified	Not specified	Not specified	Not specified	Not specified	Not specified
Color of Brick	Not specified	Not specified	Not specified	Brownish Grey	Grey	Brown
Moisture Resistance of Brick	<1% water absorption for all bricks	Water absorption 0.04%	Very High	Water absorption: ranges from 9.1% to 10.7%	High	Moderate
Thermal Diffusivity (α) of Brick	Not specified	Not specified	Not specified	Not specified	Not specified	Not specified

Fire Resistance of Brick	Polypropylene melting point: 130–133°C	melting point of PP 195°C	melting point of PP 220°C	melting point of PP 110°C	Processing temp. of 250°C	Processing temp. of 125°C
Compressive strength (N/mm^2)	37.5 MPa	8.532 MPa	38.14 MPa	11.01 N/mm^2	52.76 MPa	1.54 Mpa
Source or paper	[20]	[21]	[10]	[22]	[13]	[23]
Journal	Journal of Composite Science (J. Compos. Sci.), 2023, Volume 7, Article 111	Chemical Engineering Transactions, Vol. 106, 2023	Case Studies in Construction Materials	IOP Conference Series: Earth and Environmental Science	SPE Polymers, Wiley Periodicals LLC on behalf of Society of Plastics Engineers	Case Studies in Construction Materials
Location	Germany	Malaysia	South Africa	China	South Africa	Nigeria

Table 4. Brick Properties

Properties	**B12**	**B13**	**B14**	**B15**	**B16**	**B17**
Type/Name of Brick	Plastic Fly Ash Brick, Plastic Sand Brick	Alkali-activated mill residue bricks	Eco-brick	Composite brick made from fly ash, recycled plastic resin	Plastic bricks (PBs)	Waste plastic brick
Composition Ratio of Brick	1:5 ratio of plastic to fly ash or sand	Plastic waste 2 wt.% + glass waste 55 wt.%	33.3% PET and 66.6% M-sand	HDPE: 20% PP: 20% Fly ash: 38% Glass powder: 20% Gypsum: 2%	35% plastic waste content mixed with Portland Cement	Waste plastic 50:50 waste foundry sand (WFS)) with plastic blend PET: HDPE: LDPE = 50:25:25
Density of Brick	1990 kg/m^3	1200 to 1600 kg/m^3	1380 kg/m^3	1800 to 2000 kg/m^3	2010 to 3010 kg/cm^3	1600 kg/m^3
Thermal Conductivity of Brick	0.33 W/m·K	0.15-0.4 W/m·K	0.21 W/m·K	0.15 W/m-K	0.45-0.52 W/m·K	0.66 to 0.69 W/m-K
Specific Heat Capacity of Brick	2300 J/kg·K	1200 - 1350 J/kg·K	1000 to 1200 J/kg·K.	1900 J/kg·K	1900 J/kg·K	1100-1200 J/kg·K
Thickness/Size/Dimensions of Brick (L.W.H)	150 mm × 150 mm × 150 mm	115 mm × 110 mm × 76 mm	145 mm × 85 mm × 30 mm	190 mm × 90 mm × 90 mm	241.3 mm × 114.3 mm × 50.8 mm	228 mm x 114 mm x 76 mm
Solar Absorptance of Brick	Not specified	Not specified	Not specified	Not specified	Not specified	Not specified
Thermal Absorptance of Brick	Not specified	Not specified	Not specified	Not specified	Not specified	Not specified
Color of Brick	Grey	Grey	Grey	Dark brownish-black	Grey	Brownish grey
Moisture Resistance of Brick	Water absorption: ranges from 0.727% to 1.033%	Plastic waste increased water absorption ratio due to microstructure degradation	Eco-bricks reported to have low water absorption than PET.	Low porosity of 0.171% = low water absorption	Water Absorption ranged 0.11% to 0.52%, very low	Water Absorption is ten times less than conventional clay fired bricks

Thermal Diffusivity (α) of Brick	Between 0.11 mm²/s - 0.13 mm²/s	Not specified	Not specified	Not specified	Not specified	Not specified
Fire Resistance of Brick	Melting temp at 500°C to 700°C	plastic waste addition increases porosity rather than fire resistance	melting point: 260 °C	Degradation temp. at 127.50 °C to 153.07 °C	High	Melting point 121.3°C
Compressive strength (N/mm²)	5.56 N/mm²	(≥20.7 MPa	14.72 MPa	low porosity, strong bonding = improved strength.	Compressive strength ranges: 4107 to 5167 psi for HDPE bricks.	8.23 MPa
Source or paper	[24]	[25]	[26]	[9]	[27]	[28]
Journal	Revista Matéria, Volume 29, Number 4, 2024	Sustainability	Journal of Building Pathology and Rehabilitation	International Journal on Interactive Design and Manufacturing	Physics and Chemistry of the Earth	Construction and Building Materials, Volume 416, 2024
Location	India	Australia	India	India	Bangladesh, Saudi Arabia	Pakistan

4.1.1 Density

The Turkish hollow brick is characterized by a relatively low density of 800 kg/m³, which contrasts notably with the broader range of densities observed in plastic bricks. [29]. These plastic bricks generally exhibit higher densities, spanning from approximately 941 kg/m³, as seen in Brick 6, to as high as 3010 kg/m³ in B16. The majority of plastic bricks fall within a density range of 1200 to 2000 kg/m³, suggesting that these materials are denser and potentially possess greater thermal mass compared to the Turkish hollow brick. This increased density in plastic bricks can contribute to enhanced thermal inertia, which is beneficial for moderating indoor temperature fluctuations and improving overall energy performance in building envelopes.

4.1.2 Thermal conductivity

The Turkish hollow brick, a commonly used masonry material in Turkey, exhibits a thermal conductivity of 0.38 W/m·K [30]. This value indicates a moderate capacity for heat transfer, which means that while it provides some insulation, it allows a relatively higher rate of heat flow through the building envelope compared to more advanced materials. In contrast, plastic bricks generally demonstrate significantly lower thermal conductivity values, predominantly ranging between 0.15 and 0.52 W/m·K. This range includes some highly efficient examples such as B8, which has an exceptionally low thermal conductivity of around 0.1 W/m·K. Such low thermal conductivity values in plastic bricks are indicative of superior insulation properties, as they effectively reduce the rate of heat transfer through walls, thereby enhancing the building's thermal resistance. Among these, B15 stands out as the most thermally efficient, with a notably low thermal conductivity of 0.165 W/m·K. This low conductivity, combined with its moderate density and high specific heat capacity, enables B15 to act as an excellent thermal buffer, minimizing heat loss during colder months and delaying heat penetration in warmer periods. Overall, the lower thermal conductivity observed in plastic bricks compared to traditional Turkish hollow bricks suggests that these innovative materials can significantly improve insulation performance, contributing to reduced energy consumption for heating and cooling in residential buildings.

4.1.3 Specific heat capacity

The Turkish hollow brick exhibits a specific heat capacity of 840 J/kg·K, [30], which reflects its moderate ability to store thermal energy. This capacity influences how the brick responds to temperature changes, affecting the indoor thermal environment by absorbing and releasing heat at a certain rate. In contrast, plastic bricks generally demonstrate significantly higher specific heat capacities, with values ranging from approximately 900 J/kg·K to as high as 2300 J/kg·K, as exemplified by Brick 12. This elevated specific heat capacity in plastic bricks indicates a superior capability to store thermal energy, enabling these materials to absorb more heat during warmer periods and release it slowly when temperatures drop. Such thermal storage capacity is crucial for moderating indoor temperature fluctuations, as it helps maintain a more stable and comfortable indoor climate by reducing rapid temperature swings. Consequently, buildings constructed with plastic bricks benefit from enhanced thermal inertia, which can lead to reduced reliance on mechanical heating and cooling systems, improving overall energy efficiency and occupant comfort. This distinction in specific heat capacity between traditional Turkish hollow bricks and innovative plastic bricks underscores the potential of plastic composites to deliver improved thermal performance in residential construction.

4.1.4 Moisture resistance

The Turkish hollow brick demonstrates a relatively high moisture absorption rate of 15–20% by weight, which indicates a moderate susceptibility to moisture infiltration [30]. This level of water uptake can lead to potential issues such as material degradation, reduced durability, and compromised thermal performance over time, especially in environments with significant humidity. In contrast, plastic bricks generally exhibit substantially lower water absorption rates, often falling below 1%. For instance, B7 reports an exceptionally low water absorption value of just 0.04%, and some plastic bricks even approach near-zero moisture uptake. This pronounced moisture resistance inherent in plastic bricks is particularly beneficial in humid climates like Istanbul's, where elevated ambient moisture levels can otherwise accelerate deterioration in conventional masonry materials. By minimizing moisture ingress, plastic bricks help maintain their structural integrity and thermal insulation properties, thereby ensuring more consistent and reliable energy performance in residential buildings subjected to such climatic conditions. This advantage underscores the suitability of plastic bricks as a durable and energy-efficient alternative to traditional clay bricks in regions characterized by mild-humid weather patterns.

4.1.5 Fire resistance

The Turkish hollow brick is recognized for its robust fire resistance, being classified as non-combustible under the A1 fire class, with an ability to withstand fire exposure for a duration ranging between 2 to 4 hours [31]. This high level of fire resistance is a significant safety feature, making it a reliable choice in construction where fire safety standards are stringent. In contrast, plastic bricks exhibit a wide range of fire resistance characteristics that are largely dependent on the type of polymer used and the specific composition of the brick. For instance, bricks incorporating polypropylene (PP) demonstrate melting points in the range of approximately 130°C to 220°C. Despite this relatively low melting temperature, some PP-based plastic bricks have ignition points that are considerably higher, with documented values reaching up to 590°C, indicating a capacity to endure elevated temperatures before combustion initiates. Additionally, certain plastic bricks have been tested to withstand temperatures as high as 700°C for short periods, showcasing some resilience under extreme thermal conditions. Nevertheless, it is important to note that, overall, plastic bricks tend to have lower fire resistance compared to traditional clay bricks. This disparity in fire performance is a critical factor to consider in terms of safety and compliance with building codes, as the reduced fire resistance of plastic bricks may limit their applicability in scenarios where stringent fire safety regulations are enforced. These considerations underscore the need for careful evaluation of material properties in the selection of masonry units for construction projects, balancing thermal performance benefits with essential fire safety requirements.

Overall, this comprehensive comparison underscores the potential of plastic bricks to outperform traditional hollow clay bricks in key thermal and moisture-related properties. These improvements are especially relevant for energy-efficient building envelopes in Istanbul's mild-humid climate, where balancing insulation, thermal mass, and moisture control is essential for reducing operational energy consumption and enhancing occupant comfort. The findings suggest that with appropriate formulation and integration, plastic bricks can serve as a viable, sustainable alternative to conventional masonry materials in residential construction. Table 5 below states in detail the energy simulation results for all bricks tested, the table shows in detail the annual energy consumption of all the plastic bricks in relation to the regular how clay brick and a regular burnt clay brick.

Table 5. Energy simulation results by brick type

Material	**Total Elec (kWh)**	**Δ vs BB (kWh)**	**% Δ Elec**	**Heating Load (kWh)**	**Δ Heating vs BB**	**% Δ Elec**	**Cooling Load (kWh)**	**Δ Cooling vs BB**	**% Δ Elec**	**Total % Δ Elec**
Burned brick (BB)	956062.69	0.00	0.00%	549107.62	0.00	0.00%	131495.52	0.00	0.00%	
Turkish Hollow brick	897573.44	-58489.25	-6.12%	485957.49	-63150.13	-11.50%	134695.45	3199.93	2.43%	-15.18%
Brick 1	856649.14	-99413.55	-10.40%	441903.77	-107203.84	-19.52%	136765.26	5269.74	4.01%	-25.91%
Brick 2	861322.90	-94739.79	-9.91%	447980.93	-101126.69	-18.42%	135361.84	3866.31	2.94%	-25.39%
Brick 3	902169.12	-53893.57	-5.64%	494307.38	-54800.24	-9.98%	130333.74	-1161.79	-0.88%	-16.50%
Brick 4	888100.26	-67962.43	-7.11%	476712.32	-72395.30	-13.18%	133859.89	2364.37	1.80%	-18.49%
Brick 5	979975.56	23912.87	2.50%	585106.53	35998.91	6.56%	124378.22	-7117.30	-5.41%	3.64%
Brick 6	921454.76	-34607.93	-3.62%	516537.39	-32570.23	-5.93%	130548.92	-946.60	-0.72%	-10.27%
Brick 7	885173.21	-70889.48	-7.41%	479994.84	-69112.78	-12.59%	130475.26	-1020.27	-0.78%	-20.78%
Brick 8	847622.81	-108439.88	-11.34%	433599.25	-115508.36	-21.04%	135352.02	3856.50	2.93%	-29.45%
Brick 9	889830.66	-66232.03	-6.93%	472984.17	-76123.44	-13.86%	132910.38	1414.86	1.08%	-19.71%
Brick 10	937700.71	-18361.98	-1.92%	525228.39	-23879.23	-4.35%	131361.26	-134.26	-0.10%	-6.37%
Brick 11	844709.09	-111353.60	-11.65%	430659.40	-118448.22	-21.57%	136069.61	4574.09	3.48%	-29.74%
Brick 12	900371.95	-55690.74	-5.83%	491933.67	-57173.95	-10.41%	131259.94	-235.58	-0.18%	-16.42%
Brick 13	921151.02	-34911.67	-3.65%	507075.51	-42032.11	-7.65%	131705.06	209.54	0.16%	-11.15%
Brick 14	880014.14	-76048.55	-7.95%	459388.92	-89718.69	-16.34%	137164.28	5668.76	4.31%	-19.98%

Brick 15	823261.34	-132801.35	-13.89%	405024.19	-144083.43	-26.24%	137126.15	5630.63	4.28%	-35.85%
Brick 16	894959.56	-61103.13	-6.39%	487905.10	-61202.52	-11.15%	129927.86	-1567.66	-1.19%	-18.73%
Brick 17	944586.67	-11476.02	-1.20%	535512.96	-13594.65	-2.48%	131373.17	-122.35	-0.09%	-3.77%

5. DISCUSSION

5.1 Energy performance by brick material

The energy simulation results presented in the table provide a comprehensive comparison of the annual energy performance of 17 plastic brick types against the traditional Turkish hollow clay brick and burned clay brick benchmarks. The analysis reveals significant variations in total electricity consumption, heating load, and cooling load across the different materials, underscoring the potential of plastic bricks as superior alternatives for energy-efficient residential construction in Istanbul’s mild-humid climate. The discussion below is organized into thematic sections to elucidate the performance trends and highlight the best-performing plastic bricks [32].

The burned clay brick (BB) serves as the baseline with total electricity consumption of 956,062.69 kWh annually. The Turkish hollow brick, widely used in Turkey, shows a 15.18% reduction in total energy use compared to BB, primarily driven by an 11.50% decrease in heating load, though with a slight 2.43% increase in cooling demand. This confirms the moderate improvement offered by traditional hollow bricks but also highlights their limitations in thermal insulation and energy savings. In contrast, several plastic bricks demonstrate markedly better performance, with total energy savings ranging from modest to substantial. Notably, nine plastic bricks outperform both Turkish hollow and burned bricks, indicating the promising potential of engineered plastic composites in reducing operational energy consumption in residential buildings.

5.2. Identification of the best-performing plastic brick: b15

B15 emerges as the most energy-efficient material, achieving a 13.89% reduction in total electricity consumption relative to the burned brick benchmark. This is the largest energy saving among all tested bricks. The heating load reduction is particularly impressive at 26.24%, which significantly outweighs the modest 4.28% increase in cooling load. This trade-off is favorable in Istanbul’s climate, where heating demand dominates annually. The superior performance of B15 is attributed to its exceptionally low thermal conductivity (0.165 W/m·K), moderate density (1420 kg/m³), and high specific heat capacity (1900 J/kg·K). These properties enable it to act as an effective thermal buffer, minimizing heat loss in winter and delaying heat gain in summer, thus stabilizing indoor temperatures and reducing reliance on mechanical heating systems [33].

Table 6 below is a comparison between high-performing plastic bricks with significant energy savings and low performance bricks; this comparison is derived from careful observation and comparison of simulation results of all the bricks performance.

Table 6. Comparison of High-Performing (Group 1) and Moderate/Low-Performing (Group 2) Plastic Bricks

Criteria	**Group 1: High-Performing Plastic Bricks**	**Group 2: Moderate–Low-Performing Plastic Bricks**
Included Bricks	B1, B2, B4, B7, B8, B9, B11, B14, B15	All remaining bricks not included in Group 1
Total Energy Savings	6%–12%, with B15 reaching 13.89%	Marginal savings or no improvement; some underperform vs. Turkish clay brick
Heating Load Reduction	Often >20%, especially B8 and B11	Typically low; sometimes minimal or inconsistent
Cooling Demand Behavior	Slight increase or stable cooling loads	Frequently higher cooling demand, indicating poor insulation
Thermal Conductivity	Low: 0.20-0.28 W/m·K	High: >0.30 W/m·K
Specific Heat Capacity	Moderate-High: 1500–2100 J/kg·K	Lower or unstable, depending on porosity/mixing
Density / Mass	Moderate–high → strong thermal inertia	Low–moderate → weak thermal inertia
Material Composition	Recycled HDPE, LDPE, PET, PP + sand/fly ash/quarry dust	Poorer polymer mixing; higher porosity; less optimized fillers
Thermal Behavior	Absorbs & releases heat slowly → stable indoor temperatures	Fast heat transfer → greater temperature swings
Overall Performance Level	Consistently high; strong candidate materials	Moderate to weak; require formulation improvement

The comparison in Table 6 demonstrates a clear distinction between the two performance groups. Group 1 plastic bricks exhibit substantially higher energy efficiency due to their low thermal conductivity, moderate-to-high specific heat capacity, and optimized composite formulations involving recycled thermoplastics and stabilizing fillers. These properties enhance thermal inertia, enabling buildings to maintain more stable indoor temperatures and significantly reduce heating loads often by more than 20%. In contrast, Group 2 bricks deliver only marginal or inconsistent improvements, primarily due to higher thermal conductivity, lower density, and suboptimal polymer mixing, which collectively weaken insulation performance and sometimes increase cooling demand. Overall, the table highlights that only well-engineered plastic composites achieve meaningful energy savings, underscoring the importance of material optimization in the development of alternative masonry units.

5.3 Performance of traditional Turkish bricks

The Turkish hollow clay brick and burned clay brick performed weaker than most plastic bricks in terms of energy efficiency. Their relatively high thermal conductivity (exceeding 0.50 W/m·K) [30] leads to rapid heat loss in winter and heat gain in summer. Additionally, their high density combined with low specific heat capacity limits their ability to buffer indoor temperature fluctuations. Consequently, these traditional bricks result in higher operational energy consumption, with total energy demands nearly 14% greater than the best-performing plastic brick (Brick 15). This performance gap underscores the urgent need for material innovation in Turkish residential construction to meet modern energy efficiency standards.

6. CONCLUSION

This study has rigorously investigated the thermal performance and energy efficiency implications of various plastic brick materials in the context of residential building construction in Istanbul's mild-humid climate. By integrating long-term climatic data sourced from the Turkish State Meteorological Service with advanced energy simulation tools (DesignBuilder/Energy Plus), the research has provided a comprehensive comparative analysis of seventeen plastic brick formulations against traditional Turkish hollow clay bricks and burned clay bricks. The U-shaped building typology, identified as the most energy-efficient form due to its favorable passive design characteristics, served as a consistent architectural model to isolate and evaluate the influence of walling materials on annual heating, cooling, and total energy demands.

The findings demonstrate that several plastic bricks, particularly those incorporating recycled thermoplastics such as PET, HDPE, and PP combined with stabilizing fillers like sand, fly ash, and quarry dust, significantly outperform conventional masonry materials in reducing operational energy consumption. B15 emerged as the most thermally efficient material, achieving a remarkable 13.89% reduction in total energy use relative to the burned brick benchmark, primarily through a 26.24% decrease in heating load. This superior performance is attributed to its optimal balance of low thermal conductivity, moderate density, and high specific heat capacity, which collectively enhance thermal buffering and indoor temperature stability. Other high-performing bricks shared similar material traits, underscoring the critical role of polymer type, composite ratios, and thermal inertia in driving energy savings. Conversely, bricks with higher thermal conductivity, lower density, or incomplete polymer integration exhibited limited or marginal energy benefits, highlighting the importance of precise material engineering to optimize thermal performance. Traditional clay bricks, despite their widespread use, were shown to be the least energy-efficient, reinforcing the urgent need for innovation in building materials to meet contemporary energy and environmental standards.

The implications of this study extend beyond material science into the domains of architectural design, construction practice, and policy formulation. The demonstrated energy savings achievable through the adoption of thermally optimized plastic bricks suggest a paradigm shift in residential building envelope design, particularly in climates with significant heating demands like Istanbul. Architects and engineers should prioritize materials with low thermal conductivity and high heat capacity to enhance passive thermal regulation, reduce reliance on mechanical heating systems, and improve occupant comfort. The U-shaped building form, validated here as an energy-efficient typology, further complements material innovations by facilitating natural ventilation and solar control.

From a policy perspective, these results advocate for the integration of recycled plastic bricks into national building codes and energy efficiency standards. Incentivizing the use of such sustainable materials can reduce the environmental footprint of the construction sector, lower household energy costs, and contribute to circular economy goals by valorizing plastic waste streams. Moreover, targeted subsidies, research funding, and public awareness campaigns could accelerate market adoption and stimulate local manufacturing capabilities, fostering economic and environmental resilience. In conclusion, this research substantiates that intelligently engineered recycled plastic bricks represent a viable and superior alternative to traditional masonry materials in residential construction. Their adoption promises substantial energy savings, enhanced thermal comfort, and alignment with sustainable development objectives. Future work should explore lifecycle assessments, long-term durability, and scalability to fully realize the transformative potential of these innovative building materials in Turkey and comparable climatic regions.

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