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THERMAL CONDUCTIVITY OF LIGHTWEIGHT SOLID BRICKS MADE FROM WASTE MIXTURES AND ITS IMPACT ON BUILDING ENERGY EFFICIENCY

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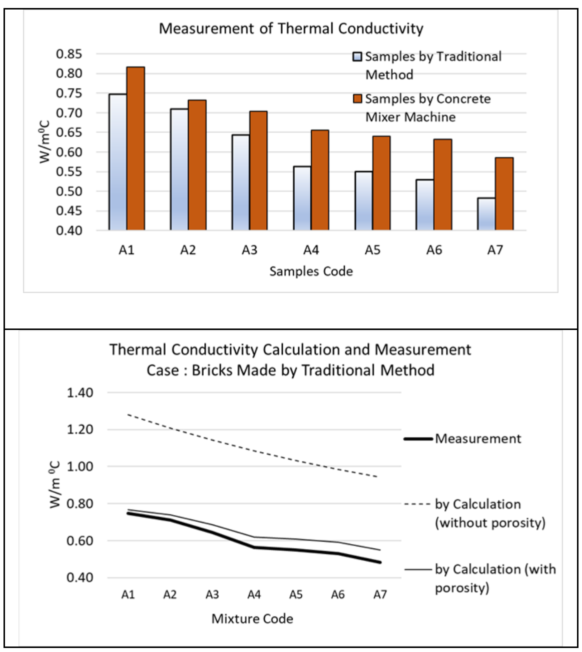
Graphical abstract



Abstract

This study investigates the thermal conductivity of lightweight solid bricks made from waste mixtures and evaluates their impact on building energy efficiency. The waste materials used in the brick mixtures include plastic, paper, rice husks, wood shavings, and coconut fibers, with cement and sand as primary components. Seven variations of these mixtures were analyzed, and thermal conductivity measurements were conducted using a Quick Thermal Conductivity Meter, supplemented by theoretical calculations based on the general heat transfer equation. The study also applied the Overall Thermal Transfer Value (OTTV) method to assess the bricks' contribution to energy efficiency, incorporating them into cube-shaped and office building models. The results reveal that the thermal conductivity of the bricks ranges from 0.48 to 0.82 W/m°C, with porosity values between 12% and 26%. Compared to conventional bricks, those incorporating waste materials demonstrate a modest improvement in energy efficiency, reducing the OTTV by 5% to 13% in cube-shaped models and by 0.2% to 0.69% in office buildings. These findings suggest that while the bricks made from waste mixtures provide some benefits in terms of energy efficiency, further optimization of the material composition is necessary to achieve more substantial improvements.

Keywords: bricks, waste, thermal conductivity, energy, building

1.0 INTRODUCTION

The urgent need to address global warming and its associated environmental challenges has driven global efforts toward sustainable development. One widely accepted strategy in this endeavor is adopting sustainable development models, which emphasize environmentally friendly practices across various sectors. This approach is often conceptualized under green development, a framework that harmonizes economic growth with environmental preservation. Green development spans multiple sectors, including green industry, green transportation, green buildings, and the green economy, each contributing to a comprehensive strategy for reducing environmental impact and promoting sustainability. In the construction industry, green buildings have gained prominence as part of the broader green development initiative. Green buildings are designed to minimize resource consumption and reduce the environmental footprint associated with construction and operation. They achieve this by incorporating sustainable materials, utilizing renewable energy, optimizing water use, and reducing waste. Given its significant impact on energy consumption and resource depletion, the construction sector's contribution to sustainable development is critical. Integrating green materials and energy-efficient building designs is essential for achieving long-term sustainability goals. Several recent authors have highlighted that green building focuses on the creation of environmentally friendly and sustainable resources by optimizing the use of energy, materials, water, and land, while also minimizing waste [2,7,12, 26, 32,33, 48].

A key component of green building design is the building envelope, consisting of transparent elements (e.g., windows and skylights) and opaque elements (e.g., walls, roofs, and floors). In tropical climates, the building envelope is particularly crucial in mitigating the effects of excessive solar heat gain. Reducing the amount of heat entering the building directly influences the energy required for air conditioning and cooling. Therefore, improving the thermal performance of the building envelope can significantly enhance a building's energy efficiency, contributing to lower energy consumption and reduced carbon emissions [1,14,19]. One of the primary focuses of this study is the use of lightweight concrete bricks made from waste materials, which can serve as an energy-efficient solution for building envelopes in tropical climates. Traditional bricks, such as red fired bricks, have been widely used in construction but come with certain environmental drawbacks, such as high carbon emissions during the firing process and the depletion of natural resources like clay. Additionally, red fired bricks tend to have lower thermal conductivity compared to newer materials, which can contribute to increased indoor temperatures in warm climates, thus raising the energy demands for air conditioning.

In contrast, lightweight concrete bricks made from a mixture of cement, sand, and various waste materials offer a potential solution to these challenges. By incorporating waste materials such as plastic, paper, rice husks, wood shavings, and coconut fibers, these bricks reduce the need for raw materials and address the growing problem of urban waste accumulation. Utilizing waste materials in brick production is aligned with the principles of green development, contributing to waste reduction and environmental sustainability improvement. Moreover, the inclusion of these materials has the potential to alter the thermal properties of the bricks, improving their capacity to resist heat transfer and thus enhancing the overall energy efficiency of the buildings in which they are used.. In developing countries like Indonesia, lightweight concrete bricks are often produced by small-scale enterprises or household businesses. These traditional production methods, while cost-effective, may not always meet the desired standards for strength and thermal performance. Typically, lightweight bricks produced in this way have a density below 1800 kg/m³ [44] and a compressive strength of around 27 kg/cm² [4], which can result in higher thermal conductivity than red-fired bricks. This increased thermal conductivity can lead to higher indoor temperatures, exacerbating energy demands in tropical climates. Given these challenges, there is a clear need for research into the thermal properties of bricks made from various organic and inorganic waste materials to better understand their potential for improving energy efficiency in green buildings.

This study focuses on the thermal conductivity of lightweight concrete bricks made from waste mixtures [30]. and their impact on buildings' overall Thermal Transfer Value (OTTV). The OTTV is a widely recognized performance metric used to evaluate the energy efficiency of a building envelope by measuring the average heat gain transmitted into a building [6, 8, 24, 49]. In tropical climates, where solar heat gain is particularly high, controlling the OTTV is essential for reducing energy consumption related to air conditioning [16,46]. According to Indonesia's national standards for energy-efficient buildings, the OTTV should not exceed 35 W/m² to ensure optimal energy performance. Other tropical countries, such as Singapore, Malaysia, and the Philippines, also adhere to similar OTTV standards in their efforts to promote energy-efficient building designs.. Currently, red fired bricks are frequently being replaced by lightweight concrete bricks. However, this substitution poses challenges, as lightweight concrete bricks made from sand and cement exhibit higher thermal conductivity than red fired bricks, leading to increased energy consumption for air conditioning. In practice, both fired and lightweight concrete bricks can be produced by incorporating organic and inorganic wastes and cement, clay, sand, and other materials. This raises important questions about the thermal properties of these alternative materials. Bricks made from a combination of organic and inorganic waste must possess specific thermal properties to support green building objectives. These properties include low thermal conductivity and the ability to resist heat transfer from the outside to the inside. Therefore, the materials' thermal conductivity, density, and specific heat capacity are critical in reducing heat flow.Inorganic waste, such as plastics, does not naturally decompose in the environment. Therefore, additional processing is required to prevent environmental pollution, aligning with the principles of sustainable development [18, 20, 22]. Incorporating inorganic waste into building material mixtures is an effective way to reduce urban waste accumulation [5, 9, 11, 21].

A study by Ramos et al. [38] demonstrated that eco-friendly clay (fired) bricks made with organic waste improve thermal insulation, reduce bulk density, and increase porosity. However, few authors have focused on the thermal properties of lightweight or unfired bricks made from waste mixtures [45] , as most studies primarily explore the strength properties of bricks incorporating waste materials [3,16,37,43,47].

[6, 8, 24, 49] The main objectives of this study are to (1) investigate the thermal properties of lightweight concrete bricks made from different compositions of organic and inorganic waste materials, and (2) assess their impact on building energy efficiency using the OTTV method. By doing so, we aim to contribute to the development of sustainable building materials that can reduce the energy demands of buildings in tropical climates. The results of this study will provide valuable insights into the potential for waste-composite bricks to serve as an environmentally friendly, energy-efficient alternative to conventional building materials, thereby supporting the broader goals of green development and sustainable construction.The novelty of this study lies in the combination of organic and inorganic waste materials in brick production and the comprehensive analysis of their thermal properties. While many studies have focused on the strength and structural properties of bricks made from waste materials, few have examined their thermal behavior, particularly in the context of lightweight concrete bricks. The use of waste materials such as plastic and coconut fibers, which are difficult to decompose and contribute to environmental pollution, presents an innovative solution for both waste management and energy-efficient construction. By analyzing the thermal conductivity of these waste-composite bricks, this study aims to determine their effectiveness in reducing heat transfer and improving the energy efficiency of buildings.

2.0 METHODOLOGY

The flowchart illustrates the research process as shown in Figure 1. It begins with the preparation of making light concrete bricks using a waste mixture, followed by the mixing and molding of the bricks. Subsequently, the process involves measurements, calculations, and analysis.

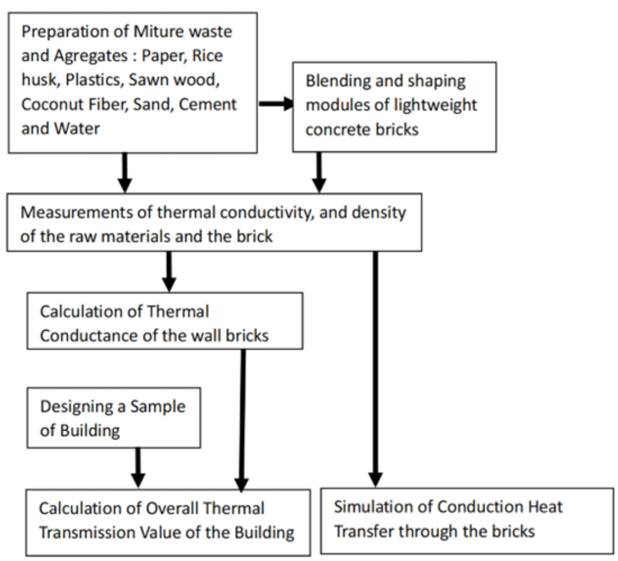


Figure 1 Flowchart of the research

An experiment was conducted at the Architecture Engineering Laboratory in the Faculty of Engineering at Sam Ratulangi University to test the thermal properties of lightweight concrete bricks' with mixed organic and inorganic waste. The wastes include paper, rice husk, plastics, sawn wood/ shaving wood and coconut fiber (Figure 2). A quick thermal conductivity meter (QTM-710 by KEM) and balance were used to measure the thermal conductivity and density of the bricks.

The rice husk waste should be crushed, pounded, or cut into pieces using a crusher or cutter. Similarly, paper waste, plastic waste, and sawn wood/ wood shavings waste undergo the same treatment process. The coconut coir is retained in the form of coco-fiber with a length ranging from approximately 5 to 10 cm.

The aggregates were blended according to the composition outlined in Table 1. The mixing and sample-making process consists of two types: traditional manual method and using machines. In the traditional method, the samples are molded into the size of (10 x 20 x 40) cm3, similar to bricks produced by household or small-scale industries. The other type involves mixing using a concrete mixer machine, then molded into cubes with dimensions of (15 x 15 x 15) cm3. All samples are left to harden for 22 days before measurements are taken.

The Indonesian Ministry of Public Works standard specifies that the mixture for bricks meeting strength criteria consists of 75 % sand, 20 % cement, and 5% water [15]. The study by Prasetyo (2005) [35], which experimented with a light concrete brick mixture having a cement-to-sand ratio of 1:12, or approximately 8% cement, indicates that its strength still meets the Indonesian standards for use as a non-load-bearing wall. This study created a composition with only 15 % cement, 60 % to 30 % sand, and the remaining portion were waste materials (Table 1).

Table 1 Sample Code and Composition of Raw Materials

Raw materials	Composition of Aggregate of the samples (in %)						
	A1	A2	A3	A4	A5	A6	A7
Sand	60	55	50	45	40	35	30
Cement	15	15	15	15	15	15	15
Coconut Coir	5	10	15	20	25	30	35
Rice husk	5	5	5	5	5	5	5
Paper	5	5	5	5	5	5	5
sawn wood waste	5	5	5	5	5	5	5
Plastic	5	5	5	5	5	5	5
Total	100	100	100	100	100	100	100

The percentage of sand is varied from 60% in sample A1 to 30% in sample A7, while the percentage of coconut coir increases from 5% in A1 to 35% in A7. This progressive variation in both materials is designed to investigate their effects on thermal conductivity and the insulation properties of the bricks. The reduction in sand, which generally has higher thermal conductivity, and the corresponding increase in coconut coir, known for its insulating properties, are expected to enhance the thermal performance of the bricks.

The thermal conductivity of the samples were obtained through both measurements and calculations. Subsequently, a comparison were made between the calculated and measured results. The measurements of the samples were conducted using the Quick Thermal Conductivity Meter (QTM-710) device, where 5 points were measured for each lightweight brick sample, and the final result is obtained by averaging (Figure 3).

The thermal conductivity measurements were extend to the aggregate materials, including wastes, cement, and sand. This was done to gather input data necessary for estimating the thermal conductivity of bricks that incorporate mixed waste materials with various compositions. This comprehensive approach ensures a thorough understanding of how the different components contribute to the overall thermal conductivity of the bricks.

Figure 2 The raw materials, mixing process, and the samples produced

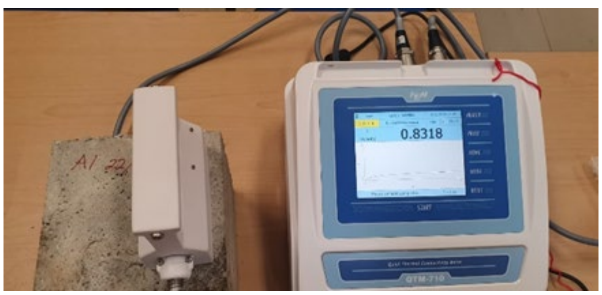


Figure 3 Testing process

The estimation of the thermal conductivity of the bricks was conducted through analogical approaches, considering the thermal conductance of a multilayer or composite brick. In this analogy, the layers represent the raw materials (Figure 4). The thermal conductance of a multilayer brick can be then calculated. As the thermal conductivity of each raw material is known from measurements, the thermal resistance can be estimated by introducing an equivalent thickness for each layer (as per Eq.1) based on the percentage of raw material in the composition (refer to Table 2). The thickness values for each component can then be determined using a simple equation. as follows:

$$d_n = L \times C_n \quad \text{(Eq.1)}$$

Where *d* is the thickness of each component of the raw material, *L* is the thickness of the brick (10 cm), and *C* is the percentage of the composition of the raw material in the brick (Table 1). The value of d of each raw material is shown in Table 2.

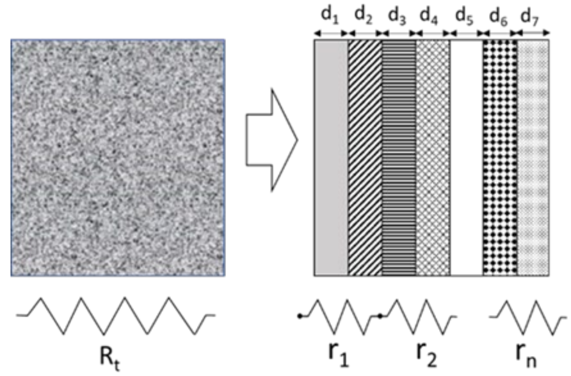


Figure 4 Analogical resistance of a solid mixture as a multilayer of composite brick

Estimation of the thermal conductivity of a composite brick can be conducted by general analogical equation as follows [36]:

$$r_n = \frac{d_n}{k_n} \quad \text{(Eq.2)}$$

$$r_t = r_1 + r_2 + \cdots r_n \quad \text{(Eq.3)}$$

$$k_t = \frac{1}{r_t} \quad \text{(Eq.4)}$$

Where k_n is each raw material's thermal conductivity, r_n is the thermal resistance of the raw material, and d is its thickness of each layer of the raw material.

The results of the calculations using the theoretical approach were then compared to the measurement results. Differences will be present, and this is normal because there is a possibility of the influence of factors such as porosity or air bubbles within the brick, due to the fabrication process, resulting in imperfect compaction. Calculations have also been performed in the same manner to determine the percentage of porosity or the presence of air pores in the bricks, namely by assuming the existence of an air layer in the electrical analogy equation.

In the next stage, calculations were carried out to determine the Overall Thermal Transfer Value (OTTV) for a building model, aiming to assess the contribution of this brick to the energy efficiency of building. The OTTV formula is as follows: [24, 28, 49,50].

$$OTTV = \alpha[(1 - WWR) \times U_W]T_{Deq} + (WWR \times U_f \times \Delta T) + (WWR \times SC \times SF) \quad \text{(Eq.5)}$$

Where α is the thermal absorption coefficient of the wall surface, WWR is the Window Wall Ratio, U_W is the thermal conductance of the opaque wall, T_{Deq} is the temperature difference between outdoor and indoor for the opaque wall system (according to the National Standard of Indonesia SNI-6389:2020, the value of T_{Deq} depends on the weight characteristic of the wall), U_f is the thermal conductance of the glass/transparent window, ΔT is the temperature difference between outdoor and indoor for the glass window system (according to the National Standard of Indonesia SNI-6389:2020, the value of ΔT is set 5°C), SC is the Shading Coefficient of the fenêtre system, and SF is the Solar Factor on the façade. In this case, the Solar Factor magnitude refers to the SF of Manado City, Indonesia, where its value is specified in the SNI-6389:2020.

In order to determine the extent of the influence of bricks on the energy efficiency of a building, it is necessary to create scenarios for calculation of OTTV, with two cases. The first case involves a cubic structure, with all walls made of brick from waste, measuring (15x15x24)m3. The second case is a building designed for office use (Figure 5). A comparison was made between the OTTV in the case of buildings using original bricks versus bricks incorporating waste materials. In this study, simulations were also conducted to determine the temperature changes on the surface of the indoor walls. HEAT2 software was utilized for these simulations. The purpose of these simulations is to ascertain the extent of temperature differences on the surface of walls between those constructed with original bricks and those incorporating waste materials.

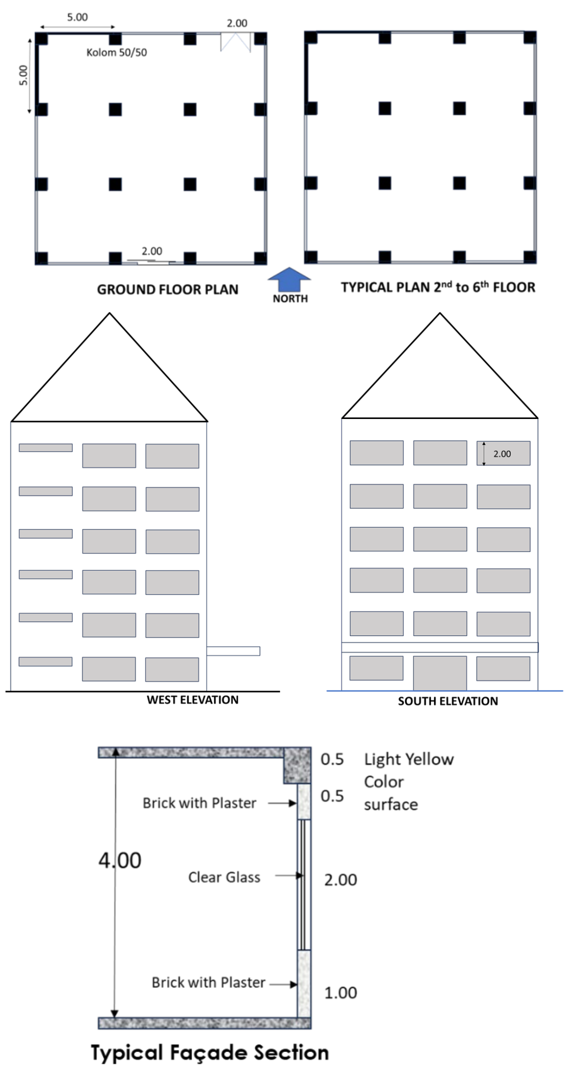


Figure 5 Model of office building

3.0 RESULTS

The thermal conductivity measurements demonstrate a relatively consistent decline for samples A1 to A7 (Figure 6). This downward trend is visible across both types of samples, whether produced using traditional methods or with a concrete mixer machine. For sample A1, the thermal conductivity measured for traditionally mixed bricks reached 0.75 W/m°C, while sample A7 showed a reduction to 0.48 W/m°C (Figure 6). This decline correlates with the increasing coconut fiber content, ranging from 5% in A1 to 35% in A7.

Initial thermal conductivity measurements were also conducted for the individual aggregate materials, including waste materials, cement, and sand. These measurements serve as input for the thermal conductivity calculations using an electrical analogy method. The results reveal that the thermal conductivity values of the organic waste materials vary between 0.063 and 0.075 W/m°C (Table 2), with these values being relatively close to one another.

Following the thermal conductivity measurements for all raw materials, the thickness of each material layer was determined based on the heat transfer analogy (Figure 4) and applying equations 2 to 4. The total brick thickness was fixed at 10 cm, and the thickness of each layer was calculated according to the percentage of each material within the mixture, excluding the air layer (Table 4). Initially, thermal conductivity calculations were conducted without considering porosity, implying the absence of an air layer in the electrical analogy calculations (Figure 7 and Figure 8). The calculations performed under this assumption resulted in significant deviations from the measured values, as shown in Figure 7 and Figure 8.

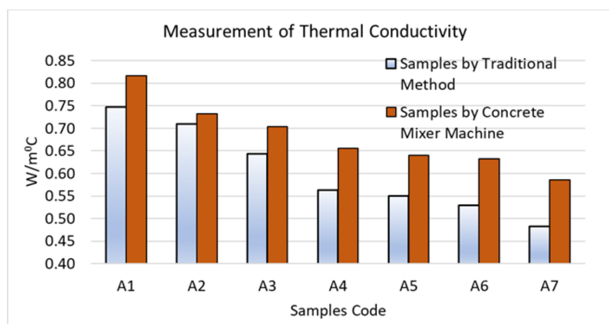


Figure 6 Measurement results of thermal conductivity of the samples

Table 2 Thermal Conductivity of the raw materials by measurement

Material	W/m⁰C
Sand	0.152
Cement (Hard)	1.114
Coconut fiber waste	0.063
Rice husks waste	0.061
Paper waste	0.075
Thin sawn wood waste	0.064
Plastic portion sheet waste	0.071

Table 3 Thermal Conductivity by measurement and by calculation (calculation without considering porosity) in W/m^{0}C)

Sample Code	By Measurement		By Calculation
	Brikcs by using Concrete Mixer Machine	Brikcs by using Traditional Manner	without considering porosity
A1	0.75	0.82	1.28
A2	0.71	0.73	1.21
A3	0.64	0.70	1.14
A4	0.56	0.66	1.09
A5	0.55	0.64	1.03
A6	0.53	0.63	0.99
A7	0.48	0.59	0.94

The results of the thermal conductivity calculation simulation of bricks, considering porosity, show consistency with measurement results (Figures 7,8, and Table 3). In this calculation, porosity is considered a layer of air with a certain percentage or thickness. According to the analogy calculation model (Figure 4), within this resistance system, there is a layer of air with a certain thickness. It is known that the thermal conductivity of air is 0.026 W/m°C [34]. Through simulation methods by applying percentage of air composition (equivalent to the thickness of the composition layer), it is possible to obtain thermal conductivity value that are the same or very close to the measurement results. The presentation of air porosity is not the same for every type of sample (Table 5). Therefore, the percentage of air composition is expressed as porosity.

Table 4 Values of dn without considering Air Layer

Raw Material	d (thickness equivalent) in m						
	A1	A2	A3	A4	A5	A6	A7
Sand	0.060	0.055	0.050	0.045	0.040	0.035	0.030
Cement	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Coconut Coir	0.005	0.010	0.015	0.020	0.025	0.030	0.035
Rice husk	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Paper	0.005	0.005	0.005	0.005	0.005	0.005	0.005
sawn wood	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Plastic	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Total thick	0.100	0.100	0.100	0.100	0.100	0.100	0.100

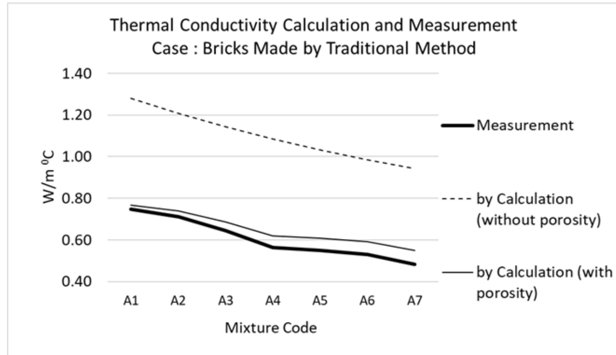


Figure 7 Calculation and measurement for case of bricks made by traditional method

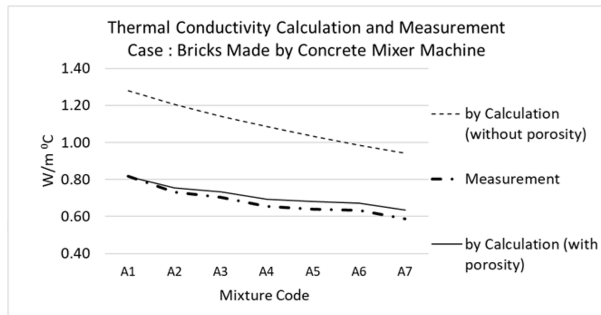


Figure 8 Calculation and measurement for case of bricks made by concrete mixer machine

Table 5 Percentage of air layer (as porosity) of The Samples

Sample Code	Percentage of Air layer of the Bricks	
	By Traditional Method	By Concrete Mixer Machine
A1	14%	12%
A2	15%	14%
A3	18%	14%
A4	22%	16%
A5	22%	15%
A6	23%	15%
A7	26%	17%

In order to evaluate the impact of this waste composite brick on the energy efficiency of the building, it is necessary to calculate the Overall Thermal Transfer Value (OTTV) by applying this waste composite traditional brick as the building envelope. In this calculation it was used bricks made by cincrete mixer machine. For case of a box shape building of size (15x15x24)m3 and by applying the Solar Factor for the location of Manado city, Indonesia, the OTTV obtained were between 11.11 to 10.32 W/m2 (Table 6. and Figure 9). For case of an office building mode, it was obtained OTTV between 61.1 to 60.68 W/m^2(Table 7 and Figure 10).

Table 6 OTTV for a box shape model

Brick Type	Code	k brick (W/m⁰C)	OTTV (W/m^2)	% Efficiency
Original Lighweight Solid Brick	0	1.06	11.65	0%
Lighweight Solid Brick with waste mixture	A1	0.75	11.11	5%
	A2	0.71	11.02	6%
	A3	0.64	10.84	8%
	A4	0.56	10.61	10%
	A5	0.55	10.57	10%
	A6	0.53	10.51	11%
	A7	0.48	10.32	13%

Table 7 OTTV for an office type model

Brick Type	Code	k brick (W/mK)	OTTV (W/m^2)	% Efficiency
Original Lighweight Solid Brick	0	1.06	61.1	0%
Lighweight Solid Brick with waste mixture	A1	0.75	60.98	0.20%
	A2	0.71	60.94	0.26%
	A3	0.64	60.88	0.36%
	A4	0.56	60.79	0.51%
	A5	0.55	60.77	0.54%
	A6	0.53	60.75	0.58%
	A7	0.48	60.68	0.69%

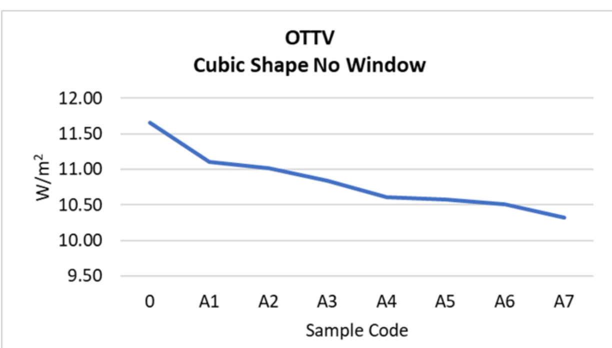


Figure 9 Decrease of OTTV value by different brick type of a cubic shape model

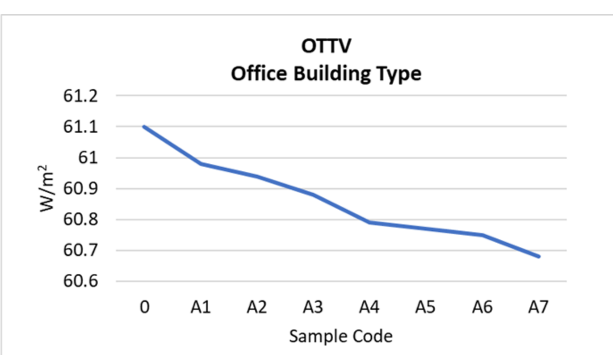


Figure 10 Decrease of OTTV value by different brick type of an office building type.

It is also necessary to determine the ability of these waste composite brick walls to block or conduct heat, which affects the surface temperature changes of the walls. HEAT2 software was used for this purpose. On the outer side of the vertical walls, it is assumed that there is an inclined penetration of solar radiation, resulting in a radiation temperature of 35°C touching the outdoor side of the wall. Meanwhile, inside the room, it is assumed that there is air temperature penetration from the air conditioning system at 25 °C. If the conditions are steady, in the case of original brick walls, the indoor surface temperature reaches 29.95 °C, while if using traditional bricks incorporating waste materials sample number A7 made by concrete machine, the temperature is 28.48 °C (Figure 11).

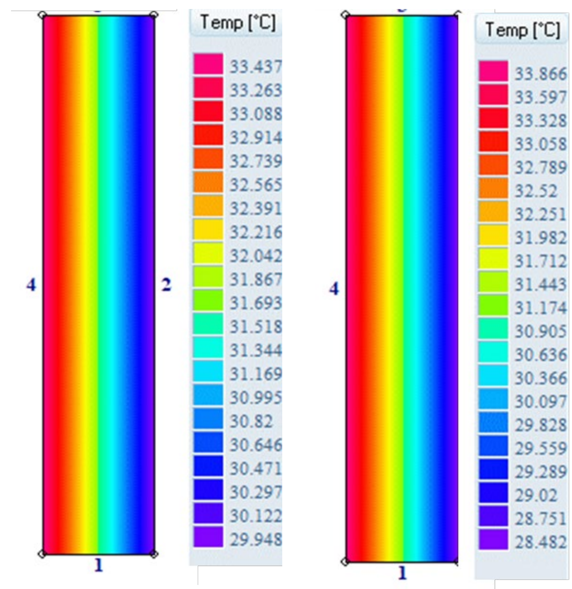


Figure 11 Visualization of temperature changes of wall section using original bricks (left), and bricks made by waste mixture (right)

4.0 DISCUSSION

The measurement results of the samples (Figure 6) show a clear and consistent reduction in thermal conductivity as the percentage of coconut coir in the brick mixtures increases. As an organic waste material, Coconut coir appears to significantly contribute to the reduction in thermal conductivity. As the coir content increases from 5% (sample A1) to 35% (sample A7), thermal conductivity decreases from 0.75 W/m°C to 0.48 W/m°C. This result indicates that coconut coir enhances the thermal insulation properties of the bricks by introducing more air pockets and reducing the density of the material. These air pockets act as barriers to heat transfer, making the bricks more effective at insulating against external heat. In comparison, materials like rubber and plastic, when used in similar mixtures, also contribute to lowering thermal conductivity, with values reported below 0.3 W/m°C [19]. For traditional red-fired bricks made from clay, thermal conductivity typically ranges around 0.3 W/m°C [31]. The results of this study place the coconut coir mixture bricks closer to these lower values, reinforcing the effectiveness of organic waste materials as thermal insulators.

The study's findings indicate that the proportion of coconut coir is more significant in reducing thermal conductivity than the mixing method (manual or machine). While samples produced using a concrete mixer tend to have higher thermal conductivity than those mixed manually, this difference is likely due to variations in material density. Machine-mixed samples are denser, as the uniform mixing process reduces porosity. In contrast, the manual mixing process can introduce more air pockets, resulting in lower thermal conductivity due to increased porosity. However, the primary factor influencing thermal performance remains the composition of the material, particularly the volume of coconut coir in the mixture. A comparison with the thermal conductivity values from other studies supports the findings of this research. For example, the thermal conductivity of coconut coir in this study is 0.063 W/m°C, which aligns with the reference value of 0.048 W/m°C [39]. Similarly, rice husks and paper waste also exhibit low thermal conductivity values, making them effective insulating materials. The measured thermal conductivity for plastic waste (0.071 W/m°C) falls within the range reported in other studies, which cite values between 0.068 and 0.128 W/m°C [27].

Porosity, or air bubbles within the bricks, is critical in determining thermal conductivity. Calculations show that porosity values range from 14% to 26% for traditionally mixed bricks and 12% to 17% for machine-mixed bricks (Table 5). The higher porosity in traditionally mixed bricks explains their lower thermal conductivity, as air acts as an insulating layer. With its fibrous structure, Coconut coir likely contributes to this increased porosity by trapping air during the mixing process. This effect is consistent with findings from Kristiawan [51], who reported that adding coconut husk to lightweight concrete bricks increased their water absorption rate, further supporting the idea that coconut fibers increase porosity. The porosity values in this study were determined using a heat transfer-based approach rather than the more common water absorption method used by other researchers. By assuming that the porosity contains air with a specific thermal conductivity value, we could calculate the influence of air on the overall thermal performance of the bricks. This approach highlights the importance of air as a thermal insulator, though excessive porosity could reduce the compressive strength of the bricks.

The OTTV calculations show that bricks containing coconut coir offer modest improvements in energy efficiency. The OTTV was reduced by 5% to 13% for a cube-shaped building model, while for an office building model, the reduction ranged from 0.2% to 0.69% (Tables 6 and 7). These reductions in OTTV suggest that the waste-composite bricks effectively reduce heat transfer, particularly in simpler building designs with fewer windows. Finally, the heat conduction simulations using HEAT2 demonstrated a small but meaningful decrease in indoor wall temperature when using bricks with a 35% coconut coir mixture (sample A7). The inner wall temperature was 28.45°C for the waste-composite bricks, compared to 29.95°C for traditional bricks, indicating a 1.5°C reduction. While this temperature difference may seem modest, it reflects coconut coir's contribution to improving the bricks' thermal insulation properties.

This study demonstrates that increasing the percentage of coconut coir in lightweight concrete bricks significantly reduces thermal conductivity, making these bricks more effective as insulating materials. The findings suggest that coconut coir, as an organic waste material, is a valuable component for enhancing the thermal performance of bricks, particularly in tropical climates where reducing heat gain is essential for energy-efficient building design. Future research could further explore optimizing the mix proportions to achieve improved thermal performance and sufficient structural integrity.

5.0 CONCLUSION

This paper reveals the opportunity to use organic and inorganic waste as a mixture for ligh-weight solid bricks. This way can reduce household and office life and industrial waste deposits. The results of testing bricks with waste mixture show that the quality of its thermal conductivity, is also still reliable as a wall material that can block heat from outside into the room.

Through this research, a comparison has been made between measurements and predictive calculations of thermal conductivity using electrical analogy, revealing slight differences in the results. Consequently, thermal conductivity predictions for bricks with waste can be calculated, but accurate data on the thermal properties of each type of waste material used in the mixture are required.

The porosity factor in this study is determined using the thermal conduction equation, assuming that the porosity contains air with a specific conductivity that influences the conductivity value of the composite material containing that air.

There is not much energy efficiency expected from this study's waste and cement composition. In order to achieve greater energy efficiency, it is necessary to create bricks with a higher proportion of heat-insulating waste mixtures and increase porosity or air bubbles.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

References

[1] Abubakar, I.R.; Maniruzzaman, K.M.; Dano, U.L.; Al-Shihri, F.S.; Al-Shammari, M.S.; Ahmed, S.M.S.; Al-Gehlani, W.A.G.; Alrawaf, T.I. 2022. Environmental Sustainability Impacts of Solid Waste Management Practices in the Global South. *International Journal of Environmental Research and Public Health.* 19(19): 12717. DOI: https://doi.org/10.3390/ijerph19191271.

[2] Albaali, A.G.; Shahateet, M.I. 2022. Energy Applications in Green Building to Fulfil the Goals of Sustainable Development: The Case of Jordan. *International Journal of Energy Economics and Policy.* 12(6): 188-193. DOI: https://doi.org/10.32479/ijeep.13547.

[3] Anggakusuma, D.R.; Supardi, Purwanto, E. 2014. Kuat Tekan Batako dengan Penambahan Semen Merahdari Limbah Gerabah *e-Jurnal Matriks Teknik Sipil*. 2(3): 328-335.

[4] Anhadi, A.R.; Yulianto. H. 2018. Karakteristik Kuat Tekan Dan Penyerapan Air Batako Dengan Penambahan Serbuk Kayu Dan Fly Ash. Universitas Islam Indonesia. Retrieved from https://dspace.uii.ac.id/handle/123456789/13057. Date: 18-12-2018.

[5] Batayaneh, M.; Marie,I.; Asi, I. 2007. Use of Selected Waste Materials in Concrete Mixes. *Waste Management*. 27(12): 1870-1876. DOI: https://doi.org/10.1016/j.wasman.2006.07.026.

[6] Biswal, C.; Mue, D.N.; Upender, K. 2021. Concept of Overall Thermal Transfer Value (OTTV) in Design of Building Envelope to Achieve Energy Efficiency. *Turkish Journal of Computer and Mathematics Education*. 12(07): 3461-3468. DOI: https://doi.org/10.17762/turcomat.v12i7.13462

[7] Bungau, C.C.; Bungau, T.; Prada, I.F.; Prada, M.F. 2022. Green Buildings as a Necessity for Sustainable Environment Development: Dilemmas and Challenges. *Sustainability*; 14(20): 13121. DOI: https://doi.org/10.3390/su14201312.

[8] Chan, L.S. 2021. Investigating the Thermal Performance and Overall Thermal Transfer Value (OTTV) of Air-Conditioned Buildings Under the Effect of Adjacent Shading Against Solar Radiation. *Journal of Building Engineering*. 44(2): 103211. DOI: https://doi.org/10.1016/j.jobe.2021.103211.

[9] De Paiva, F.P.G.; Tamashiro, J.R.; Silva,L.H.P; Kinoshita,A. 2021. Utilization of Inorganic Solid Waste in Cementitious Materials – A Systematic Literature Review. *Construction and Building Material*. 285: 122833.
DOI: https://doi.org/10.1016/j.conbuildmat.2021.122833.

[10] Du, Y.; Ge,Y. 2021. Multiphase Model for Predicting the Thermal Conductivity of Cement Paste and Its Applications. *Materials*. 14(16): 4525. DOI: https://doi.org/10.3390/ma14164525.

[11] Elsayed,H.; Mehta, A.; Mahmoud, M.; Kraxner,J.; Lucas, H.; Friedrich, B.; Bernardo,E. 2023. Engineering of Mixtures of Inorganic Waste for Sustainable Structural and Functional Materials. *Proceeding of 8th International Slag Valorisation Symposium*. 18-20/04/2023. Mechelen, Belgium.

[12] Goubrand,S.; Cucuzzella,C. 2019. Integrating the Sustainable Development Goals in Building Projects. *Journal of Sustainability Research*. (1): e190010. DOI: https://doi.org/10.20900/jsr20190010.

[13] Hamdhan, I.N.; Clarke,B.G. 2010. Determination of Thermal Conductivity of Coarse and Fine Sand Soils. In *Proceedings World Geothermal Congress*.1-7. 25-29 April 2010. Denpasar.

[14] Hajam, Y.A.; Kumar,R.; Kumar,A.. 2023. Environmental Waste Management Strategies and Vermi Transformation for Sustainable Development. *Environmental Challenges*. 13(1): 100747. DOI: https://doi.org/10.1016/j.envc.2023.100747

[15] Hayati, D.S.N.2020. Uji Pratekan Kualitas Batako dari Berbagai Daerah di Kabupaten Jember. Skripsi Jurusan Pendidikan Fisika, Universitas Jember. https://repository.unej.ac.id/jspui.

[16] Irwansyah.; Isma, F.; Purwandito.M. 2018. Karakteristik Batu Bata Tanpa Pembakaran Dari Limbah Industri Pertanian dan Material Alam, *Educational Building. Jurnal Pendidikan Teknik Bangunan dan Sipil*. 4(2). DOI: https://doi.org/10.24114/ebjptbs.v4i2%20DES.

[17] Ismail.; Mardiani; Lismayani,D.; Fauzi. 2014. Sawdust for Thermal Insulation Building. In *Proceedings of the 2nd International Conference on Natural and Environmental Sciences* (ICONES) September 9-11, Banda Aceh, Indonesia.

[18] Juliana,N.; Syaharuddin,J.; Kiranti KP. 2020. Education of Inorganic Waste Management Through Training of Creations. *Advances in Social Science, Education and Humanities Research*. 525: 127-130. DOI:10.2991/assehr.k.210222.017

[19] Karslioglu, A.; Balabani,E.; Onur, M.I.2021. Insulation Properties of Bricks with Waste Rubber and Plastic: A Review. 2021. *Journal of Nature, Science & Technology* 1: 20-27. DOI:10.36937/janset.2021.001.004.

[20] Kibria, M.G.; Masuk,N.I.; Safayet,R.; Nguyen,H.Q.; Mourshed.M. 2023. Plastic Waste: Challenges and Opportunities to Mitigate Pollution and Effective Management. *International Journal of Environmental Research*. 17(20). DOI: https://doi.org/10.1007/s41742-023-00507-z.

[21] Kim,J.; Tae,S.; Kim,R. 2018. Mineral's Creation of Recycled Cement Utilizing Inorganic Construction Wastes. *International Journal of Sustainable Building Technology and Urban Development*. 9(4): 258-265. DOI: https://doi.org/10.22712/susb.20180024.

[22] Kumar, R.; Verma, A.; Shome, A.; Sinha,R.; Sinha, S.; Jha, P.K.; Kumar,R.; Kumar, P.; Shubham, Das,S.; Sharma,P.; Prasad.P.V.V.2021. Impacts of Plastic Pollution on Ecosystem Services, Sustainable Development Goals, and Need to Focus on Circular Economy and Policy Interventions. *Sustainability*, 13(17): 9963. DOI: https://doi.org/10.3390/su13179963.

[23] Kumaraand,W.K.P.; Rosa,S.R.D. 2014. Investigation of Thermal Conductivity of Sawdust and Constructing an Environmental Friendly Insulating Container. In *Proceedings of the Technical Sessions*, 30: 97-104. Institute of Physics – Department of Physics, University of Colombo, Sri Lanka.

[24] Kurniawan, T.B.; Delshinta,D.A.; Usman, F.;Fadly.F. 2023. Towards Energy Analysis and Efficiency for Sustainable Buildings. *Emerging Science Journal*. 7(6): 2226-2238. DOI: http://doi.org/10.28991/ESJ-2023-07-06-022.

[25] Lavrykov,S.A.; Ramarao,B.V. Thermal Properties of Copy Paper Sheets. 2012. *Drying Technology*. 30: 297–311. DOI: https://doi.org/10.1080/07373937.2011.638148.

[26] Liu, T.; Chen,L.; Yang, M.; M Sandanayake, M.; Miao, P.; Shi, Y.; Yap,P.S. 2021. Considerations of Green Buildings: A Detailed O verview on Current Advancements and Future onsiderations. *Sustainability*. 14(21): 14393. DOI: https://doi.org/10.3390/su142114393.

[27] Mourid, A.; El Alami,M.; Saadani, R.; Rahmoune M. 2023. Valorization of Different Types of Plastic Waste for Developing Innovative and Ecological Thermal Insulating Materials in Building. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4501156. DOI: https://doi.org/10.2139/ssrn.4501156.

[28] Muhfizaturrahmah, Yuniarti, N.; Sukisno,T.; Urdifat,Y. 2021. The influence of Overall Thermal Transfer Value (OTTV) on Building Energy Consumption. *Journal of Physics Conference Series* 1833(1). DOI: 10.1088/1742-6596/1833/1/012046.

[29] Muthuraj, R.; Lacoste,C.; Lacroix,P.; Bergeret,A. 2019. Sustainable thermal insulation biocomposites from rice husk, wheat husk, wood fibers and textile waste fibers: Elaboration and performances evaluation. *Industrial Crops and Products*. 135: 238-245. DOI: https://doi.org/10.1016/j.indcrop.2019.04.053.

[30] Noerwasito,V.T.; Mas Santosa. 2006. Pengaruh Thermal Properties Material Bata Merah dan Batako Sebagai Dinding, Terhadap Efisien Enerji Dalam Ruang di Surabaya. *Dimensi Teknik Arsitektur*. 34(2): 147 – 153.

[31] Paliwal, R.; Shivarkar,Y.; Pund,A.; Jha,P.; Bhavsar,P. 2018. Formation of Insulationg Bricks From Agricultural Waste & Determination of Thermal Properties by Comparing with Present Bricks. *International Journal of Creative Research Thoughts*. 6(2): 127-131. http://www.ijcrt.org.

[32] Patel,P.; Patel,A. 2021. Use of sustainable green materials in construction of green buildings for sustainable development. *IOP Conf. Series*: *Earth and Environmental Science*. 785: 012009. DOI :10.1088/1755-1315/785/1/012009.

[33] Patki, P.; Rasane, A.; Deshpande,S. Study of the Concept of Green Buildings, Practice from Paste and Its Applicability Today. In *Proceedings of International Conference on Sustainable Development (ICSD 2019)*. 18-24.

[34] Perumal,S.; Rajendrian, S.; Venkatraman,V.; Sundresan, D.; Pandiyan.L. 2020. Experintal Study About Thermal Resistance of Windows with Air Gap Between Two Glasses Used in Single House. *Thermal Science*. 24(1): 515-518. DOI: https://doi.org/10.2298/TSCI190411031P

[35] Prasetyo, H.D. 2005. Pengujian Kuat Tekan Batako dengan Menggunakan Camouran Trass. Proyek Akhir. Jurusan Teknik Sipil. Universitas Jember.

[36] Pukhkal, V.; Murgul,V. 2017. Calculated heat-and-technical indicators of brick external walls of the historical residential buildings. *IOP Conference Series*: *Earth and Environmental Science*. 90(1): 012211. DOI:10.1088/1755-1315/90/1/012211.

[37] Putri,D; Artiani,G.P.; I Handayasari,I. 2017. Studi Pengaruh Penambahan Limbah Serutan Bambu Terehadap Kuat Tekan Batak. *Jurnal Konstruksia*. 9(1): 12-17. DOI: https://doi.org/10.24853/jk.9.1.27-40

[38] Ramos, A.; Saez,M.P.; Rodriguez,M.A. Anton, M.N. JGomez,J.; Piloto,P. 2019. Thermal Properties of Fired Clay Bricks from Waste Recycling. A review of studies. *Fire Research*. 3(1): 8-13. DOI:10.4081/fire.2019.71.

[39] Rodriguez,N.J.; Yanez-Limon,M.; Gutierez-Micelli,F.A.; Matadamas-Ortiz,T.P.; Lagunez-Rivera,L.; Vazquez-Feijoo.J.A.. 2011. Assesment of Coconuts Fibre Insulation Characteristics and Its Use To Modulate Temperatures in Concrete Slabs With the Aid of a Finite Methodology. *Energy and Buildings*. 43(6): 1264-1272. DOI: https://doi.org/10.1016/j.enbuild.2011.01.005.

[40] Sangkertadi,S.; Syafriny, R.; Wuisang,C.E.V. 2023. Thermophysical Properties of Landscape Material and Its Effect on Daytime Outdoor Thermal Comfort in Tropical City. *Advances In Science, Technology & Innovation, IEREK Interdisciplinary Series for Sustainable Development*. 2023: 127-134. DOI: https://doi.org/10.1007/978-3-031-20182-0_10.

[41] Sangkertadi,S.; Syafriny,R.; Wuisang, C.E.V. 2022. Influence of Landscape Material Properties on Microclimate Change in a Tropical Area with Case in Manado City. *IOP Conference Series: Earth and Environmental Science*. 1007(1): 012006. DOI:10.1088/1755-1315/1007/1/012006.

[42] Sujatmiko,B; Nizarsyah, F. 2016. Pemanfaatan Limbah Abu Ampas Tebu dengan Substitusi Semen Sebagai Bahan Mortal dan Beton Ditinjau Terhadap Kuat Tekan. *Jurnal Rekayasa Teknik Sipil Universitas Madura*. 1(2): 11-14. DOI: http://dx.doi.org/10.53712/rjrs.v2i1.183.

[43] Santoso,H.H. 2013. Pemanfaatan Limbah Kertas Sebagai Bahan Campuran Batako Dengan Alat Tekan Manual. Skripsi Jurusan Teknik Sipil. Univesitas Negeri Semarang.

[44] Sumbawaty, N.; Ahzan,S.; Prasetya,D.S.B. 2018.Uji Porositas dan Kuat Tekan Batako Ringan Berbahan Dasar Limbah Pengolahan Emas (LPE) dengan Filler Pohon Pisang (FPP). *Jurnal Penelitian dan Pengkajian Ilmu Pendidikan: e-Saintika*. 1(2): 87-93. DOI: 10.36312/e-saintika.v1i2.107.

[45] Sunil, N.; Srnivasa, R.G.V.R.; Manjunatha, M.; Nagaraju,D.; Sifatullah,B. 2023. Potential Use of Sustainable Industrial Waste Byproducts in Fired and Unfired Brick Production. *Advances in Civil Engineering*. 2023(8): 1-16. DOI: https://doi.org/10.1155/2023/9989054.

[46] Supriyadi; Septinar. 2018. H. Kerusakan Lingkungan Akibat Industri Batu Bata di Desa Pangkalan Benteng Sebagai Sumber Pembelajaran Ilmu Pengetahuan Sosial (Geografi) di MTS GUPPI Sukamoro. *Jurnal Swarnabhumi*. 3(2). DOI: https://doi.org/10.31851/swarnabhumi.v3i2.2605.

[47] Tumanduk, M.S.S.; Kembuan, E.Dj.R.; Lumeno, S. 2020. Pengujian Kuat Tekan Batako dengan Variasi Penambahan Serat Ijuk. *ARSKON-Jurnal Arsitektur dan Konstruksi*. 1(1): 1-6.

[48] Wang,Y. 2022. Research on the Sustainability in Green Building. In *Proceedings of the 2022 7th International Conference on Social Sciences and Economic Development (ICSSED 2022*): *Advances in Economics, Business and Management Research*. 215: 1388-1393. DOI: 10.2991/aebmr.k.220405.231

[49] Vijayalaxmi, j. 2010. Concept of Overall Thermal Transfer Value (OTTV) in Design of Building Envelope to Achieve Energy Efficiency. *The International Journal of Thermal & Environmental Engineering.* 1(2): 75-80. DOI: 10.5383/ijtee.01.02.003.

[50] Yasser, A.; Hassan,A.S.; Al-Absi, A.A.Z; Achour,H.; Witchayangkoon, B.; Qaana.B. 2023. Retrofitting of a High-Rise Residential Building for Energy Efficiency with OTTV as an Assessment Tool. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*. 102(2): 110-119. DOI: https://doi.org/10.37934/arfmts.102.2.110119.

[51] Kristiawan, A.; Suwandi, P.A.P. 2015. Pengaruh Penambahan Kapur dan Sabut Kelapa Terhadap Bobot dan Daya Serap Air Batako. *Jurnal Ilmiah Teknosains*. 1(1): 43-52. https://journal.upgris.ac.id/index.php/JITEK/article/view/835/753.