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Optimization of Seed Bank Design with Window Placement Analysis in the Development Area of Forest and Germplasm Conservation in East Kalimantan

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Abstract – This study evaluates temperature conditions within the seed bank building at the National Forest and Germplasm Conservation Development (PKHPNN) in East Kalimantan, focusing on temperature control to ensure seed viability in a tropical environment. Thermal simulation results using Grasshopper Ladybug-Honeybee software indicate that the incubator and storage rooms meet the SNI standard, with temperatures ranging from 28.22°C to 28.71°C. However, the laboratory area has a maximum temperature of 28.62°C, exceeding the Ministry of Health's standard of 26°C. A design modification addressed this issue by relocating the windows to the south side to reduce direct sunlight exposure. A re-simulation showed a temperature reduction to 26.43°C, though slightly above the maximum allowable limit. This study has several limitations, including excluding building material types, which can impact temperature stability. Additionally, humidity control factors were not analyzed, even though humidity plays a crucial role in seed storage. Therefore, further research should consider additional strategies such as selecting materials with better thermal insulation, implementing ventilation systems, and integrating passive cooling technologies to improve energy efficiency. With a more comprehensive approach, the seed bank building design can be optimized to maintain stable temperature and humidity while meeting established seed conservation standards.

Keywords: *seed bank, thermal simulation, climate, Grasshopper Ladybug-Honeybee.*

I. INTRODUCTION

A seed bank is an efficient ex-situ conservation method for preserving genetic diversity and ensuring the availability of plant species for future use. Ex-situ conservation in seed banks is the most common approach to preserving plant genetic resources. These seed banks provide facilities for storing germplasm seeds in specially designed cold storage modules. (Sharmila et al., 2019). This facility is crucial in conservation efforts, especially for endangered plant species and crops. Additionally, it helps protect against biodiversity loss caused by environmental changes, habitat destruction, or climate change (Kasso & Balakrishnan, 2013). Its contribution extends beyond preserving genetic diversity; it also enhances ecosystem resilience by storing genetic information that enables species to survive under extreme conditions (Lennon et al., 2021). Seed banks also play a crucial role in preserving genetic diversity, which is key to species' resilience against environmental changes and disease threats (Schwartz et al., 2023). Additionally, seed banks, gene banks, nurseries, and other institutions can contribute to preserving genetic resources (Yadav et al., 2024). Effective seed bank management requires an understanding of seed dormancy and germination traits, which significantly impact the success of ecosystem restoration (Turner et al., 2022). Seed germination time is highly responsive to environmental influences, with temperature crucial in regulating the germination process (Mitchell et al., 2020).

However, in practice, seed banks face various challenges, particularly those related to climate change and local environmental conditions. Tropical regions like East Kalimantan experience high temperatures and relative humidity, which can accelerate seed degradation. Excessive humidity increases the risk of fungal growth and speeds up seed viability loss, while high temperatures can accelerate seed metabolism, thereby reducing its storage lifespan (Assefa, 2016). Additionally, high rainfall and the risk of forest fires due to hydrological drought are external factors that can affect seed banks' stability and operational efficiency in this region (Taufik et al., 2017). The effectiveness of seed banks is limited by factors such as climate change and habitat loss, which require a broader approach to biodiversity conservation. Climate change poses a significant threat to global biodiversity, affecting species distribution and leading to population declines. Many species are unable to adapt quickly enough to changing conditions, resulting in increased extinction rates (Uddin et al., 2024). Therefore, environmental management within seed bank facilities must be carried out carefully, particularly in controlling temperature, humidity, lighting, and air circulation.

In the National Forest and Germplasm Conservation Development (PKHPNN) project in East Kalimantan, the primary focus is optimizing seed bank design to support germplasm conservation within the tropical forest environment. The seed bank building has several rooms, including a preparation room, biology room, morphology room, kitchen and service area, incubation room, and seed storage room. To ensure the sustainability of this facility, each room serves a specific function and is integrated into the overall system. The core of the seed bank building is the seed storage room, where seeds are preserved under controlled conditions to maintain their viability over time. Proper treatment is essential to ensure seed quality during storage. Several key factors influence seed preservation, including the initial moisture content of the seeds at the time of storage, the use of airtight packaging, and storage conditions with low temperature and humidity levels (Rahmawati & Aqil, 2020). Low temperatures trigger significant changes in gene expression in seeds, promoting germination through molecular reprogramming (Mitchell et al., 2020). Cold storage can effectively maintain seed viability but requires a consistent power supply and optimal temperature and humidity conditions. This study found that germination rates were significantly higher in short- and medium-term storage than ambient conditions, enhancing seed germination (Sharmila et al., 2019).

Tropical environmental conditions, such as those in East Kalimantan, are characterized by high temperatures and humidity, posing significant challenges for the construction and operation of seed banks. The region's humid tropical climate, marked by high annual rainfall, supports lush rainforests and diverse ecosystems. However, hydrological drought, exacerbated by climate change, has led to increased tree mortality and severe forest fires (Taufik et al., 2017). This region harbors rich tree species diversity, with environmental factors such as soil texture, humidity, and elevation influencing species distribution and diversity patterns (Slik et al., 2009). High relative humidity (95% and 75%) combined with high temperatures (35°C) significantly accelerates seed deterioration, leading to a noticeable decline in germination and seed vigor (Assefa, 2016).

The seed bank building must meet thermal requirements to maintain the quality of stored seeds, considering the sensitivity of various seed types to temperature fluctuations. Temperature is one of the most crucial environmental factors influencing germination (Schwartz et al., 2023). Therefore, specific temperature regulations must be followed in the seed storage process. The room temperature for storing intermediate, orthodox, and recalcitrant seeds ranges from 25°C to 30°C, while the temperature in cool, dry storage (air-conditioned) is maintained between 18°C and 20°C. Meanwhile, humid cold storage ranges from 4°C to 8°C (SNI Standard, 2014). Proper temperature regulation prevents fungal growth and nutrient loss, preserving seed quality (Sokolovskaya & Valevskaya, 2023).

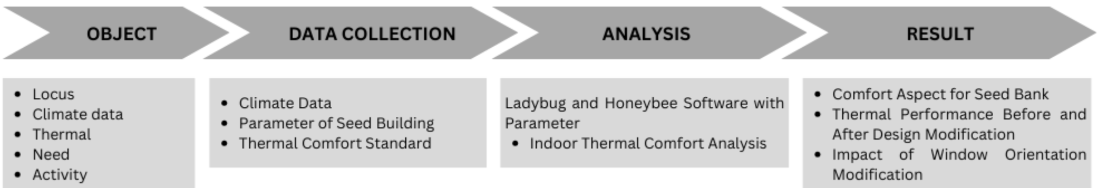
In addition to proper temperature and humidity control, the design of the seed bank building must also consider other factors, such as adequate lighting and air circulation. Excessive lighting can damage seeds, while poor air circulation can lead to excessive humidity, accelerating seed decay. Implementing an optimal design is crucial for maintaining long-term seed viability and ensuring that the seed bank functions as an effective conservation tool. Furthermore, seed banks are often used in research that requires controlled lighting conditions to study seed behavior and viability over time (Bhattacharya & Mummenhoff, 2024).

To address these challenges, this study utilizes Grasshopper software with the Ladybug and Honeybee plugins to analyze building thermal comfort and energy performance while optimizing the building design through realistic environmental simulations. In a study conducted in Egypt, simulations revealed significant variations in UTCI values across different climate zones, demonstrating the effectiveness of Ladybug in assessing thermal comfort in urban environments (El-Bahrawy, 2023). Environmental performance simulations based on local climate data use computer-generated mathematical models to calculate performance metrics. These simulations effectively demonstrate indoor and outdoor environmental quality from various perspectives (Lu et al., 2022).

Ladybug can perform various analyses, including sun path tracking, wind rose visualization, shadow range assessment, solar radiation mapping, and thermal comfort evaluation for indoor and outdoor environments. It also generates psychrometric charts and climate data visualizations in 2D and 3D formats, making it a comprehensive tool for environmental analysis. Ladybug lets users import EnergyPlus weather files (.epw) into the Grasshopper interface. This integration ensures that simulations are based on validated environmental data, crucial for accurate thermal comfort assessments (El-Bahrawy, 2023). Ladybug and Honeybee support thermal simulations by integrating weather data with building performance analysis. This integrated workflow enables real-time adjustments based on climatic conditions, enhancing indoor thermal comfort in architectural design (Tong, 2023).

The objective of this study is to optimize the design of the seed bank building by utilizing realistic environmental simulations to enhance thermal comfort. Using a climate data-driven approach and computer modeling, this research aims to develop adaptive design solutions suited to tropical climate conditions, thereby supporting more effective and sustainable germplasm conservation.

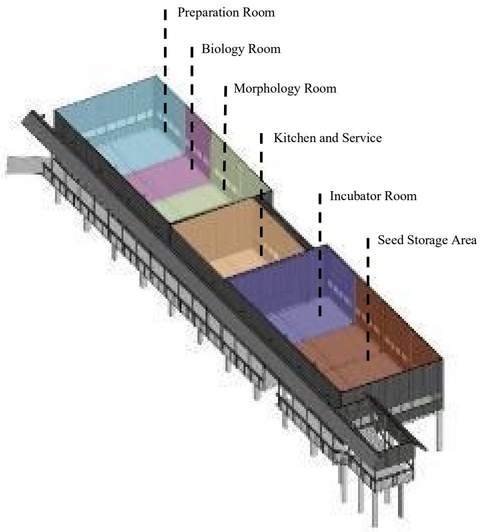
II. METHODOLOGY



This study was conducted at the seed bank in the National Forest and Germplasm Conservation Development (PKHPNN) area in East Kalimantan. This location was chosen due to its humid tropical climate with high temperature and humidity levels, which can potentially affect seed storage stability. The seed bank building consists of several main rooms, including a preparation room, a biology room, a morphology room, a kitchen and service area, an incubation room, and a seed storage room. Each room has a specific function to support long-term seed conservation and storage.

The primary data measured in this study is indoor air temperature. Measurements were conducted over seven days in September 2024, which marks the peak of the dry season in East Kalimantan. Data samples were collected from September 22 to 28, 2024, to capture the building's thermal conditions under extreme environmental conditions. Temperature data was recorded using digital temperature sensors placed at various points within the building to obtain an accurate temperature distribution.

This study employs a computer-based simulation approach to analyze and optimize building design for maintaining temperature stability. The initial simulation was conducted to determine the temperature levels before any design modifications. Subsequently, modifications were made by adjusting window dimensions to improve the building's thermal efficiency. After implementing these changes, a second simulation was performed to evaluate the effectiveness of the modifications in stabilizing the temperature within the seed storage room.



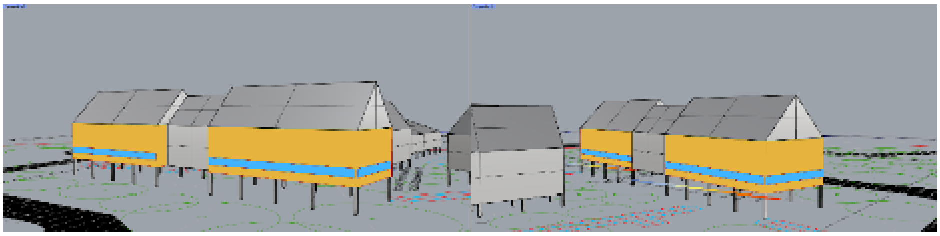
The Grasshopper software, along with the Ladybug and Honeybee plugins, was used in this study to simulate thermal comfort and building energy performance, specifically in seed bank design. Grasshopper was chosen for its ability to model parametric geometry flexibly, allowing for quick and precise design modifications based on analysis needs. Ladybug plays a crucial role in analyzing the sun's path, wind rose, solar radiation, and both indoor and outdoor thermal comfort (El-Bahrawy, 2023). Meanwhile, Honeybee enables the integration of weather data from EnergyPlus, allowing for more in-depth thermal simulations to evaluate the impact of design modifications on the room's thermal conditions (Tong, 2023). The selection of this software is based on its advantages in realistically modeling environmental conditions, providing comprehensive result visualizations, and enabling the testing of various design scenarios to achieve optimal thermal conditions.

One of the main advantages of Ladybug in architectural design analysis is its ability to perform accurate and efficient thermal simulations, allowing designers to evaluate the impact of openings on indoor thermal comfort. A study by Kim et al. demonstrated that Ladybug can be used to calculate the Sky Exposure Factor, which aids in designing optimal shading masks to maximize natural lighting while minimizing excess heat. Additionally, Ladybug supports multi-objective analysis, allowing for the simultaneous evaluation of various design parameters. A study by (Molake et al., 2023) demonstrated that Ladybug can be used to explore lighting performance and thermal comfort in courtyard houses in cold regions, proving its role in balancing natural lighting and thermal comfort—an essential aspect of sustainable building design. Furthermore, research by Dissanayake et al. has demonstrated that the use of Ladybug in urban design contexts can aid in understanding the impact of vegetation arrangements on outdoor thermal comfort (Dissanayake et al., 2023)By utilizing analyses conducted with Ladybug, designers can plan openings and other design elements that not only enhance thermal comfort but also contribute to mitigating the urban heat island effect.

The integration of Grasshopper, Ladybug, and Honeybee in this study enables a more in-depth analysis of indoor temperature distribution, particularly in the context of design modifications for the seed bank. The simulations aim to evaluate the effectiveness of design changes, such as window repositioning, in optimizing the storage room temperature to remain within established standards. This simulation-based approach helps understand the thermal impact of each design decision and serves as a foundation for developing more energy-efficient and sustainable building design strategies.

III. Result and Discussion

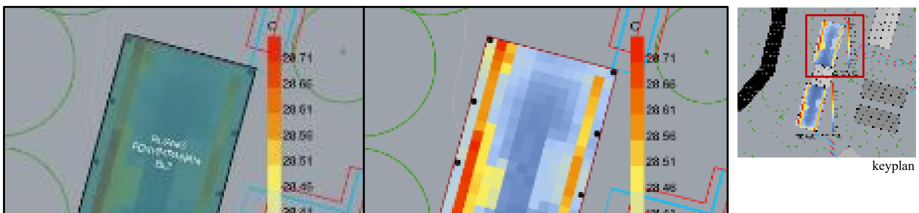
The design of the seed bank building developed by PT Hema Cipta Kreastika is still in the preliminary design stage, meaning that its architectural and functional elements have not yet been determined in detail. Therefore, this study conducts a room temperature simulation based on the existing preliminary design. Building material factors have not been considered as a primary variable at this stage, as material selection has not yet been determined. The main focus of the simulation is to analyze the impact of building massing and orientation on indoor temperature distribution.

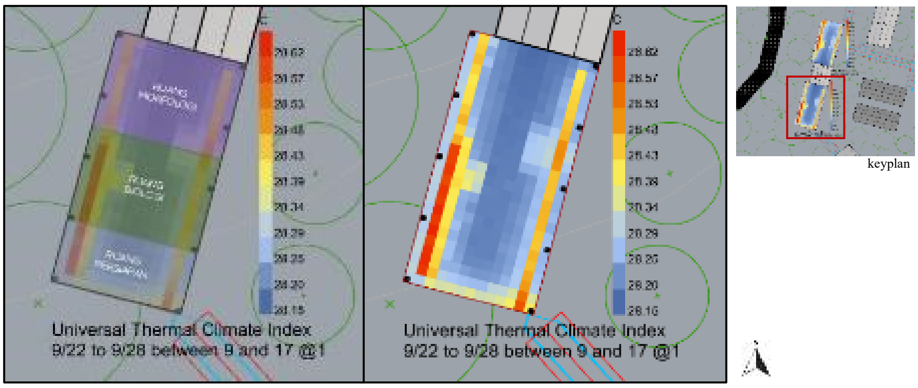


In **Figure 4**, the existing seed bank building has windows on all four sides—east, west, north, and south—with a height of one meter and a windowsill positioned one meter above the floor. This configuration results in high exposure to direct sunlight inside the room, particularly from the west and east sides, which contributes to an increase in indoor temperature. The building is located in East Kalimantan, a tropical region with relatively high ambient temperatures, so this condition can disrupt indoor temperature stability.

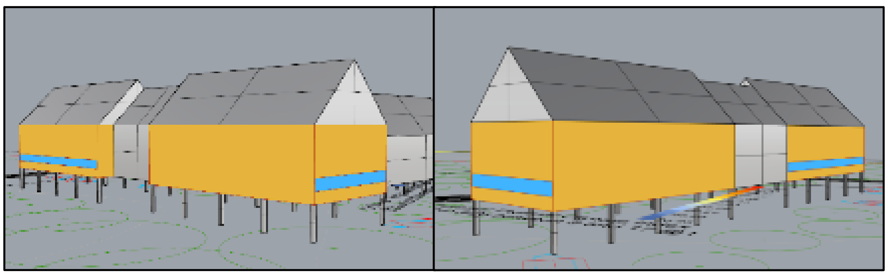
The simulation was conducted using Grasshopper software with the Ladybug-Honeybee plugin, with an observation period from September 22 to 28, 2024, during the peak of the dry season in East Kalimantan. The simulation was performed from 09:00 WITA to 17:00 WITA to analyze indoor temperature variations throughout the day.

This simulation incorporates trees and surrounding buildings as parameters in the thermal performance analysis. **In Figure 5**, the initial simulation results indicate that the seed storage room and incubator room have the highest temperature on the west side, reaching 28.71°C. In contrast, the lowest temperature is recorded in the central area of the room at 28.22°C. The temperature distribution is visualized in the simulation results, where light blue and dark blue colors dominate the seed storage room. A slight presence of orange appears on the west side, indicating higher heat exposure. This temperature range remains within the SNI (Indonesian National Standard) requirements for storing intermediate, orthodox, and recalcitrant seeds, which fall within the range of 25°C–30°C.



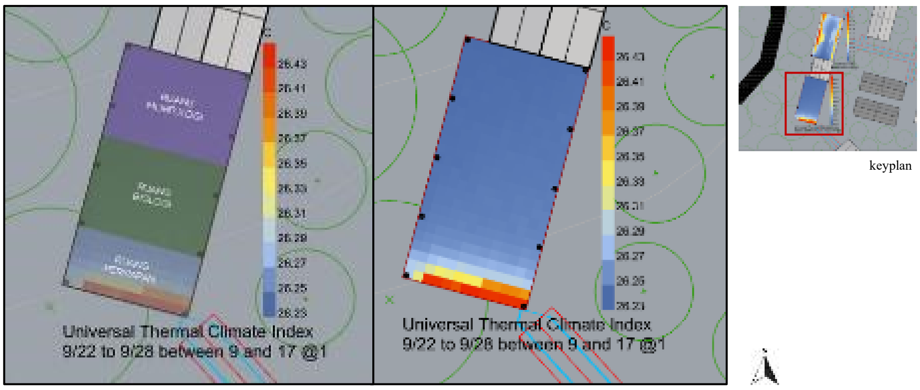


In Figure 6, conversely, the morphology room, biology room, and preparation room recorded the highest temperature at 28.62°C, particularly on the west side, while the lowest temperature was observed in the central area of the room at 28.15°C. The yellow and orange colors in the simulation results indicate areas with higher temperatures near the windows on the west, east, and south sides. According to the Ministry of Health standards, laboratory temperatures should range between 22°C and 26°C. Therefore, the temperatures observed in this study do not yet meet the established standards.



The next step, after determining that the laboratory building's temperature did not meet the standards set by the Ministry of Health, was to modify the window placement. The windows, which were previously located on the west, east, and south sides, were relocated to the south side only, as shown in Figure 7. This adjustment was made to reduce direct sunlight exposure, especially during midday, and help maintain temperature stability inside the room. The objective of this modification was to ensure that the indoor temperature complies with the established standards.

After confirming that the laboratory building's temperature did not meet the required standards, a design modification was implemented by repositioning the windows. Previously located on the west, east, and south sides, the windows were moved exclusively to the southern side. This change aimed to minimize direct sunlight exposure from the east and west, which was identified as a factor in raising indoor temperatures. By relying solely on windows on the south side, the indoor temperature distribution is expected to become more stable and lower compared to the initial condition.



In Figure 8, the re-analysis after the design modification showed a significant temperature reduction. In the initial design, the highest room temperature reached 28.62°C, whereas after repositioning the windows, the peak temperature dropped to 26.43°C, marking a difference of 2.19°C. The simulation visualization displayed a dominance of dark blue shades within the room, indicating a lower and more evenly distributed temperature than the previous condition. The yellow and orange colors, which were previously prominent around the windows, are now only visible on the south side, showing that heat remains concentrated near the openings.

Although the design modification successfully reduced indoor temperatures significantly, the results were still slightly above the standards set by the Ministry of Health. The highest temperature recorded after the design change was 26.43°C, while laboratory standards require temperatures to range between 22°C and 26°C. Therefore, this study recommends further optimization, such as using materials with better thermal insulation properties, implementing shading devices to reduce direct sunlight exposure, and evaluating the ventilation system to ensure a more even temperature distribution.

The results of this study align with previous research on the influence of openings on indoor temperature in tropical climates. According to a study conducted by [relevant reference], temperature distribution within a building can be controlled by adjusting the position of openings and aligning them with the building's orientation relative to the sun. The energy conservation theory also explains that reducing direct exposure to solar radiation can decrease heat accumulation within a building, as demonstrated in the simulations conducted in this study. Therefore, this temperature management strategy for the laboratory can serve as a reference for developing a more optimal seed bank design in the futureThis study aims to evaluate the indoor temperature conditions of a seed bank building in the National Forest and Germplasm Development Area (PKHPNN) in East Kalimantan, focusing on temperature control efforts to ensure seed viability in tropical environmental conditions. The findings indicate that the building design for the incubator and storage rooms meets the SNI standards, with a maximum temperature of 28.71°C and a minimum temperature of 28.22°C. However, the temperature in the laboratory area remains outside the standards set by the Ministry of Health, with a maximum temperature of 28.62°C and a minimum of 28.15°C, whereas the ideal laboratory temperature standard ranges from 22°C to 26°C. To address this issue, a proposed design modification was implemented by relocating window openings exclusively to the south side of the building to reduce direct sunlight exposure from the east and west.

Temperature simulations using the Grasshopper Ladybug-Honeybee software revealed that repositioning the windows significantly reduced indoor temperature by 2.19°C, from 28.62°C to 26.43°C. Although this temperature reduction is substantial, the results still do not fully meet the Ministry of Health's standards. This indicates that modifying the window position alone is insufficient to achieve optimal thermal conditions. Therefore, further optimizations, such as using building materials that effectively regulate temperature and incorporating climate control systems, are necessary.

IV. CONCLUSION

This study has several limitations that should be considered for further analysis. First, the research focuses only on indoor temperature simulation based on building massing and orientation without accounting for building materials. Materials play a crucial role in temperature regulation, as those with good thermal insulation properties, such as insulation panels or lightweight concrete, can help reduce heat transfer and maintain more stable indoor temperatures. Additionally, this study has not considered the role of ventilation systems and active cooling solutions, which could improve temperature control efficiency.

Humidity control is also a critical factor in laboratory and seed storage room design that this study has not analyzed. High humidity can negatively impact seed storage conditions, particularly for orthodox seeds that require a controlled environment. Therefore, future research should explore humidity control strategies beyond temperature regulation, such as using dehumidifiers or ventilation systems with enhanced humidity management.

Furthermore, this study has yet to explore energy efficiency strategies to optimize temperature and humidity control. Energy-efficient designs, such as cross-ventilation utilization, shading devices, and passive cooling technologies, can help reduce the reliance on artificial cooling systems. Building operations can become more sustainable and environmentally friendly by implementing a more energy-efficient design approach.

By incorporating considerations of materials, humidity control, and energy efficiency in future design developments, the seed bank building is expected to achieve better stability in temperature and humidity while complying with the standards set by SNI and the Ministry of Health. Future research should include these factors in a more comprehensive analysis to develop effective design solutions for thermal and humidity control in laboratory and seed storage spaces.

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