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Towards Sustainable Architecture: Energy Storing Bricks and Photovoltaic Systems for Self-Sufficient Residential Housing

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Abstract

This paper addresses the urgent global challenge of climate change by proposing a novel approach to residential architecture that combines passive design with active energy systems. Current studies show that buildings contribute 30% of the global energy consumption and is expected to increase with world wide rising energy demands including in Indonesia. Studies have shown the abundance of solar exposure in Indonesia. This calls for the maximisation of photovoltaic system an electricity generation system that produce the least amount of CO^2. The existing public preference of bricks as residential building materials for its structural integrity and passive design qualities highlights the potential of implementing energy storing bricks technology findings from Washington University. This paper presents a concept that combines photovoltaic (PV) systems with energy-storing bricks to create a self-sufficient home that can produce and store its own electricity. Our goal is to optimize both passive and active design approaches in order to maintain or enhance the standard of living that exists today while simultaneously move toward a sustainable future at the same time. Further empirical research is required to confirm the viability and efficiency of this innovative architectural approach.

Keywords : Energy Storage, PEDOT-Coated Bricks, Photovoltaic, Self-Sufficient Housing, Tropical Climate.

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1. Introduction

Rising temperatures drive iceberg evaporation leading to increasing sea water levels and causing local climate change. One of the factors causing global warming is the buildings sector contribute to 30% of the world's total material consumption and 26% of global emissions attributed to energy consumption (Al-Ghussain, 2019). More detail, 8% emissions from buildings and 18% electricity activity, International Energy Agency (2023) recorded that in 2022, emissions of CO^2 from buildings dropped to 3 gigatons contrary buildings' CO^2 energy consumption emissions increasing 6,8 gigatons. This is a challenge for many countries to improve their quality of life while maintaining building energy consumption in these countries will continue to rise (Li et al., 2021).

The main ecological driving forces within the tropical regions are relatively stable high temperatures and air humidity compared to their temperate counterparts, which allows the inhabitants to dwell relying on passive design (Val, De Almeida-Val and Randall, 2005). However, the escalating needs of users and climate change-driven temperature increases the need for more energy for construction and performance, including air conditioning (Sekartaji et al., 2023; Xiong Bo et al., 2021; Lundgren-Kownacki et al., 2018). The air conditioning market continues to grow (TechSci Research, 2023). It highlights the challenge of balancing energy consumption with comfort and sustainability. Thus, the adoption of sustainable energy sources such as solar power, which is abundantly available in tropical countries like Indonesia, can reduce energy issues through CSP and PV systems (Haugan, 2013; Desideri and Campana, 2014; Chao Xu et al., 2017). Innovations like energy storing bricks for stationary (Wang et al., 2020) and the orevalent use of photovoltaic modules highlight the potential for integrating passive and active design to meet sustainable development goals related to clean energy and responsible consumption (Sharaf, 2020; Ogbomo et al., 2017; United Nations, 2023).

Current research and development efforts in photovoltaics are focused on enhancing the efficiency, affordability, and deployment of solar energy technologies. The current state of photovoltaic cell technology predominantly features silicon-based cells due to their market--dominance and efficiency. There are also thin film, perovskite, and multi-junction alternatives that promise lower costs and high efficiency. The efficiency of photovoltaic cells varies widely from as low as 5% for dye-sensitized cells to 36% for advanced multi-junction cells (Pardo, 2023).

Energy-storing bricks, in parallel, offer a novel solution by turning a conventional building material into energy storage devices (Wang et al., 2020). This innovation presents a potential for localized energy storage. Therefore, it reduces the reliance on traditional battery storage systems.

The trend in sustainable energy development is towards integrating various energy sources. An example is combining solar and wind with innovative storage solutions such as battery energy storage system, (BESS) (Gomez, Aldaco, and Alquicira, 2023). This trend underscores the foundation of this research on integrating photovoltaics with energy storing bricks. It is a holistic approach to revolutionize sustainable energy development.

While there is a growing body of literature on energy efficiency, the integration of photovoltaic (PV) systems and energy storing bricks has not been extensively explored. Current research predominantly focuses either on improving the efficiency of photovoltaic systems for energy generation, enhancing building materials for better thermal performance, or the very novel finding of energy storing bricks (Wang et al, 2020). However, the concept of combining these strategies presents a novelty that addresses integration of passive and active design. This study aims to present the theoretical exploration to fill this gap by proposing a model that capitalizes on the abundant solar energy in tropical regions like Indonesia and addresses the under utilization if building materials themselves as energy storage mediums.

2. Method

This study centers around the review of existing literature targeting the efficiency and potential of PEDOT- coated brick technology and photovoltaic (PV) systems in Surabaya, Indonesia. A mixed-method approach is employed in this study. The method used in this study involves synthesizing academic and industrial findings to gain understanding of the current state of the technologies.This study is then complemented-

-with calculations to estimate the needs of a house in general. The calculations of expected electricity generation potential from the system under local conditions are added as well.

This methodology aligns with the study's aim to conceptually design a self-sufficient residential architecture model that integrates PEDOT- coated bricks and PV systems. The framework combines theoretical exploration with energy calculations to underpin the feasibility of combining these technologies for sustainable residential buildings in tropical regions. The methodology also aligns with the overarching goal of optimizing both passive and active design approaches to achieve a balance between increasing the standards of living and comfort as well as sustainable energy sources.

However, the study's primary limitation is that it only relies on theoretical and conceptual foundation. Thus, there is a gap between theoretical potential and practical viability. It needs further empirical research and evidence to validate the practical effectiveness of the proposed architectural integration. The actual application and long-term operational efficiencies in tropical climate still require field testing.

3. Result and Discussion

Essentially, this paper proposes a combination of passive and active design strategy utilising bricks, a commonly used material for housings in Indonesia, as well as photovoltaic as the source of energy used for HVAC. In Indonesia, bricks are the most popular material used to build houses.

Taking a look at Indonesia's vernacular architecture, it can be seen that the predominant materials for buildings were wood for walls and floors (Lee, Kaneko and Sharifi, 2020). This is because wood was the available material in their immediate surroundings. The shift from wood to bricks can be traced back to the historical influence of Dutch colonial architecture. During the time of colonisation, the Dutch imported construction methods and techniques to build using strong brick walls to withstand earthquake danger and shear loads. Indonesians adopt this technology and now, prefer bricks to wood buildings for many reasons. The resilience of numerous old colonial structures in Indonesia is attributed to their dependence on these robust brick walls (Idham, 2021). Beside bricks' structural durability, they're also preferred-due to their ability to contribute to passive design in hot humid tropical climates. Bricks' high thermal mass allows them to store large amounts of heat and thus making them a good temperature regulator in tropical regions. During the day, bricks will receive and absorb heat from the sun, keeping the temperature inside cooler (Vijayan et al., 2021). After the sun sets the walls will remain warm. According to new studies from Washington University, bricks can also store electricity (Wang et al., 2020). Another advantage of tropical climate is the fact that Indonesia is exposed to sunlight all year round, making it possible to obtain solar energy at all times.

Bricks can be converted into rechargeable energy storage batteries to keep electricity. Brick's porous characteristic can potentially be utilised to store energy. This structural component, commonly available in various shades of red, primarily consists of fused particles such as silica dioxide (SiO_2), alumina oxide (Al_2O_3) and hematite (α-Fe_2O_3). The brick's red hue is derived from hematite, and advanced energy storage materials, including FeNx, FeP, and Li_5FeO_4, are fabricated through processes like anionic or cationic exchange, enabling their application in potassium-ion batteries, Zn–air batteries, pseudocapacitors, and lithium-ion batteries 8–11. The electrochemical transformation of hematite also results in $FeHO_2$ supercapacitor anodes (Wang et al., 2020). These iron chemical compounds are necessary for storing energy.

The pores with acid vapour (HCl vapour) will partially dissolve the iron compound (α-Fe_2O_3) 160 °C, liberate iron (Fe_3+), encourages hydrolysis and triggers the precipitation of colloidal 1D $FeHO_2$ nuclei. This reactive iron will then create a chemical synthesis and further additional specified gas flows through the cavity and fills the cavity with a sulfur-based material that reacts with iron and leaves the pores with electrically conductive plastic known as PEDOT. The thickness of a PEDOT coating is regulated by both reaction time and stoichiometry, facilitating a process that produces surface-polymerized PEDOT- coated bricks with a core/shell architecture or fully polymerized bricks with a monolithic PEDOT architecture (Wang et al., 2020).

Unlike batteries, these bricks act as a supercapacitor . The difference is that supercapacitors, as shown in table 1, exhibits-

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-rapid charging and discharging capabilities within seconds, a high-power density (with lower energy compared to a battery), and a highly reversible process enduring over 500.000 cycles, hence it's considered more eco-friendly and safer. Other advantages include wider operating temperature at -40°C - 70°C (Barzegar, 2018).

The proposed solution is to capitalise on solar power in a sunny region using photovoltaic panels to obtain and turn said energy into electricity. The fact that brick walls, which take so much space and surface, are now utilised for energy storing makes those occupied spaces no longer redundant for they're also necessary not only to protect the occupants from the weather but also to provide energy for the household activities occurring inside. When needed, the electricity will be conducted to an inverter to change direct current (DC) to-alternating current (AC) following a distribution board and eventually electrical appliances (figure 1).

To put this plan into action, calculation of the requirements for photovoltaic panels and bricks based on the energy needs and potential of a specific area is necessary. In this case, the focus is put on Surabaya in East Java, Indonesia. It's important to consider the local climate, as Surabaya experiences a tropical climate characterized by hot and humid conditions throughout the year. Wet or rainy season occurs around October to April marked by increased rainfall and frequent cloud covers whereas dry season occurs from April to October, providing ample sunlight to the region.

It is estimated that the need for daily household electricity in Indonesia to provide energy for rice cooker, refrigerator, TV, electric fan, AC, water-

Table 1. Difference Between Supercapacitor and Battery

Available Performance	Supercapacitor	Battery
Charge/Discharge Time	0,3 to 30 seconds	0,5 to 10 hours
Energy Storage	W-Sec of energy	W-Hr of energy
Energy (Wh/kg)	1 to 10	8 to 700
Cycle Life	>500.000	<1.500
Specific Power (W/kg)	<10.000	<1.000
Charge/Discharge Efficiency	0,85 to 0,98	0,7 to 0,85

Source : (Barzegar, 2018)



Figure 1. Diagram of PV and energy-storing bricks

-dispenser, washing machine, electric iron, water pump and other electronics collectively sum up to 25.187 Wh. The details are outlined in table 2. Notably, staples such as the rice cooker and refrigerator play crucial roles, both resulting in 4.640 Wh of electricity in total. Residing in a hot and humid region, individuals who own air conditioners typically use them for an average of 11 hours, resulting in the highest energy consumption of 8.085 Wh among all appliances.

During transmission from solar panels, there are many factors that can reduce the amount of energy output. According to a study performed by Sulaiman et al. (2014), the solar panel's output can power experience a reduction ranging from 25% to 31% when influenced by the presence of talcum, and between 65% and 74% when affected by sand or dust. Additionally, the impact of moss results in a decrease of output power ranging from 15% to 86%, whereas water droplets, such as those from rain or mist, lead to a minimal reduction between 0,5% and 4,3%. Substances like moss, being opaque, obstruct the penetration of light radiation onto the solar cells, further affecting their efficiency. This factor must be considered as the hot-and humid environment of Indonesia potentially foster the development of fungi and moss on the photovoltaic panel. Whereas substances like water, that is transparent, will not cause any significant reduction. Located in a hot humid region, these factors should be put into consideration. However, we must also consider how often each factor is likely to affect solar panels in your specific region or scenario. To make a general and conservative estimate for the overall energy loss, a weighted average based on the potential impact of each factor is considered. Weights are assigned to each factor based on the likelihood or prevalence of occurrence. This calculation below provides a simplified and raw estimation of potential energy loss in a photovoltaic system, factoring in various environmental elements and weighted influences. The overall weighted average estimate suggests a potential energy loss of 46,23%. The calculations can be seen on table 3.

Although Surabaya is exposed to the sun for approximately 12 hours a day (figure 4), in keeping with information acquired from BPPT (Agency for the Assessment and Application of Technology) and BMKG (Meteorology, Climatology, and Geophysics-

Table 2. Itemised Daily Electricity Consumption

Electronics	Wattage	Duration of Usage	Watt hours
Rice Cooker	350 W	6,4 hours	2,240 Wh
Refrigerator	100 W	24 hours	2,400 Wh
TV	75 W	19 hours	1,425 Wh
Electric Fan	79 W	13 hours	1,027 Wh
AC	735 W	11 hours	8,085 Wh
Water Dispenser	200 W	24 hours	4,800 Wh
Washing Machine	300 W	1 hour	300 Wh
Electric Iron	350 W	2 hours	700 Wh
Water Pump	200 W	5 hours	1000 Wh
Miscellaneous	200 W	12 hours	2,400 Wh
	Total		25,187 Wh

Source : Modified from (CLASP and Ipsos, 2020)

Table 3. How Materials Affect PV Efficiency

Material	Average Percentage	Weight	Weighted Value
Talcum	28 %	10 %	2,8 %
Sand or Dust	69,5 %	40 %	27,8 %
Moss	50,5 %	30 %	15,15 %
Water Droplets	2,4 %	20 %	0,48 %
	Overall Estimate		46,23 %

Source : (Sulaiman et al, 2014)

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-Agency), the premiere time of photovoltaic use in Indonesia is only 4 – 5,5 hours consistent with day. This indicates that, in spite of having 12 hours of daylight, the most optimum use of photovoltaic systems in Indonesia is in the unique time range. Specifically in East Java, the radiation intensity is approximately 4.300 Wh/m². This parameter shows the quantity of solar energy that reaches a particular area over a given time period. The vast radiation depth in this vicinity highlights its huge solar ability.

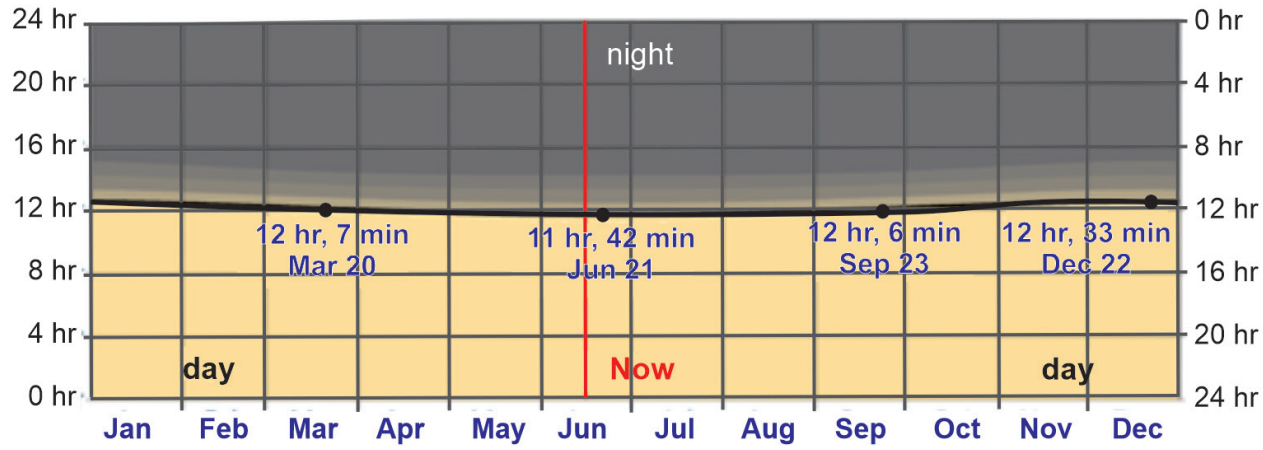
Besides the data that has been collected about the optimal time of photovoltaic duration, the reason why the optimal time can be limited is because the solar energy sources are intermittent (or not physically available continuously), thus affecting the electricity that can be generated. Apart from the absence of light from the sun at night, other intermittent factors can influence this phenomenon. An example of this is the presence of clouds (cloudy weather) that blocks sunlight from reaching photovoltaic solar panels.

Between November and April during rainy season, the data indicates that the area seldom encounters clear skies, with conditions ranging from partly cloudy to mostly cloudy or overcast (Weatherspark, 2023). Other factors incude shadows of trees as well as buildings or the influence of other objects around photovoltaic solar panels. These things cause electricity cannot be produced by solar cells during the shadow effect (shading) it happens. Additionally, on average, photovoltaics has conversion efficiency ranging from 17% to 20%, meaning, only said amount of solar energy-can be converted to electricity. The solar energy also assumed to be lost by 5% when going through the inverter.

Based on the considerations, the number of photovoltaic panels and bricks needed to generate and store energy is calculated. First, we must consider that most commercial photovoltaic panels can only convert 17% - 20% of solar energy into electricity. Additionally, the potential energy loss due to external factors must also be calculated. If data shows that the solar radiation intensity is 4.300 Wh/m², we can assume that this number can be reduced by 46,23% due to factors such as talcum, sand and dust, moss, as well as water covering the photovoltaic surface. Approximately, there will be a total energy loss of 1.983,09 Wh/m². Therefore, the total energy that can be generated is 2.316,91 Wh/m².

The calculation is as follows : most commercial photovoltaic panels can only convert 17% - 20% of solar energy into electicity. Therefore, only 1.853,53 Wh/m² amount of energy can be converted. In the conversion from direct current (DC) to alternating current (AC) electricity, there will be 5% loss of energy. Therefore, only 1.761,85 Wh/m² will be usable. Average residential photovoltaic panels are approximately 65 x 39 inches, meaning each as an area of 1,636 m². In order to reach the 25.187 Wh energy in total, 9 photovoltaics panels are needed. The visual summarization can be seen on table 4.

Once the number of photovoltaics needed is found, the number of bricks needed to work as supercapacitor must be calculated as well. According to (Wang et al., 2020), 50 bricks can-



The number of hours during which the Sun is visible (black line), From Bottom (most yellow) to top (most gray), the color bands indicate : full daylight, twilight (civil nautical, and astronomical), and full night.

Figure 2. Hours of daylight and twiling in Surabaya [Source: Weatherspark, 2023]

-store energy enough to power lighting for 5 hours straight. The volumetric energy density of the brick-based supercapacitor is reported to be 394 μ Wh/m³. This value indicates the amount of energy that can be stored per unit volume of the supercapacitor. According to SNI 6897:2008, the standardised size of a brick is 5 cm × 11 cm × 22 cm. Meaning, it has the volume of 1.210 cm³ in total. Therefore, the energy that can be stored in one brick is 0,47614 Wh. In practice, it would require quite a large building to store 25.187 Wh. The larger the building, the more electricity it may require. Theoretically, it would need 52.823 bricks to store this amount of energy. The calculation is shown on table 5.

However, if we were to estimate 5.000 to 10.000 bricks for a small house with minimal walls 10.000 to 20.000 bricks for a medium-sized house with standard construction and 20.000 to 50.000 bricks or more for larger houses, then the result is on table 6. ——

4. Conclusion

The concept of energy self-sufficient brick-house is to use photovoltaic panels as tools to generate solar power which is then stored in bricks, the most commonly used material in Indonesia, utilising the PEDOT mechanism invented by Washington University scientist. Hence the advantage of applying bricks as wall materials will extend from exploiting its thermal mass for passive temperature control but also to store energy needed for active temperature control.

The impact that we predict may come after the implementation of this particular idea is to help provide inhabitants with the desired thermal comfort using both passive design strategies as well as active temperature control while taking responsible energy consumption into consideration. Houses will no longer be seen only as shelters to protect humans from weather but also help support the activities by providing energy. With houses being self-sufficient, utilising-

Table 4. Summary of Solar Energy Conversion Process

Stage	Calculation	Value	Note
Initial Solar Energy Potential		4.300 Wh/m²	Initial solar irradiance
Energy Loss due to External Factors	4.300 × 0,46234.300 × 0,4623	1.983,09 Wh/m²	Reflects losses such as reflection, absorption, etc.
Net Solar Energy Generated	4.300 − 1.983,094.300 − 1.983,09	2.316,91 Wh/m²	Energy available after accounting for external losses
Optimal Generation Time		4 hours	Assumed effective sunlight duration
Total Daily Solar Energy Generated	2.316,91 × 42.316,91 × 4	9.267,64 Wh/m²	Total energy generated over the optimal time
Conversion to Electricity (at 20% Efficiency)	9.267,64 × 20%9.267,64 × 20%	1.853,53 Wh/m²	Energy converted by PV panels
AC Conversion Loss (5%)	1.853,53 × 95%1.853,53 × 95%	1.761,85 Wh/m²	Usable energy after DC to AC conversion loss

Table 5. Summary of Solar Energy Conversion Process Calculation of The Number

Description	Result	Units	Note
Volume of One Brick	1.210	cm³	Initial volume of the brick
Energy Density	394	μWh/cm³	Energy stored per cubic centimeter
Conversion of Energy Density	0,000394	Wh/cm³	Convert μWh/cm³ to Wh/cm³
Energy Stored in One Brick	0,47614	Wh	Calculated using converted energy density
Number of Bricks for Total Energy	52.823	Bricks	Calculated number for bricks needed

Table 6. Estimated Capacity of Different House Sizes of Bricks Needed to Store Total

House Size	Estimated Number of Bricks	Energy Storage Capacity Range
Small House	5.000 – 10.000	2.380,7 – 4.761,4 Wh
Medium-Sized House	10.000 – 20.000	7.142,1 – 9.522,8Wh
Large House	20.000 – 50.000 or more	9.522,8 – 23.810,7 Wh

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-renewable energy source, it will reduce the environmental impact of our energy dependent lifestyles.

This paper adopts a theoretical and conceptual framework. To validate the viability of the proposed approach, additional experiments are essential. Empirical evidence is required to determine its practical effectiveness.

The current energy-storing brick findings and PV technology might not fully meet the total power storage needs of all residential buildings considering it is still in its early stage. However, the idea of incorporating energy storage into bricks to avoid redundant wall space is promising and could be beneficial with further development.

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