Building climate resilience in Indonesia:

The role of cool roofs

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Workers painting a roof with BeCool solar-reflective paint

Beta Paramita is an Associate Professor in the Architecture Department at Universitas Pendidikan Indonesia (UPI), with a Doctorate in Engineering from The University of Kitakyushu, Japan. She is currently chair of the center of excellence for low carbon building material and energy in UPI. Her research focuses on sustainable cities and green buildings, particularly building performance and outdoor thermal comfort. In 2022, she won the Million Cool Roofs Challenge and founded BeCool Indonesia, a start-up promoting passive cooling designs across Indonesia through BeCool solar reflective paint produced by PT Driya in collaboration with Universitas Pendidikan Indonesia.

The urban population in Indonesia is characterized by rapid growth, while urban microclimates are developing in the context of climate change, increasingly having a detrimental impact on human health, especially due to significant heat-related challenges. BeCool's solar reflective paint allows for a cooler surface on painted roofing materials, similar to the effect of wearing white clothes during the day. This innovative technology helps make a concrete contribution to global warming mitigation efforts in Indonesian cities, as it combats the urban heat island effect and its negative impacts, thereby preserving the health of urban dwellers. By reflecting sunlight back into the atmosphere, applying paint can reduce outer surface temperatures by 15°C and inner space temperatures by 3°C, resulting in an 80% reduction in ozone warming.

BeCool's commitment to mitigating global warming extends beyond developing innovative products. The company actively participates in various programs, including painting public buildings, residences, worship and educational buildings. Additionally, BeCool provides education to students across different regions in Indonesia and builds solar reflective houses. These initiatives aim to foster sustainable environmental improvements, ultimately enhancing the health and quality of life within the community.

INTRODUCTION

As urban populations grow, so does urban development, which accounts for 40% of the world's energy consumption. The densely populated urban areas in Indonesia suffer from poor ventilation, leading to the trapping of heat in buildings throughout the day. This trapped heat is only released at night, resulting in what is known as the urban heat island effect. Consequently, achieving thermal comfort becomes challenging, especially when humidity levels are high and air conditioning is lacking, leading to various respiratory diseases.

Unfortunately, these conditions persist and have a detrimental impact on health, often going unnoticed. Ironically, the use of air conditioning to achieve thermal comfort further negatively contributes to global warming. The lack of proper air circulation allows diseases to thrive and circulate in a repetitive pattern. Therefore, concrete measures are necessary to mitigate global warming and preserve the environment and well-being of the community.

INDONESIAN CITIES AND URBAN DWELLERS FACE IMPORTANT HEAT-RELATED CHALLENGES, WHICH ARE EXPECTED TO WORSEN DUE TO CLIMATE CHANGE

Indonesia's urban population has now reached 59%.[1] Cities face higher potential disaster losses than rural or suburban areas due to the concentration of population and economic activities.[2] The United Nations Environment Program (UNEP) reported that the built environment is responsible for 40% of global energy consumption, 30% of greenhouse gas emissions, waste production, and natural resource utilization. This energy is released as heat, leading to the formation of urban heat islands, where temperatures are higher than those of the surrounding areas.

"The incorrect choice of building materials and design can lead to adverse effects caused by high ambient temperatures and humidity. This, in turn, can contribute to the prevalence of different diseases."

Urban villages in Indonesia's major cities are characterized by a rapid growth in residential areas. The high building density and extensive surface area contribute to the formation of a unique urban microclimate, leading to a noticeable increase in local temperatures. The lack of proper air circulation systems in densely built urban villages hinders the quick dissipation of heat trapped within the structures. Consequently, the heat is released during the afternoon and evening, causing nighttime air temperatures to be higher than in the morning.

The increasing development of such urban microclimates in the context of a changing climate has a detrimental impact on the living conditions of the communities, as evidenced by the elevated thermal discomfort index in outdoor areas. Furthermore, the lack of proper ventilation exacerbates humidity levels, resulting in increased reliance on air-conditioning systems that contribute to global warming.

Furthermore, Indonesia, as a tropical archipelago, is known for its hot and humid climate. The duration of daylight and nighttime is almost equal throughout the year, resulting in consistently high temperatures, high humidity, and relatively calm winds. Consequently, the cities in Indonesia generally struggle to provide comfortable outdoor spaces.

Typically, coastal cities in Indonesia experience a peak air temperature of 33°C, while lowland cities have a maximum air temperature of 30°C. On the other hand, cities situated in hilly areas have the lowest maximum air temperature ranging from 25-28°C. The incorrect choice of building materials and design can lead to adverse effects caused by high ambient temperatures and humidity. This, in turn, can contribute to the prevalence of different diseases, particularly in densely populated residential areas affected by the urban heat island phenomenon.

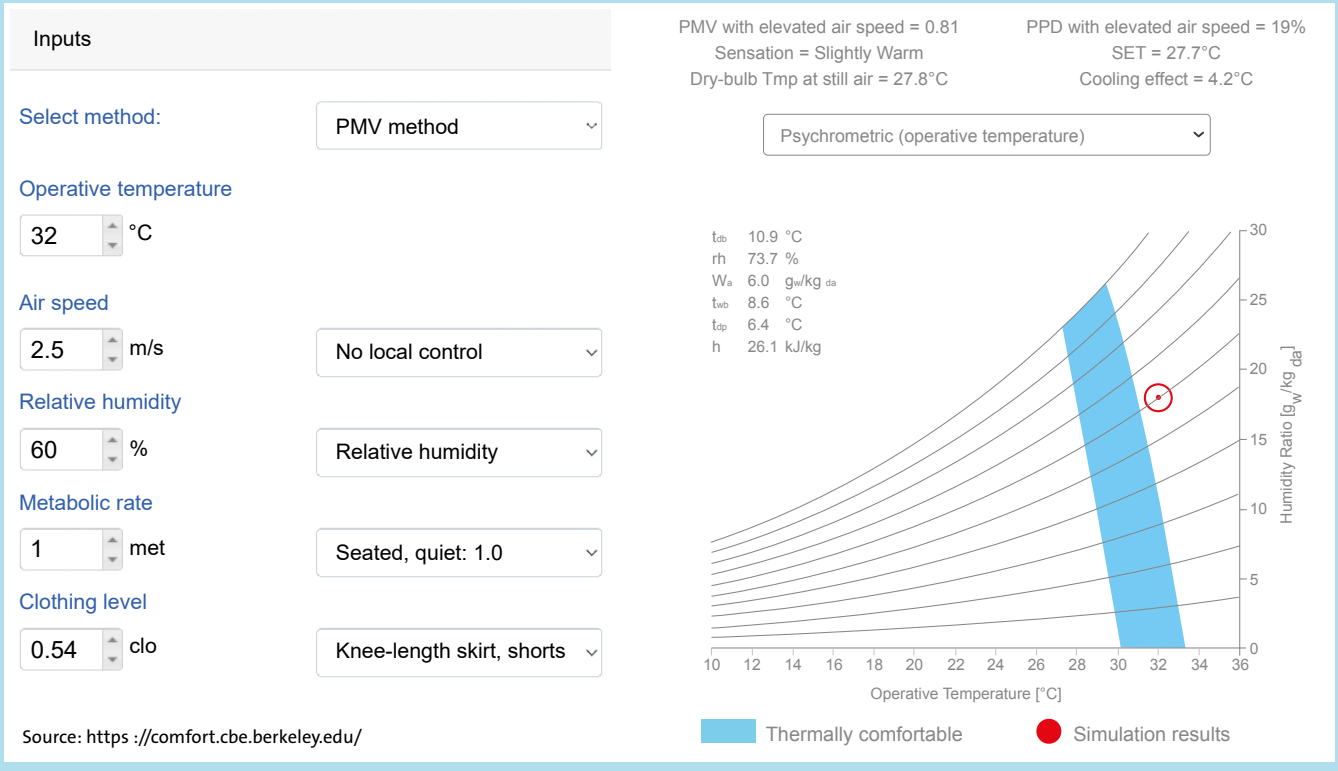
Indonesia ranks second globally in terms of tuberculosis cases, according to the World Health Organization's 2023 report.[3] Various studies have revealed that the environment, including

1 Statista. (2024). Share of the urban population in Indonesia 2014-2023. Statista. https://www.statista.com/statistics/761113/share-of-urban-population-indonesia/.

2 Dickson, E. (2012). Urban risk assessments: Understanding disaster and climate risk in cities. The World Bank.

3 World Health Organization. (2023). Global tuberculosis report: Tuberculosis incidence. World Health Organization. https://www.who.int/data/gho/data/themes/mortality-and-global-health-estimates/ghe-life-expectancy-and-healthy-life-expectancy.

Figure 1: **Thermal Discomfort Index (Simulation in Bandung Dense Housing Area at 12.00 AM with CBE Thermal Comfort Tool)**



Source: https ://comfort.cbe.berkeley.edu/

houses and residential areas, plays a significant role in the transmission of tuberculosis, with a potential impact up to 35 times higher.[4] This is due to the region's high population density, elevated temperatures, and limited airflow, resulting in heat being retained within the building materials. This accumulation of heat contributes to increased humidity levels in the air, which can lead to health issues. Furthermore, the use of air conditioners in such conditions can contribute to the spread of airborne diseases. Typically, respiratory tract diseases are the most common health issues associated with unhealthy living spaces.

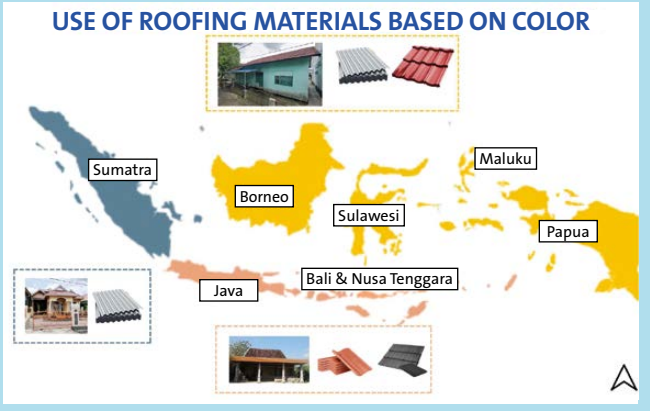
The low latitude region of Indonesia, situated close to the equator, experiences a hot, humid climate heavily influenced by solar radiation. The intense sunlight in this region drives significant heat transfer, making it a key factor in determining outdoor conditions.

The expansion of urban villages is steadily rising each year, necessitating the implementation of passive design strategies to minimize the heat absorbed from solar radiation. It is crucial for materials in urban areas to possess specific qualities such as high u-value,[5] high albedo value,[6] and a high SRI (solar reflectance index) value. Utilizing materials such as BeCool solar reflective paint, which fulfills these requirements, can serve as an effective solution for urban villages characterized by dense slums.

MATERIAL USED FOR ROOFING HAVE A SIGNIFICANT IMPACT ON INDOOR TEMPERATURE, AND THEIR CHOICE IS INFLUENCED BY ENVIRONMENTAL AND CULTURAL FACTORS

Indonesia, made of 17,508 islands, exhibits a diverse architectural approach in each region. The design philosophy considers the unique attributes of each area, including natural calamities potential, climate conditions, and the socio-cultural fabric of the local community.

Figure 2: **Use of roofing materials across Indonesia**



4 Wahyudi, A. S., Raufuddin, & Suarilah, I. (2019). The relationship between healthy housing conditions and pulmonary tuberculosis. Proceedings of the International Conference on Environment and Urban Sustainability, 657–663. https://doi.org/10.5220/0008330506570663.

5 The U-value (or thermal-transmittance) measures how effective a material is an insulator.

6 The albedo value indicates how well a surface reflects solar energy, varying between 0 and 1. Albedo commonly refers to the "whiteness" of a surface, with 0 meaning black and 1 meaning white.

Natural calamities are very likely to occur in the country due to its location in the "Ring of Fire" region, where four major tectonic plates interact. The country comprises three primary islands: Java Island, Sumatra Island, and Kalimantan Island (Borneo).

Sumatra, the westernmost island in Indonesia, is particularly prone to earthquakes and tsunamis. These factors greatly influence the selection of roof covering materials, favoring lightweight options like zinc, alderon, and zincalume. In contrast, in Java Island, clay or asphalt roof tiles are more commonly used. There exists a belief within the community in Sumatra that using roof materials derived from soil is equivalent to self-burial, leading to the avoidance of clay roof tiles by certain populations on the island.

On the other hand, in Kalimantan Island, the choice of roof covering materials differs, ranging from clay, asphalt, or metal roof tiles to lightweight options. This variation is due to Kalimantan Island being less susceptible to risks compared to its counterparts, as it is not situated within the Pacific Ring of Fire.

The temperature of the indoor space of a building is influenced by the roof coverings used. Structures featuring lightweight roof coverings like zinc, alderon, or zincalume tend to be warmer as these materials lack efficient thermal conductivity unless treated. Nevertheless, these lightweight materials are extensively employed in Java and Kalimantan, particularly in regions with high residential density and low economic conditions due to their affordability. Industrial buildings also commonly use these materials.

Buildings featuring clay or asphalt roof tile coverings, which possess low thermal conductivity, lead to lower room temperatures in the space below compared to structures with other roofing materials.

CASE STUDY: ENHANCING URBAN RESILIENCE AND HUMAN HEALTH IN INDONESIA WITH SOLAR REFLECTIVE PAINT

a. Solar reflective paint for cooler, healthier indoors

BeCool produces solar reflective paint that works by reflecting a greater amount of solar radiation and absorbing less heat compared to a typical roof. Similar to wearing light-colored clothing in the daytime, roofs treated with such a paint will remain cooler than dark-colored roofs, resulting in lower room temperatures below and decreasing the need for air conditioning, thus offering thermal comfort to occupants.

The use of dark-hued materials on roofs results in a 38% contribution to atmospheric warming, whereas the use of solar reflective paint leads to only 10% of heat being absorbed into the atmosphere, with 80% of sunlight being reflected back through invisible waves, thus helping prevent global warming on Earth.

BeCool's global warming mitigation initiatives, implemented from 2019 to 2023, have taken place on numerous Indonesian islands like Sumatra, Kalimantan (Borneo), Sulawesi, and Nusa Tenggara. These initiatives encompassed residential areas, industrial zones, educational institutions, public buildings, and more, targeting primarily clay tile and metal materials. These efforts benefited not only the occupants of the structures but also the environment at large.

Figure 3: Map of BeCool's actions in Indonesia from 2019 to 2023

1. Tangerang
- Industrial Building
- Elementary School
- Low-cost housing
- Religious building
- Government building

1. Jakarta - Elementary School
2. Jepara - Elementary School
3. Wantilan, Subang
- Elementary School
- Low-cost housing
- Gymnasium

4. Bandung - Junior High School
5. Cikelet, Garut - Senior High School
6. Pameungpeuk, Garut - Senior High School
7. Sukabumi - Elementary School
8. Kupang, NTT - Religious building
9. Manado - Junior High School
10. Pontianak - Orphanage Building
11. Bangka Belitung - University Building
12. Langsa, Aceh - School (elementary, junior, senior)
13. Tasikmalaya - Industry Building
14. Subang - Industry Building

1. Banda Aceh - Universitas Syiah Kuala
2. Langsa - Universitas Samudra
3. Jambi - Universitas Adiwangsa Jambi
4. Palembang
- Universitas Tridinanti Palembang
- Universitas Indo Global Mandiri
- Universitas Sriwijaya

5. Jakarta - Universitas Tanri Abeng
6. Bandung - Universitas Pendidikan Indonesia
7. Semarang - Universitas PGRI Semarang
8. Malang - Universitas Brawijaya
9. Mataram - Universitas Mataram
10. NTT - Universitas Nusa Nipa
11. Gorontalo - Universitas Negeri Gorontalo

1. Mamuju, Aceh - Mosque Al Munawaroh
2. Deli Serdang - Church Injili Nusantara
3. Sikakap, Mentawai - Mosque Al Ikhla
4. Indragiri, Riau - Mosque Baitur Rahma
5. Bengkulu - Mosque Fathul Jannah
6. Tangerang - Mosque Arrahman
7. Cimahi - Mosque Al Hanif
8. Kolikapa, NTT - Mosque At-Taqwa
9. Nagakeo, NTT - Church GMIT Ebenhaezer
10. Banggai, Sulawesi - Mosque Nurul Jamil

Kampung BeCool
1. Bengkulu - Pasar Bengkulu
2. Kab. Bandung - Tipar
3. Gorontalo - Tanjung Kramat

Applying reflecting paint can indeed lower the roof surface temperature by approximately 10-15°C and decrease indoor temperature by 1-3°C. This leads to a decrease in air conditioning usage, resulting in reduced carbon emissions and lower indoor humidity levels, positively impacting the occupants' health.

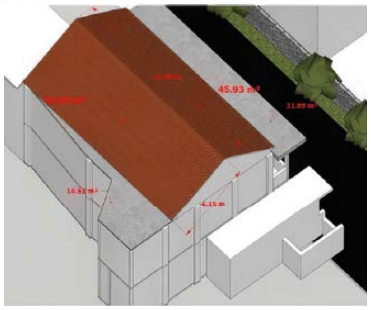
Figure 4: BeCool solar reflective paint

BeCool led multiple initiatives to provide better living conditions for Indonesians and help improve society's adaptation to climate change.

For example, the utilization of solar reflective paint on an office's roofing material in Bandung reduced the surface temperature by 13°C, thereby lowering the indoor temperature from 29.8°C to 27.7°C ***(Figure 5)***. This cooling effect not only curtails the reliance on air conditioning units but also enhances the overall thermal comfort experienced by the employees.

Figure 5: BeCool Project on Aaksen architecture building office

βeCool **Pilot Projects: AAKSEN Studio, Bandung**



AAKSEN ARCHITECTURE CONSULTANT
https://aaksenstudio.com/
https://www.instagram.com/aaksenstudio/

Indoor temperature after being painted on Cool Roofs is 29.8°C and the result using a FLIR camera is 27.7°C which was carried out on January 20, 2022. Previously, it was 44.2°C. Then the roof surface temperature that has been coated is 38.3°C and that not coated is 51.3°C.

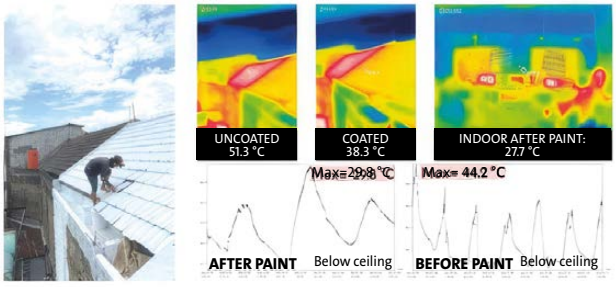
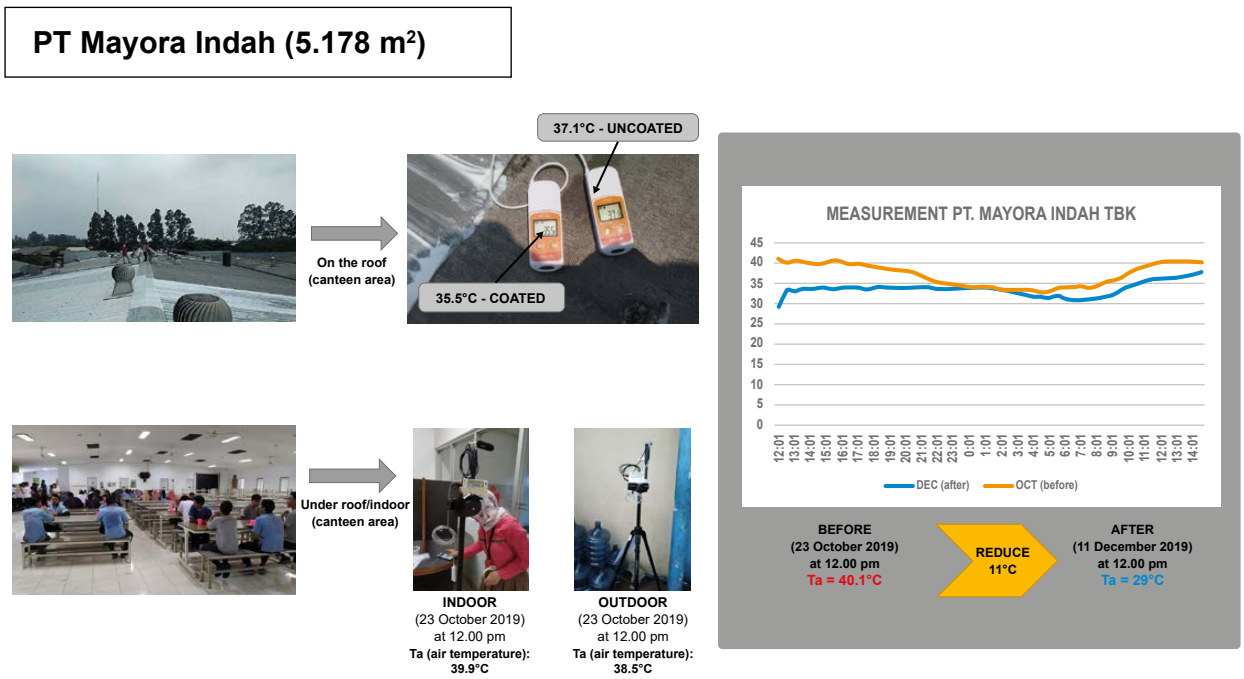


Figure 6: Results of a painting experiment conducted on and under the roof of an industrial facility



On a broader scale, BeCool was also utilized on the rooftop of an industrial facility situated in Tangerang. The application covered an area of 5,178 m² and resulted in a significant reduction in surface temperature by 11°C, thereby creating a cooler ambiance within the building.

The BeCool Village project ***(Figure 7)***, implemented in 2023, aimed at enhancing the microclimate of various residential areas across Indonesia, including Bandung, Bengkulu, and Gorontalo, by applying reflective paint on multiple roof surfaces. As a result, the indoor temperature in the residents' homes was reduced, providing a more comfortable living environment.

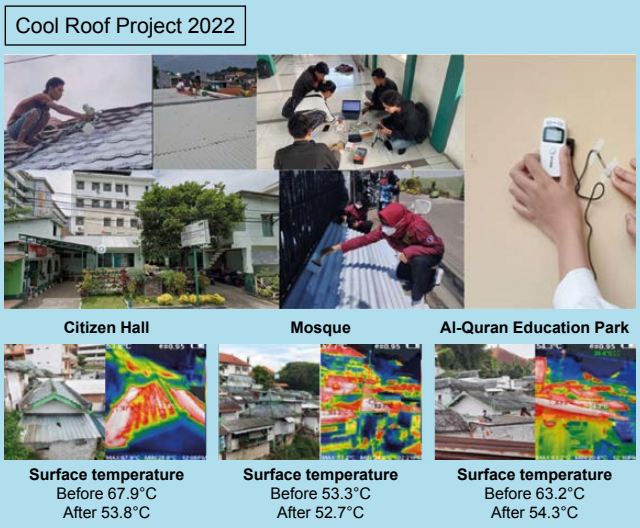
Figure 7: BeCool Village project

b. The Cool Roof Project: articulating painting projects and community engagement

Throughout 2022, BeCool led another project called the Cool Roof Project, collaborating with multiple universities in Indonesia to contribute to environmental improvements through the Global Warming Mitigation learning program. A series of lectures were conducted over a span of 16 weeks to teach students about urban heat islands and how to mitigate their impact. These lectures featured renowned practitioners and academics from both national and international backgrounds.

During the first quarter, online presentations were organized for students from different regions in Indonesia. In the subsequent weeks, the knowledge imparted during these presentations was put into practice by educating the community about global warming and undertaking painting projects on 70 buildings across 15 cities.

Figure 8: Cool Roof Project led in 2022: Pictures and results in surface temperature



A total of 267 students and 43 lecturers actively participated in this program, working together to raise awareness about the significance of global warming mitigation. The painting process involved not only the students and faculty, but also the local community, fostering knowledge sharing and enhancing the microclimate in the area. The choice of roof covering materials for the painting projects was tailored to suit the specific characteristics of each region.

The reduction in surface temperature achieved varied between 5 and 15°C, while the decrease in indoor temperature ranged from 1 to 3°C. This is anticipated to enhance the thermal comfort of the area for various activities such as living, working, and studying. A visual representation comparing the surface temperature of painted and non-painted surfaces is provided. ***(Figure 6)***

c. Extending activities beyond the painting of roof surfaces to ensure cool and resilient indoors

BeCool's activity goes beyond the painting of roofing surfaces. In collaboration with the metal industry, the company developed a metal sheet product coated with solar reflective paint, which can serve as a building envelope for walls and roofs. The result of this partnership is the creation of RAFLESIA (abbreviation for Indonesian solar reflective house).

Figure 9: RAFLESIA, a 100% solar reflective house in Indonesia

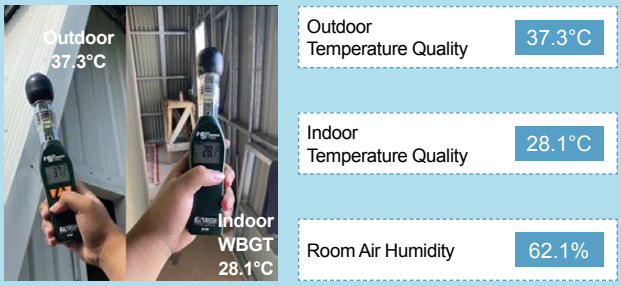
RAFLESIA has successfully built two residential units and a BeCool Lab in the West Bandung Regency. These houses serve as a residential aid for individuals who are living in inadequate housing conditions due to their physical health.

RAFLESIA houses stand out from typical Indonesian homes, which are built with concrete frames and brick walls. This unique dwelling is designed with a solar reflective concept, featuring an iron frame enveloped in metal cladding coated with BeCool paint. Despite its metal composition, the house maintains a pleasant indoor temperature, with a notable temperature difference of up to 9°C compared to the outside. As a result, it not only promotes energy efficiency but also contributes to the well-being of its occupants.

The striking design of RAFLESIA houses attracts attention within a residential neighborhood. This opportunity is leveraged by residents who establish a commercial space in front of their homes, thereby indirectly enhancing the community's quality of life.

Furthermore, RAFLESIA is tailored to suit the geographical conditions of Indonesia, a country prone to natural disasters like earthquakes. By incorporating lightweight materials, the vulnerability to earthquakes can be lessened. RAFLESIA serves as a pioneering concept for housing in Indonesia, dispelling the belief that houses must be built using bricks. Additionally, the construction expenses for RAFLESIA are lower than those for brick houses. The objective is for RAFLESIA to be used as a preventive measure in disaster-prone areas, providing safer and more sustainable housing options for communities at risk.

Figure 10: Difference between outdoor and indoor temperatures – RAFLESIA solar reflective house



CONCLUSION

BeCool contributes to improving environmental quality and addressing the effects of global warming in Indonesia, through efforts tailored to the diverse needs and characteristics of the archipelago.

The application of its solar reflective paint can lower external and internal building temperatures, which helps lower humidity levels, thus minimizing the risk of disease transmission. Moreover, by reflecting solar radiation back into the atmosphere, BeCool's technology contributes to global warming mitigation. As of 2024, the paint has been applied to approximately ±300.000 m² of surfaces through community outreach programs, excluding commercial applications.

Beyond these measures, efforts have been undertaken to educate students in Indonesia through collaborations with professionals and academics, and real action is taken to involve the community in environmental conservation. The construction of RAFLESIA, an Indonesian solar reflective house with metal walls and roofs coated in reflective paint, is envisioned as the initial step towards introducing metal housing in Indonesia and further mitigating the effects of global warming.

Becool's ultimate goal is to enhance housing quality for middle- to lower-income families in Southeast Asia while contributing to global efforts to reduce energy consumption and lower carbon emissions. Additionally, to maximize environmental benefits and improve living standards, we encourage all segments of society to participate in these efforts through tangible actions, including by applying solar reflective paint to building surfaces.