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The Implementation of Solar Refeective Technology to Reduce House Temperature and Urban Heat Island Impact: A Case Study in Pangandaran Indonesia

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ABSTRACT

Handling Urban Heat Island is very important and requires good collaboration between government, industry, educational institutions, and the community. This article aims to explain the process and results of implementing solar reflective technology (Rafflesia) as an effort to reduce house temperatures and the impact of urban heat island based on a pilot project resulting from cooperation between government, industry, and educational institutions. This study uses participatory action research and quantitative methods. In this study, initial analysis was done along with the residents and locals, an implementation plan in the form of renovating residents' houses and painting solar reflective roofs, as well as measuring house temperatures before and after implementation. This pilot project itself was carried out in Pangandaran Regency. The measurement results showed that there was decrease in temperature of 8.5OC to 22.1 OC and energy efficiency of up to 20%. With a decrease in room temperature and a decrease in energy consumption, this project shows good results and can be implemented in other homes to provide a wider and more significant impact on reducing urban heat island.

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1. INTRODUCTION

1.1. Background

Climate Change undeniably has affected every aspect of human life and influence our quality of life. The impact is especially prevalent and intense in urban areas which has more dense infrastructure, such as buildings and roads, which absorb and retain heat and lead to the rise of temperature (Kullberg & Feeley, 2023). Urban areas are also accounted for more 70% of global CO₂ emissions that leads to climate change, which shows how the critical role of cities in climate change (Churkina, 2016; Jhariya et al., 2024). One of the phenomena is Urban Heat Island (UHI) in which urban areas experience higher temperature than the surrounding rural areas due to human activities and infrastructure development (Halenka et al., 2024; Leal Filho et al., 2022). In West Java alone, the intensity of UHI reached 5.11 OC and was measured higher in satellite city with lack green areas (Nandi & Dede, 2022).

There are many factors that could cause UHI, such as the use of materials in buildings and road, lack of vegetation, and high level of CO₂. In Indonesia specifically, one of contributing factors of Urban Heat Island (UHI) is solar radiation reflected by roof and wall surfaces in the form of short waves, which contributes to increasing global temperatures. When sunlight reaches the roof surface, three main processes occur: absorption, solar reflection, and thermal emissivity. Absorption occurs when the material stores some of the heat, while solar reflection allows some of the solar energy to be reflected back. Thermal emissivity is the process by which the roof releases the absorbed heat back into the atmosphere (Paramita et al., 2022). Although there are many types of roof materials available, many Indonesians use affordable and lightweight materials to cover their roof. One of the common roofing materials in zinc, which is commonly used due to its weight and ease of installation. However, it has high thermal conductivity, which can lead to overheating indoors, making it less ideal for thermal comfort in tropical climates (Lapisa et al., 2020).

Urban Heat Island also not only becomes a large contributors of climate change, but also poses significant threat to urban population especially vulnerable communities. Many disasters such as flood, sea level rise, heat wave, and extreme weather are the cause of amplification of UHI in urban areas, which also expose urban population to dangers (Rosenbaum, 2024). UHI also disproportionately affect vulnerable population due to socio-economic, demographic, and environmental factors, especially in urban areas. The ramifications of Urban Heat Islands (UHIs) are intensified by variables including substandard housing conditions, restricted availability of cooling mechanisms, and a deficiency in green spaces. People within low-economic background often reside in overly dense areas with minimal cooling infrastructure such as vegetation, shaded areas, and well-circulated environment (Pontius & McIntosh, 2024; Szemerédi & Remsei, 2024). The impact of UHI also prevalent in Health. Urban demographics encounter heightened health hazards, including heat related illness and the rise of neurodegenerative disorders attributed to higher temperature and air contamination (Tewari et al., 2023). As Indonesia has hot and humid climate, 9,78% of its population or more than 26 million Indonesian comes from low-income economic group which makes them more vulnerable to UHI impacts (Paramita et al., 2022). Therefore, the impacts of UHI in human quality of life and its contribution to climate change should be mitigated urgently.

Solar Reflective House (named Rumah Reflektif Surya or RAFLESIA in Indonesian) is one of the solutions to Urban Heat Island. RAFLESIA uses innovation in a form of roofing materials and metal cladding walls which coated in highly solar reflective technology (Ramadhan et al., 2022). It becomes the most cost and time effective solutions to mitigate the impact of UHI, especially in densely populated areas and low-income housing. The roof cover and the

reflective wall was proven to be effective in reducing surface temperature to 40% to 60%. Unlike conventional roofing and wall materials, which reflect less than 50% of solar radiation and primarily reflect in the short-wave spectrum (around 700nm), RAFLESIA has a solar radiation reflectance exceeding 80%, extending into the long-wave range of 700-2,500nm. This is measured by the Solar Reflectance Index (SRI), a metric that indicates how well a material reflects solar radiation and emits absorbed heat based on its emissivity. High-SRI materials generally reflect more solar radiation, whereas low-SRI materials retain more heat. RAFLESIA significantly reduces surface temperatures by limiting heat transfer from exterior surfaces, which helps maintain a cooler indoor environment. This cooling effect can decrease energy demand for air conditioning, thus contributing to energy savings and supporting efforts to mitigate global warming.

1.2. Urgency

Although useful, RAFLESIA has to be implemented widely to be more impactful to society. Implementing technology to low-income housing is complex and multifaceted. There multiple stakeholders contribute to the success of the technology implementation. The educational institutions, which in the case is Universitas Pendidikan Indonesia, play an important role in knowledge and technology creation while industries engage in practical application and commercialization (Afonso et al., 2012). On the other hand, the government, in this case Housing Department of West Java, provides regulatory framework and create programs that can be widely implemented (Afonso et al., 2012). The community, which benefitted from the implementation, helps to ensure that implementation aligns with their value and needs (Razak et al., 2024). In this context, RAFLESIA implementation is the result of collaboration in quadruple helix model involving the aforementioned stakeholders in a program named Rutilahu (Rumah Tinggal Layak Huni or Habitable House). RAFLESIA houses were built in several locations, especially in the low-income communities and in the areas exposed to more heat. One of the implementation areas is Pangandaran, which is located in the southern coast of West Java, adjacent to the Indian Ocean. Due to its location, it has the average annual temperature of 26.8oC with the highest record of 32.9oC. The paper explores the process of RAFLESIA implementation in two houses chosen based on several criteria and how the solar reflective technology helps in reducing the house temperature. It also serves as a pilot project in a broader implementation in the future. In details, the project itself aims to encourage:

- *Energy Efficiency*: RAFLESIA can reduce the need for cooling in hot climates, reducing energy consumption and greenhouse gas emissions.
- *Human Comfort*: With lower indoor temperatures, home occupants experience a higher level of comfort, reducing the risk of diseases caused by extreme heat.
- *UHI Reduction*: By using heat-reflecting materials, RAFLESIA can also help reduce the Urban Heat Island effect in the surrounding environment, creating a more comfortable area for city dwellers.
- *Cost Savings*: The use of solar RAFLESIA can result in long-term cost savings in both energy consumption and building maintenance.
- *Reducing Global Warming*: By reducing energy use and heat emissions in urban areas, RAFLESIA can also make a positive contribution to global efforts to address global warming.

2. METODHS

The method used in the research is Action Research. Action research represents a participatory and iterative methodological approach that underscores the significance of collaboration and critical reflection to tackle real-world challenges. Within the domain of the

built environment, it functions as an essential instrument for the synthesis of theoretical frameworks with practical implementation, thereby enabling researchers to interact directly with the environments under examination. The method was chosen as it suitable particularly in the field of architecture and construction management, wherein the fluid dynamics of design and construction processes necessitate research methodologies that are both adaptable and contextually responsive. In architecture and design, action research aligns well with the iterative nature of design processes, allowing for the development of research that is both rigorous and practically applicable (Herr, 2015). It also helps facilitate collaboration between stakeholders and allow direct observations for evaluation (Thün & Velikov, 2011).



Figure 1 Flowchart Method
Source: Author, 2024

- **Plan:** The project is collaboratively designed by Universitas Pendidikan Indonesia, PT. Diwangkara Wihaya Nusantara, the local community, local government and the West Java Department of Housing. The primary goal is to investigate whether RAFLESIA roofing and cladding can effectively reduce surface and interior temperatures, improving indoor comfort and potentially reducing energy consumption in two selected houses. This step involves setting objectives, selecting temperature metrics, and establishing a timeline.
- **Describe:** Before implementation, baseline data on current temperatures in and around the selected houses are recorded. The process of selecting the houses to built and who will reside in RAFLESIA houses determined by the input from local community
- **Act:** RAFLESIA materials are installed on the roofs and cladding of the two houses. Community members are involved in the installation process to foster understanding and gain insights from hands-on experience. This phase includes active monitoring of temperature changes at different times of day to assess the cooling effect of the reflective material.
- **Evaluate:** After implementation, temperature data from both the house surfaces and interiors are analyzed to determine RAFLESIA's effectiveness in reducing heat. Community feedback and observed comfort levels are also collected. If proven effective, the results will support broader implementation across similar urban areas, contributing to local resilience and energy efficiency.

This cycle of planning, acting, and evaluating allows for adjustments and continuous improvement, with the long-term aim of applying RAFLESIA as a sustainable solution for urban cooling in vulnerable areas. The selection of the houses was based on several factors, namely

the condition of the house, the allocated budget which should be able to cover the renovation, and the willingness of the residents to contribute to the project. The assessment was done by the locals led by the community leader. The data was collected through observation, field notes, and direct measurement, which then validated through triangulation. The data was then organized, reduced, and coded to be critically reflected for further implementation.

3. RESULT AND DISCUSSION

To understand the context of the research, the location and the characteristics of the community should be understood. The research was conducted in Sidomulyo Village, Pangandaran Regency, which is a densely populated area. This location was chosen because of the diverse social and economic conditions and challenges faced by the community in terms of high ambient temperatures and rising electricity costs, especially in the summer. Due to its location close to the beach, the area is very hot especially during the day. This condition causes indoor temperatures to become uncomfortable and requires more cooling and increases electricity consumption.

Although land prices in this village are still quite affordable and land is available in abundance, The local community still could not afford to buy more land. The economy of the local residents, most of whom work as fishermen and casual workers with low incomes, also does not allow them to improve their housing conditions or increase household operating costs. Electricity costs are a significant burden, especially since many houses are old and uninhabitable. The condition adds to the challenges in improving the quality of life and welfare of the community in Sidomulyo Village. There are main problems faced by the Sidomulyo Village community, which were identified through the research, namely high indoor temperatures, which reduce the thermal comfort of building users, and uninhabitable housing conditions. Based on the input from local government and the community, there are two houses chosen to be rebuilt as RAFLESIA, which are M family's and S family's house. The houses were chosen as it is considered the most urgent to be fixed and the repair costs matches the budget.

3.1. Collaborative Roles

The program was conducted as the result of collaboration between West Java Department of Housing. The program itself was actually a part of formal and nationally recognized program that focuses on improving uninhabitable houses to be habitable. The department provided raw materials and field facilitators to help residents build their homes. It is important to ensure that the program aligns with broader social welfare goals (Harwianti, 2022). However, RAFLESIA's recipients are also required to personally contribute to the program in the form of money, materials or labors to ensure the successful delivery of the program. As research suggest, active involvement from community who benefitted from a program will encourage sense of ownership and responsibility to maintain the sustainability of the program (Ashrafuzzaman & Rahman, 2020; Hoe & Wahab, 2013; Mbise & Sosiya, 2023).

In addition, this program involved PT. Diwangkara Wihaya Nusantara, which is the main partner of Universitas Pendidikan Indonesia for the distribution of solar reflective paint "βeCool" to coat metal cladding which will be used as reflective roofs and walls. Reflective and radiative roofs are passive cooling techniques that can help reduce energy consumption in tropical homes. This is the main value of the RAFLESIA program in reducing temperature and carbon emissions. On the other hand, Universitas Pendidikan Indonesia was responsible to ensure that the inquiry process was thoroughly conducted to ensure more detailed and comprehensive evaluation. It also contributed to the development of RAFLESIA as the product

of academic process in creating habitable residential. It highlighted the importance of academics in the program, which resonates with other community programs that has been proven to be successful (Arief Sabaruddin, n.d.; Soesilowati, 2017).

3.2. The Process of Implementation



The implementation process started with the selection of beneficiaries of RAFLESIA. As The Department of Housing has a set of parameters and the data collected regularly, they could recommend several potential beneficiaries. The area was then surveyed to ensure the existing condition. The selection process itself involved the local community and local government which obtained by conducting interviews, direct measurement and observation, as well as discussion. In this context, two beneficiaries were selected, which are S family and M family. It is due to the unhabitable living conditions that the two families experience which needed urgent care. In a lengthy process, it is also agreed upon that each family should provide support for the program in the form of finance, raw materials, and labor. The construction workers were mostly local residents although many RAFLESIA components were pre-fabricated. However, the workers were also given a guideline and the facilitators were also present to ensure that the workers understand and conducting the works correctly (see figure 2 and figure 3).



Figure 3 Sample of Manuals for M Family's house
Source: Author, 2024

In details, the process of implementation can also be compared and observed in the Table 1.

Tabel 1 Process and Result Comparison of RAFLESIA Implementation

Process	S Family	M Family
Existing Condition	 <p>Figure 1 Existing Condition of S Family House</p> <p>The materials of the walls were made of woods, which was decaying. There are some leaks from the roof and the structure were no longer sound. The indoor temperature was hot and humid. The house was considered uninhabitable.</p>	 <p>Figure 2 Existing Condition of M Family House</p> <p>The materials of the walls were made of woods, which was decaying. There are some leaks from the roof and the structure were no longer sound. The indoor temperature was hot and humid. The house was considered uninhabitable.</p>
Needs	<p>S family consists of Mr. S and his son. He needs two bedrooms and a house with gable roof with better structure. They also need a kitchen and a decent bathroom at the back of the house.</p>	<p>M family consists of 4 people. They need two bedrooms, a kitchen, and a bathroom. Mr. M needs a roof that ensure the rain water runoff was distributed properly. They also need structure renovation and materials change.</p>

Design



Figure 3 Plan of S family RAFLESIA house



Figure 4 Elevations and Sections of S family RAFLESIA house



Figure 5 Plan of M Family's RAFLESIA house



Figure 6 Elevations and Sections of M family's RAFLESIA house

Process	S Family	M Family
	The Design was made by the University team along with the beneficiary. All needs were properly addressed.	The Design was made by the University team along with the beneficiary. All needs were properly addressed.

Construction Process & Result



Figure 7 The Construction Process of S family's House (top); The finished look (middle and bottom)

Figure 8 The Construction Process of M family's House (top); The finished look (middle and bottom)

Surface Temperature



Figure 9 The surface temperature of S family's house comparison with adjacent house

Figure 10 The surface temperature of M family's house comparison with adjacent house

When compared to the adjacent building with similar materials, S

Family's

Process	S Family	M Family
	Family's RAFLESIA house surface temperature was colder by 8.5°C (40.2°C to 31.7°C). It shows the materials used in RAFLESIA can reduce the temperature and potentially improve thermal comfort	RAFLESIA house surface temperature was colder by 22.1°C (53.7°C to 31.6°C). It shows the materials used in RAFLESIA can significantly reduce the temperature and potentially improve thermal comfort.

Both houses shows that RAFLESIA have a significant impact in lowering the surface temperature of the house. It can potentially reduce energy consumption by 20% and even more. The finding is consistent with similar research that lower surface temperature leads to more efficient energy use (Kaya et al., 2021). More efficient energy use lower also benefitted the beneficiaries financially as it lowers the electricity bills (Khosravi et al., 2023). It also provides better thermal comfort for the residents and reduce health risks associated with heat as heatstroke (Etxebarria et al., 2020; Omonijo, 2017; Wang et al., 2023). In wider perspective, if implemented to more houses in the same area, it could potentially reduce the effect of UHI (Hong et al., 2022; Khorat et al., 2024; Macintyre & Heaviside, 2019).

3.3. The Potentials for Further Implementation

The potential sustainability benefits of the RAFLESIA program are significant, starting with the reduction of surface temperature by approximately 20°C, which contributes to mitigating the Urban Heat Island (UHI) effect. By lowering surface temperatures, the program not only enhances indoor comfort for residents but also helps cool the surrounding urban environment, which can positively impact public health and energy efficiency in densely populated areas (Etxebarria et al., 2020; Wang et al., 2023). This success provides a strong foundation for further action, particularly in expanding the RAFLESIA model through the Rutilahu (Rumah Tinggal Layak Huni or Habitable House) program in the coming years. Such an expansion would extend the cooling and energy-saving benefits of RAFLESIA to a broader segment of vulnerable communities, enhancing overall housing quality and resilience in similar urban areas.

Additionally, the program holds promise in reducing carbon emissions. The materials used in RAFLESIA construction have been selected for their lower carbon footprint, potentially reducing emissions by up to 30% compared to conventional materials like brick and concrete (Bajare et al., 2024; Huang et al., 2023). This reduction is a meaningful contribution to environmental sustainability, aligning with broader efforts to combat climate change through green construction practices.

Furthermore, the RAFLESIA program emphasizes community participation and self-help initiatives. Through collaboration with the local housing and settlement authorities and the active involvement of community members, contributions in the form of self-funded resources, materials, and labor are facilitated. This community-driven model not only helps sustain and scale the program but also builds local ownership and skills, enhancing the long-term impact and success of the RAFLESIA initiative.

4. CONCLUSION

In conclusion, the RAFLESIA program has shown promising success in reducing surface temperatures and mitigating the Urban Heat Island effect, thereby improving indoor comfort and providing a sustainable housing solution for densely populated urban areas. The program's achievements highlight its potential for broader application, particularly within the Rutilahu initiative, to benefit more vulnerable communities with a model that promotes lower carbon emissions and fosters community participation.

However, to ensure the program's continued success and scalability, several areas require refinement. Defining clearer goals and measurable parameters will strengthen the program's impact assessment and provide a more structured approach to expansion. Additionally, agreement on financial contributions and time management among all stakeholders is crucial to prevent potential conflicts. By addressing these aspects, RAFLESIA can serve as a more robust model for sustainable urban development, aligning all partners in a shared vision and reinforcing the program's positive outcomes.

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