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Isı Yalıtımının Kritik Rolünün Ortaya Çıkarılması: Yalıtım Kalınlığının Azalan Marjinal Fayda Etkisi

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Öne Çıkarılanlar:

1. Yalıtım malzemesinin ilk 1 cm kalınlığında uygulanması, ısı kaybını % 26.87 azaltmaktadır.
2. Yalıtımı artırmak ısı kayıplarını azaltsa da; kalınlık arttıkça marjinal fayda azaldığından, optimum yalıtım kalınlığını tespit edebilmek için ekonomik analiz de yapılmalıdır.
3. İç ve dış sıvanın ısı kaybına etkisi son derece sınırlıdır.
4. Tuğla en kalın boyutunun kullanılması ile en ince boyutunun, duvar kalınlığını belirleyecek şekilde kullanılması arasında, ısı kaybında maksimum %11.2 fark bulunmaktadır.

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Amaç:
Bu çalışma, farklı katmanlardan oluşan bina duvar kalınlıklarının ısı transferi üzerindeki etkilerini incelemeyi amaçlamaktadır. En sık kullanılan iç sıva, tuğla, yalıtım malzemesi ve dış sıva olmak üzere dört katmandan oluşan modelde, termal kayıplar analiz edilerek karşılaştırıldı. Analizde bütün katmanların ısı kaybına etkisinin karşılaştırılması ve yalıtım malzemesinin marjinal faydasının belirlenmesi amaçlandı.

Metot:
Çalışmada en sık kullanılan, iç sıva, tuğla, yalıtım malzemesi (EPS) ve dış sıva olmak üzere, TS825 standardına uygun dört katmandan oluşan bir model analizler edilmiştir. İç ve dış sıva kalınlıklarının 0.01-0.05 m, tuğla kalınlığının 0.09 m, 0.19 m ve 0.135 m, EPS türü yalıtım kalınlığının ise 0 – 0.2 m arasında değiştiği göz önüne alınarak ısı kayıpları hesaplanarak karşılaştırılmıştır.

Sonuç:
Bulgular, EPS yalıtım malzemesinin haricindeki duvar katmanlarının kalınlaştırılmasının ısı kaybını önlemek için önemli bir katkı sağlamadığını ortaya koydu. 20 cm lik EPS malzemesinin uygulanmasıyla yalıtımsız bir duvarın ısı kaybını %86 oranında azalttığı hesaplandı. Bununla birlikte, sıva kalınlığındaki artışın ısı kaybını etkilemediği, tuğlanın en uzun ölçüsünü duvar kalınlığı olacak şekilde kullanmanın ise en kısa ölçüsünü kullanmaya göre %11.2 oranında bir iyileşme sağladığı tespit edilmiştir. Çalışmanın sonuçları, yalıtım malzemesi kalınlık artışının ısı kaybını azalttığı ancak marjinal faydasının da azaldığını, bu yüzden en uygun yalıtım kalınlığına karar verirken ekonomik analiz de yapılması gerektiği sonucuna ulaşılmıştır.

Anahtar Kelimeler: Duvar kalınlığı, Isı Yalıtımı, Bina enerji performansı, Duvardan ısı kaybı, Yalıtım etkisi, Sıfır Enerji Binalar

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Short Communication

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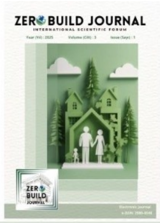

Unveiling the Critical Role of Thermal Insulation: The Diminishing Marginal Benefit Effect of Insulation Thickness

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Highlights:

1. The first cm of EPS insulation reduces the thermal loss from a wall by 26.87%.
2. Increasing insulation thickness reduces heat loss; however, the marginal benefit decreases as the thickness increases. This diminishing return highlights the need for economic analysis to determine the optimal insulation thickness.
3. Increasing Inner and Outer plaster has a negligible effect on the heat losses of an insulated of a wall
4. There is a maximum difference of 11% between using the thickest dimension of the brick and using its thinnest dimension to determine the wall thickness

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Abstract

This study investigates the effects of thickness variations in different layers of building walls on heat transfer. A four-layered wall model, consisting of interior plaster, perforated brick, expanded polystyrene (EPS) insulation material, and cement-based exterior plaster, was analyzed in compliance with the TS825 standard. By systematically increasing the thickness of each layer, the impact on the total heat loss of the wall was evaluated analytically. The results indicate that plaster layers had negligible effects on heat loss, while increasing the thickness of the perforated brick reduced heat loss by up to 11.2%. However, the most significant reductions in heat loss were achieved by increasing the thickness of the EPS insulation layer. Notably, this reduction follows a diminishing marginal benefit pattern, where the initial increases in insulation thickness yield substantial energy savings, but further increases provide progressively smaller benefits.

These findings highlight that insulation thickness cannot be the sole consideration in optimizing building energy efficiency. Economic analysis is also essential to determine the optimal insulation thickness, ensuring both energy efficiency and cost-effectiveness. This study provides valuable insights for sustainable building design, particularly for projects with limited budgets.

Keywords: Wall thickness, thermal insulation, building energy performance, heat loss through walls, insulation effect, Zero Energy Buildings

1. Introduction

The increasing awareness of the climate crisis caused by greenhouse gas emissions from fossil fuels, combined with the slow adoption of renewable energy sources, and has heightened the focus on energy efficiency [1] and zero energy buildings. Among the three major energy consumption sectors—industry, transport, and buildings—the building sector attracts significant attention due to its potential for energy savings, especially in construction and use phases [2, 3]. In Turkey, residential buildings account for 35% of energy consumption, with 80% of this used for heating and cooling [4, 5]. Therefore, improving insulation has a significant impact on energy efficiency and reducing the carbon footprint [6].

Thermal insulation, one of the most widely studied methods, minimizes heat losses through the exterior facades, roofs, floors, and other building components [7]. In Turkey, insulation thicknesses range from 2.8 cm to 9.6 cm, necessitating detailed calculations to determine optimum thickness [8]. Research indicates that applying the appropriate insulation thickness can reduce CO_2 emissions by 50% in cold climates [9]. Heat losses in buildings vary by architectural design but generally occur predominantly from external walls (40% in multi-storey buildings and 25% in single-storey houses), windows, roofs, and air leaks [10].

Heat losses primarily arise through the building envelope, including walls, windows, and thermal bridges, and may occur via direct transfer or through gaps in materials [11]. Studies show that insulated walls significantly reduce heat losses. For example, analysis of mezzanine floors with balcony extensions found that uninsulated walls had 85% higher heat loss compared to insulated walls with 5 cm insulation thickness [12]. Increasing wall thickness further enhances energy efficiency and interior comfort by mitigating outdoor influences [13].

Many studies explore the relationship between insulation material thickness and thermal conductivity. For instance, in Malaysia's hot and humid climate, non-linear polynomial models were developed to describe this relationship for materials like fiberglass and extruded polystyrene [14]. Research in Turkey shows that the optimum insulation thickness varies between 0.036 m and 0.1 m depending on climate and material type, with energy savings of up to 76.8% using expanded polystyrene (EPS) [15, 16]. Comparative analyses of insulated and uninsulated conditions demonstrate significant reductions in energy requirements and heat loss with insulation [17]. In Ankara, rock wool with aerated concrete walls and glass wool with brick walls yielded the lowest and highest optimum insulation thicknesses, respectively [18]. However, studies also reveal diminishing returns when continuously increasing EPS board thickness [19].

In this study, the authors aimed to determine the rate of heat loss prevention utilizing insulation and the marginal benefit of insulation. The investigation analyzed the effect of individual layer thicknesses—interior plaster, brick, insulation material, and exterior plaster—on heat transfer in a multi-layered building wall, considering conduction and convection mechanisms. The study theoretically presents the marginal benefit analysis of increasing insulation thickness and demonstrates how maximum energy savings can be achieved with limited budgets. The "Diminishing Marginal Benefit" expressed in the study aligns with the physical principles of insulation; however, it emphasizes the necessity of conducting thermodynamic analysis in conjunction with economic analysis.

2. Material and Method

Within the scope of the study, the heat losses of the four-layer wall model shown in Figure 1 are analyzed to represent an ordinary building wall in accordance with TS825 standard. In the analyses, the effect of the extra thickened wall layer on the heat loss was calculated by thickening each wall layer and keeping the thicknesses of the other wall layers constant. In the case of increasing the thickness of the internal and external plaster from 0.01 m to 0.05 m, obtaining 3 different brick wall thicknesses by placing the perforated brick in all 3 dimentions and thickening the EPS insulation material from 0.03 m to 0.09 m, the heat losses from the wall were calculated and compared separately.

Table 1 presents the thickness ranges, heat transmission coefficients, and densities of the materials used [20]. These materials are utilized in building walls because each contributes significantly to protecting the structure from various external factors. Consequently, this wall model and its components, identified as the most commonly used wall model within the scope of this study, were taken into consideration.

The method used in this study is explained in detail in heat transfer textbooks, which also include numerous examples on the subject. Within the scope of this study, the aim was to compare the effects of thickening each layer on the building's heat loss and to determine the impact ratios.

3. Results and Discussion

In this study, the effect of various materials comprising a wall on heat loss was examined through analytical calculations for different wall layer thicknesses. The results indicate that layer other than the insulation material (EPS) have no significant effect on preventing heat loss, while EPS becomes more beneficial as its thickness increases. However, the benefit increment diminishes with increasing thickness.

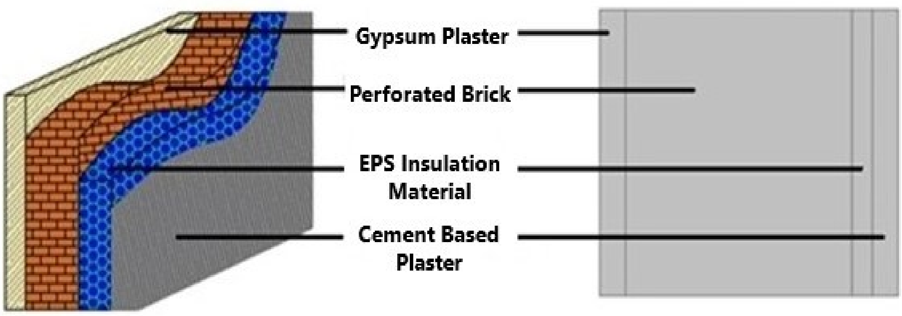

Figure 1. Four-layer wall model

Table 1. Table of Wall Materials and Thickness Changes

Material	Thickness Range (m)	Heat Transmission Coefficient (k) (W/m.K)
Gypsum Plaster	0.01 - 0.05	0,70 W/m.K
Perforated Brick	0.09 / 0.19 / 0.135 (3 settlements)	0.45 W/m.K
EPS (Polystyrene)	0.03 - 0.09	0.05 W/m.K
Cement Based Plaster	0.01 - 0.05	1.6 W/m.K

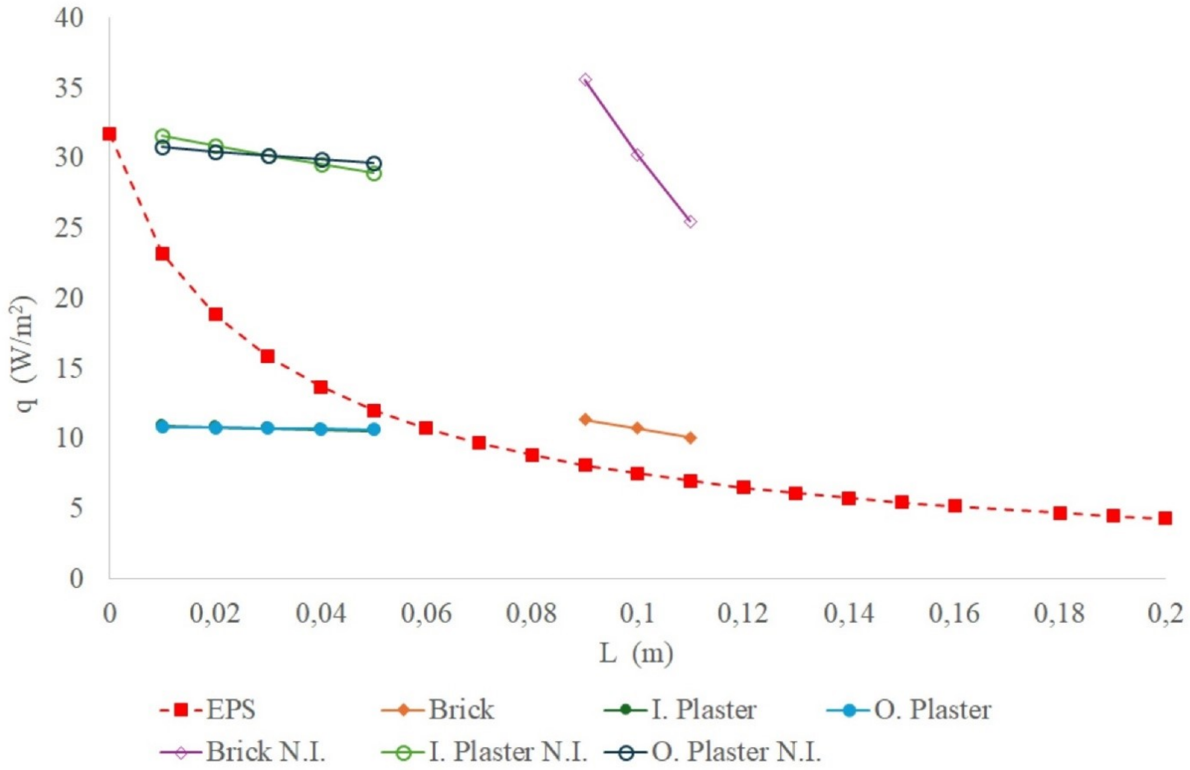

Figure 2. Effect of Different Wall Layer Thicknesses on Heat Transfer.

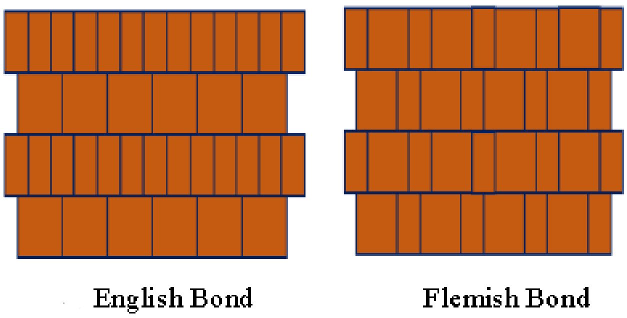

Figure 3. English and Flemish Bond [21].

In Figure 2, the red line represents EPS insulation material, "I. Plaster" denotes interior plaster, "O. Plaster" represents outer plaster, and the letters "N.I." indicate "Not-insulated." The interior and exterior plasters, whether insulated or not, provide only a very limited reduction in heat loss. The curves on the right represent changes in brick thickness. The relationship between brick thickness variation and heat loss is shown on the right side of the figure for both insulated and non-insulated wall configurations. It is observed that increasing the brick thickness alone has an effect on energy savings in a non-insulated wall. But its effect on an insulated wall is negligible.

However, it has been reported that not only the thickness of the brick used but also factors such as brick type, mortar, layout and wall structure affect the thermal insulation performance of the wall [22]. Different brick layouts can affect thermal insulation in different ways by changing the amount and distribution of air voids within the wall. For example, brick layouts such as English and Flemish bond (Figure 3) can improve thermal insulation at different rates by changing the internal structure of the wall [23]. However, ultimately, although the air layer within the perforated brick has a slightly positive effect on insulation, it can never replace proper insulation.

Figure 2 also highlights the dramatic reduction in heat loss observed with the change in EPS insulation thickness, as indicated by the red dashed line. In the non-insulated case, the heat loss from the wall is 31.74 W/m², while adding the first 1 cm of EPS insulation reduces heat loss to 26.87 W/m², corresponding to a 26.87% decrease. This demonstrates the critical impact of the initial thickness of insulation material on energy efficiency. However, as the thickness increases, the diminishing marginal benefit effect becomes apparent. For instance, increasing the insulation thickness from 19 cm to 20 cm reduces heat loss from 4.48 W/m² to 4.29 W/m², corresponding to only a 4.29% decrease. Comparing the non-insulated wall with a wall insulated with 20 cm of EPS reveals an 86% reduction in total heat loss. However, the marginal benefit of insulation continues to decrease steadily.

An important finding is that the first centimeter of EPS insulation thickness is critical for energy efficiency. While the initial 1 cm of EPS reduces total heat loss by 26.87%, the effect of each subsequent 1 cm decrease in heat loss diminishes. This demonstrates that increasing insulation material thickness exhibits diminishing marginal benefit, underscoring the importance of the concept of optimal insulation thickness. Energy efficiency and cost-effectiveness analyses can serve as critical guides, particularly for applications aiming to achieve energy savings on limited budgets. The dramatic benefit observed in the first centimeters of insulation can serve as a strategic starting point for achieving maximum energy savings with minimal budgets during insulation design. However, maintaining the insulation material thickness at an optimal level is crucial for both economic and environmental sustainability. In this context, insulation thickness design should consider not only energy savings but also cost-effectiveness.

4. Conclusion

The first 1 cm of EPS insulation reduces heat loss by approximately 26.87%, underlining its critical role in achieving energy efficiency. However, as the insulation thickness increases, the marginal benefit diminishes, as seen with the reduction in heat loss from 19 cm to 20 cm, which was limited to 4.29%. This diminishing return effect highlights the importance of determining an optimal insulation thickness that balances energy efficiency with cost-effectiveness.

Moreover, the air layer within perforated bricks, while contributing marginally to insulation, cannot substitute for proper insulation materials. These findings emphasize that for sustainable and cost-effective building designs, prioritizing insulation material and optimizing its thickness is essential. Such an approach is particularly valuable for projects with limited budgets, where maximum energy savings can be achieved through strategic initial investments in insulation.

In conclusion, incorporating insulation material with an optimal thickness not only enhances energy efficiency but also supports economic and environmental sustainability in construction practices.

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