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The Impact of Living Wall for Thermal Environmental Comfort: Case Study of Kampung Glintung, Malang, Indonesia

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Abstract Living wall (LW) is one solution to increase the comfort level of the thermal environment as urban green areas shrink. This paper aims to examine the effect of the living wall on thermal environmental comfort in the case of urban settlements. The research stages include visual observations, field measurements, and assessment of the quality of the thermal environment. The research data and analysis consisted of the type and distribution of LW, plant species, air temperature, humidity, suitability value, and the value of improving the thermal environment in the case study of Glintung Village, Malang. Visual observations revealed that 61.4% of the houses used the LW model of the modular tray type, with *Chlorophytum comosum* as the main plant species. LW reduces the air temperature by 1.7°C and humidity by 32.6%, with an average air temperature of 25.9°C. The outside environment has the highest percentage of the suitability value of the thermal environment and the value of improvement for air temperature (63%), while the terrace has the highest suitability value of humidity (58%) and airflow (62%). Expectations for improvement are mostly found on the terrace, with a decrease in air temperature by 58%, humidity by 57%, and an increase in airflow by 59%. The proposed LW model development includes dark leafy plants on top (*Amaranthus gangeticus*), wide stomata (*Aloe vera*) on the bottom, and a fresh scent (*Lavandula*) in the middle.

Keywords Living Wall, Thermal Environment, Comfort

1. Introduction

Thermal environmental conditions in urban areas are closely related to human comfort. It also affects the quality of the built environment as the city develops, particularly with changes in land use. The decrease in the city's green environment impacts the condition of the thermal environment, especially with an increase in air temperature. One indicator of this is the increasing urban heat island (UHI) phenomenon or the accumulation of heat energy that causes an area's air temperature to rise above the surrounding environment [1]. The UHI phenomenon has a wide impact, as urban green areas are limited.

Vertical greening techniques, also known as vertical greenery systems, are one solution for increasing green areas in dense urban areas [2]. According to Besir [3], the main function of the vertical greening system is to lower the air temperature for the comfort of the thermal environment and to reduce the stress level of city residents.

According to Manso and Gomes [4], the Vertical Greenery System (VGS) is divided into two types based on the planting system: Green Façade and Living Wall. Unlike the Green Facade, the Living Wall is planted in vertical panels placed in front of the building elements rather than from the top or bottom of the building [5]. A living wall is a vertical greening system that can keep a building's air temperature stable while reducing electrical energy use [6].

Several previous studies have carried out the effect of LW on the performance of the thermal environment. Wong et al. [7] discussed the role of LW in keeping the air temperature in the surrounding environment comfortable through its temperature reduction performance. Liang et al. [8] stated that the air temperature in the vicinity of the LW is cooler, and the temperature on the wall with LW is lower than without LW. According to Jim [9], LW performance improves when placed on the side exposed to sunlight, and plant transpiration provides a better cooling effect than shading and thermal insulation. Qiu et al. [10] stated that the effect of higher evapotranspiration on LW would decrease the temperature of the surrounding air. According to Olivieri et al. [11], adding thermal insulation 3-9 cm behind the LW improved temperature reduction performance. Furthermore, Nugroho [2] stated that dark leaf color and specific plant types influence the higher ability to lower air temperatures.

The application of LW in urban environments in Indonesia began to develop through the green village movement. One urban village that has implemented LW is Kampung Glintung Kultur, Malang, Indonesia. This study aims to evaluate the effect of LW on the comfort of the thermal environment using visual observation techniques, field measurements, and community assessments.

2. Method

The study method uses a qualitative and quantitative approach. Qualitative techniques are carried out by means of visual observation, suitability assessment, improvement assessment, and proposed LW development. A quantitative technique was employed to measure the temperature and humidity of the air in the outside environment.

2.1. Materials and Research Procedures

The object of the study is Glintung Village, Malang, with a population of 1047 people in 327 families. The research area is divided into four clusters based on household boundaries (Rukun Tetangga/RT). The research was conducted in June 2020. The stages of the research consisted of a visual study, a study on the measurement of the thermal environmental performance, a study on the assessment of the quality of the thermal environment, and a proposed LW model development, as shown in Figure 1.

2.2. Data Collection

Visual data collection includes observations of the distribution of green and LW elements, LW types, and plant species in each cluster. This visual data will be compared to measurement data and citizen questionnaires to determine the impact of LW on thermal environment performance and quality.

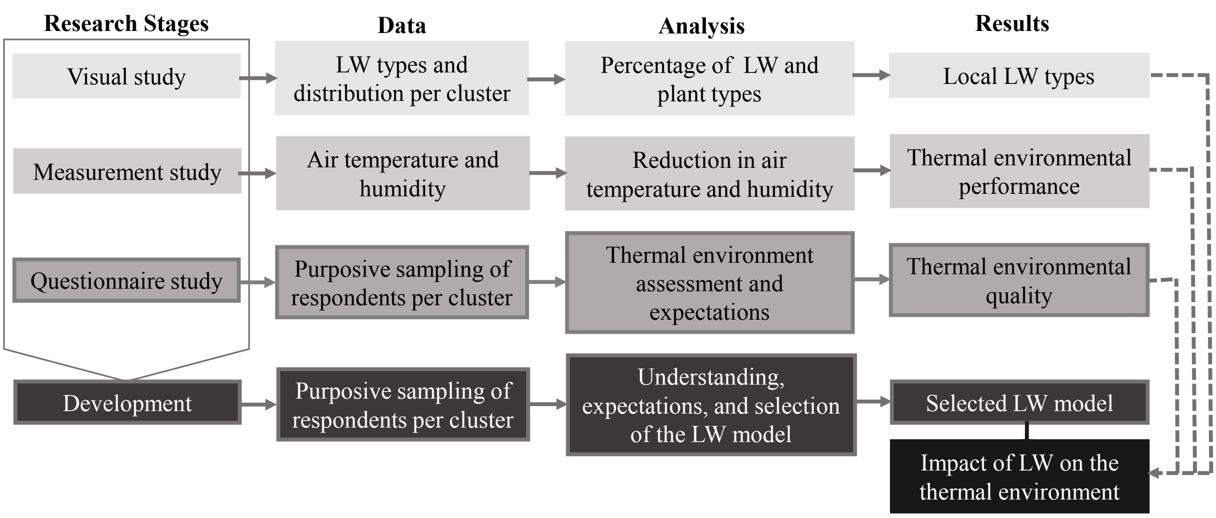


Figure 1. Stages of research, data, analysis and results

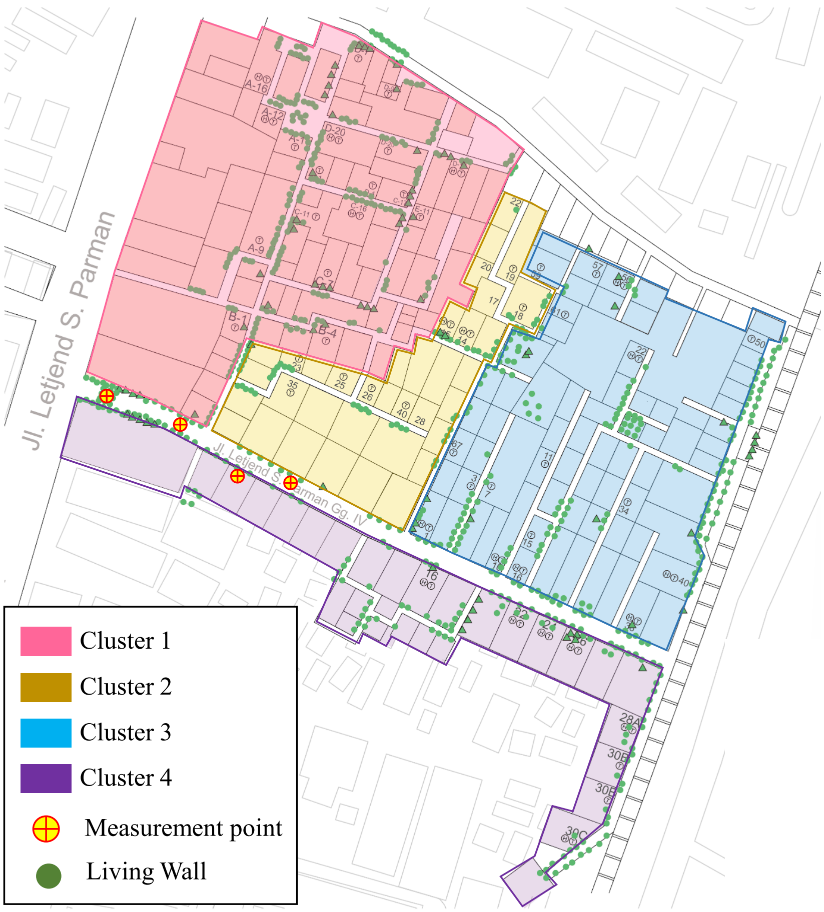


Figure 2. Map of Glintung Kultur Village showing measurement points and the distribution of LW by cluster

The performance of the thermal environment is assessed by measuring the temperature and humidity of the air at four different locations representing the green canopy shaded area, the space around the LW, the terrace of the house, and the open space. The measuring instrument used is a Temperature Humidity Data Logger, which records automatically every fifteen minutes and is installed two meters above the ground for seven days. Figure 2 illustrates the measurement points' location and the distribution of LW in each cluster.

The quality of the thermal environment is determined by distributing a hundred questionnaires using the probability cluster sampling method according to the number of residents in each cluster. The distributed questionnaire contained personal data, the condition of the house elements, the value of suitability and improvement of the comfort of the thermal environment, as well as the proposed development of the LW model.

2.3. Data Analysis

Visual analysis was carried out by identifying the distribution of green elements and LW types, followed by calculating the percentage in each cluster. Several explanations related to plant varieties and configurations were presented descriptively. The main result of this visual analysis is the type of LW and the percentage of houses with LW in the study area.

Analysis of air temperature and humidity measurements was carried out by calculating the average hourly temperature and humidity during the measurement time, maximum and minimum values, comparisons between measurement results, and evaluation of the neutral temperature of Malang City. The measurement analysis resulted in the performance of LW on the decrease in air temperature and humidity.

The analysis of the community assessment includes the value of suitability and improvement of the thermal environment's comfortable condition, as well as the proposed development of the LW model. The analysis is carried out on each component of the thermal environment, i.e., temperature, humidity, and airflow on the room, terrace, and outdoor space components. The result of this assessment analysis is the percentage of suitability and improvement of the three components of the thermal environment, which is then compared with the results of visual analysis and field measurements. Meanwhile, the proposed LW development is determined based on the value of understanding, improvement, and choice of the LW model from the community.

3. Result and Discussion

The research results consist of LW conditions, thermal environmental performance, thermal environmental quality, and LW model development.

3.1. Living Wall Condition

The LW condition studied in Glintung Kultur village includes the type of LW, the percentage of the amount in each cluster, and the type of plant. The LW used in the Glintung Kultur village is primarily a modular tray model, which is a vertical planting system with modules in the form of plant pots arranged vertically on trellises or on building walls rather than planted on the ground, as shown in Figure 3.

Figure 3. Model LW in Kampung Glintung Kultur Malang.

In Cluster 1, 74% of the houses have greenery (with conventional or VGS systems), 30% of which use the VGS system. The LW plant species in Cluster 1 consisted of: Sedum morganianum, Chlorophytum comosum, Sansevieria, Aloe vera, Phalaenopsis amabilis, Dendrobium, Epipremnum aureum, Orthosiphon aristatus, Cuphea hyssopifolia, and Nephrolepis exaltata.

Only 38% of the houses in Cluster 2 have greenery, with the VGS system accounting for 0.8%. The LW plant species in Cluster 2 are: Chlorophytum comosum, Bromeliaceae, Cuphea hyssopifolia, Sedum morganianum, Sansevieria, and Nephrolepis exaltata.

The number of houses in Cluster 3 that have greenery is 50%, and 18% of the houses have LW. The LW plant species in Cluster 3 are: Chlorophytum comosum, Bromeliaceae, Sedum morganianum, Nephrolepis exaltata, and Rhoeo discolor.

In Cluster 4, 84% of the houses have greenery, but only 15% use the VGS system. The LW plant species in Cluster 4 are: Chlorophytum comosum, Bromeliaceae, and Rhoeo discolor.

Figure 4 depicts the overall percentage of greenery and LW elements and their distribution in Glintung Kultur Village. The order of clusters with the highest percentage of greeneries number is Cluster 4 (84%), Cluster 1 (74%), Cluster 3 (50%), and Cluster 2 (38%). Cluster 1 has the highest percentage of LW (30%), followed by Cluster 3 (18%), Cluster 4 (15%), and Cluster 2 (0.8%). *Chlorophytum comosum* is the most common plant in each cluster.

Figure. 4. The percentage of the number of houses that have green and LW elements compared to the total number of houses in each cluster

3.2. Thermal Environmental Performance

The performance of the thermal environment is limited to measuring the air temperature and humidity at points near LW, under green canopies, terraces, and outdoor spaces, as shown in Figure 5.

LW had the lowest average air temperature of 25.9°C, followed by the green canopy (26.1°C), terrace (26.6°C), and outdoor space (26.9°C). Based on the average temperature value, LW can reduce up to 1°C throughout the day. The maximum and minimum air temperatures at LW are 31.2°C and 22.4°C at 11.00 and 05.00; the maximum and minimum outdoor air temperatures reach 33.9°C and 23.2°C at the same time. The maximum decrease in air temperature by LW is 1.7°C. The difference in maximum and minimum air temperatures in the green canopy is 7.1°C, whereas the difference in maximum and minimum air temperatures in the outdoor space is 11.2°C. This is similar to the performance of the LW air temperature difference, which reaches 8.8°C, indicating that the green canopy and LW can maintain a relatively stable air temperature when compared to the outdoor space. This is consistent with Wong's research [7], which found that LW can keep the air temperature from becoming too hot during the day and too cold at night.

LW achieves an average humidity of 75.4%, which is lower than the green canopy (76.8%) but higher than the veranda (74%), and outdoor space (72.5%). At 05.00 and 11.00, the maximum and minimum humidity at LW is 87% and 54.4%, respectively, as are the maximum and minimum outdoor air temperature, which are 85.1% and 46.4%, respectively. The maximum decrease in humidity by LW of 32.6% is close to the decrease in outdoor humidity of 38.7%. This demonstrates that LW outperforms the green canopy (25.1%), although areas with a lot of plants produce higher humidity values than elements without plants. A comparison of humidity performance can be seen in Figure 6.

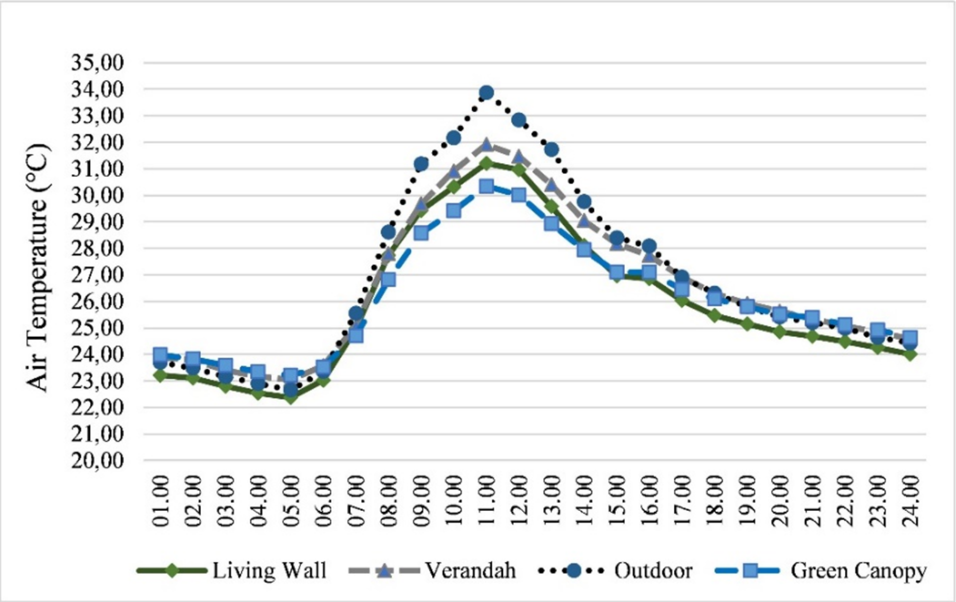


Figure 5. The average hourly air temperature for seven days of measurement at 200 cm above the ground according to the measurement point

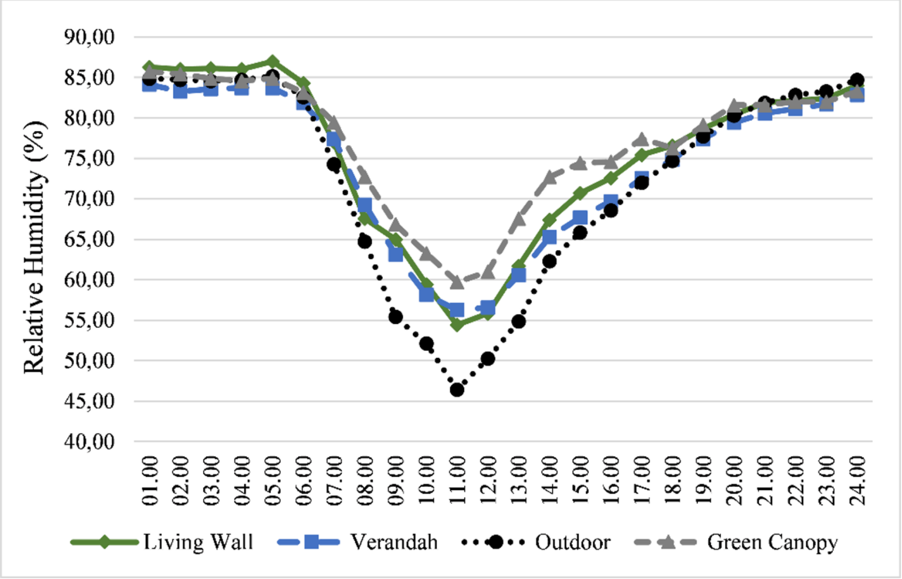


Figure 6. Average hourly relative humidity for seven days of measurement at 200 cm above the ground according to the measurement point

3.3. Residents' Assessment of the Suitability of the Comfort of the Thermal Environment

Assessment of the thermal environment's quality concerns the suitability of temperature, humidity, and airflow both inside, on the terrace, and outside the house. In general, the percentage level of suitability of the house's air temperature is 54% on a neutral scale, 30% on a suitable scale, and 16% on a very suitable scale, with no perception of unsuitable or very unsuitable. According to the findings, Glintung Kultur Village residents are generally satisfied with the air temperature in their homes. The suitability of air temperature on the suitable and very suitable scale is higher (63%) in the outdoor space than on the terrace (56%) and inside (46%), as shown in Figure 7.

The results of the humidity suitability assessment inside, on the terrace, and outside the house were nearly the same (Figure 8). However, based on the percentages of suitable and very suitable scales, Glintung Kultur Village residents are more satisfied with the humidity on the terrace (58%) than inside (57%) or outside of the house (53%).

The suitability of airflow on the terrace (62%) is greater than inside (56%) and outside the house (59%), as shown in Figure 9. Overall, the terrace has the highest level of humidity and airflow suitability. Only for air temperature suitability is the outdoor environment the most suitable.

Residents' assessment of the suitability of the thermal environmental conditions can be linked to the results of visual analysis in each cluster. Cluster 1 has the largest percentage of houses with greenery and LW elements. This differs from the percentage of houses in Clusters 2 and 3. The comparison of perception and visual analysis results shows a strong relationship in which all residents in Cluster 1 state that they are in a comfortable thermal environment. In contrast, in Clusters 2, 3, and 4, there are still residents who feel uncomfortable by giving unsuitable and very unsuitable ratings. Therefore, there is a significant relationship between the presence of LW and the assessment of thermal environmental comfort. This is consistent with previous research, which found a significant relationship between plant coverage and air temperature. The greater the value of plant coverage, the higher the air temperature comfort rating [10].

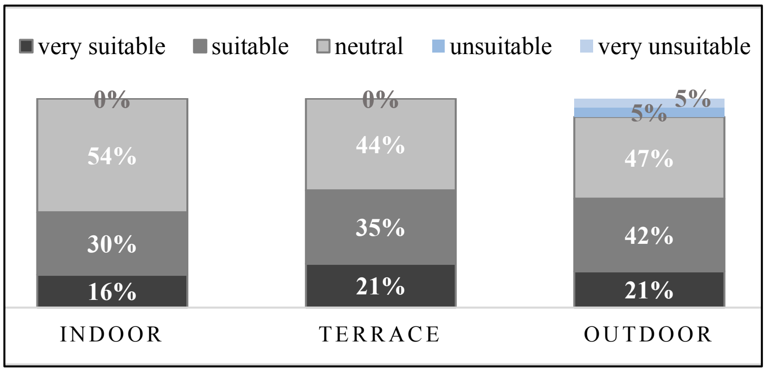


Figure 7. Assessment of the suitability level of air temperature based on the position of the room

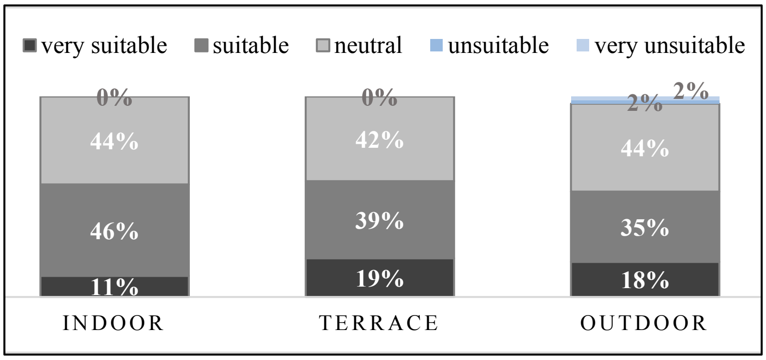


Figure 8. Assessment of the level of suitability of humidity based on the position of the room

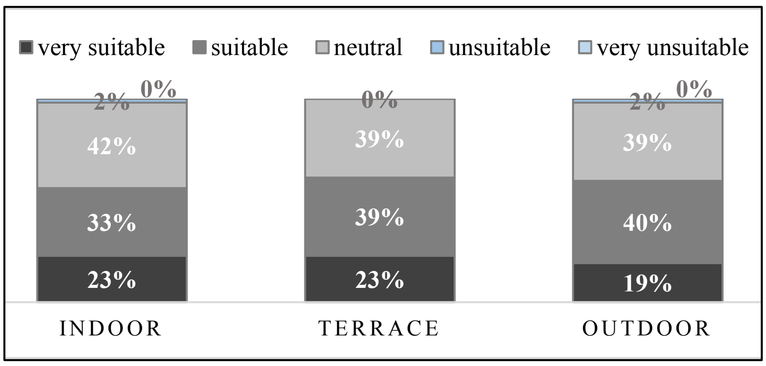


Figure 9. Assessment of the suitability of airflow based on the position of the room

3.4. Residents' Expectations for Improving the Comfort of the Thermal Environment

The residents of Glintung Kultur Village are hoping for better air temperature conditions on the terrace. This is based on the percentage of agree and strongly agree on scales that have the highest value (58%), as shown in Figure 10. The questionnaire results on the expectation of improving the air temperature aspect on terrace show 42% on a neutral scale, 39% agree, 19% strongly agree, and no one disagrees or strongly disagrees.

Figure 11 shows that the highest expectation for humidity improvements is found on the terrace and the outside environment (56%), followed by the inside of the house (53%). Humidity conditions can be improved by selecting LW plant species that easily absorb moisture, such as *Sansevieria* and *Aloe vera*.

The hope of improving airflow conditions is also on the terrace. This is indicated by the percentages of agree and strongly agree on a scale of 60% compared to the inside (54%) and the outside environment (56%) of the building (Figure 12).

Most residents would like to improve thermal environmental comfort regarding temperature, humidity, and airflow on the terrace or transition space between indoors and outdoors. This is also related to the application of LW, which is most likely to be on the terrace to provide a natural cooling effect, according to Shashua-Bar and Hoffman [12], who found that plants in the yard have a cooling effect of up to 80%.

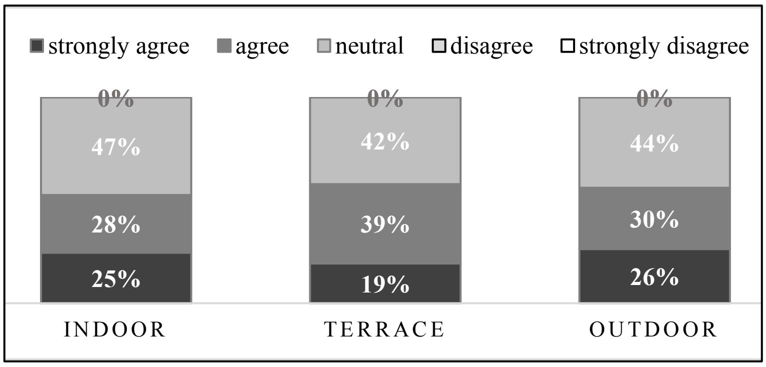


Figure 10. Residents' expectations of increasing air temperature performance based on the position of the room

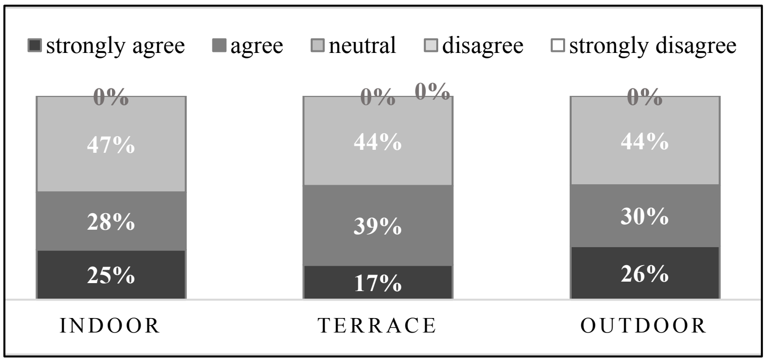


Figure 11. Residents' expectations of the level of performance improvement of humidity based on the position of the room

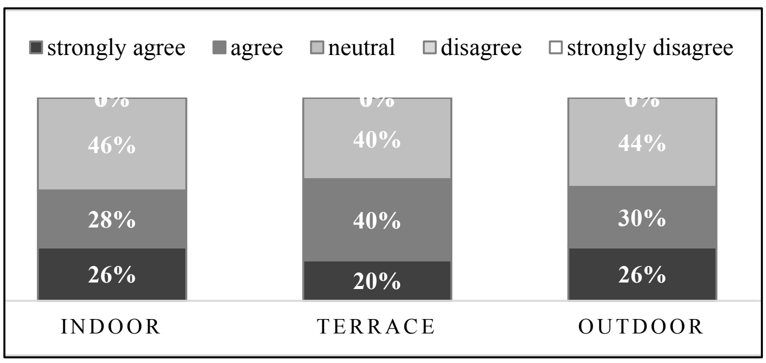


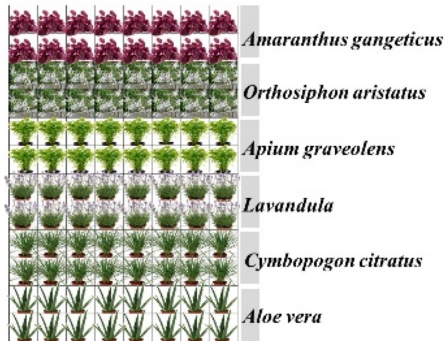
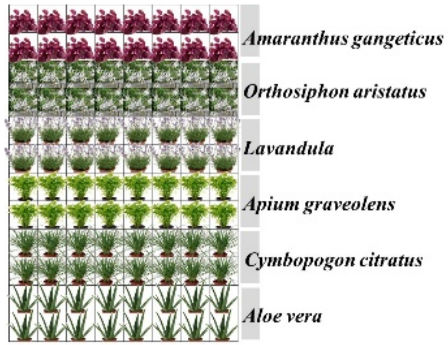
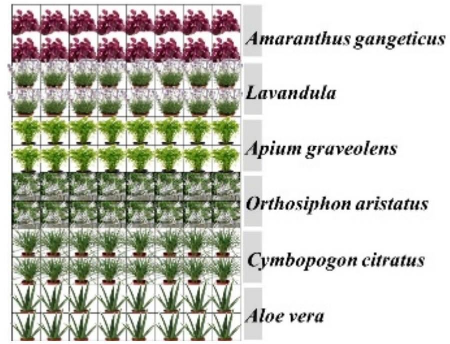
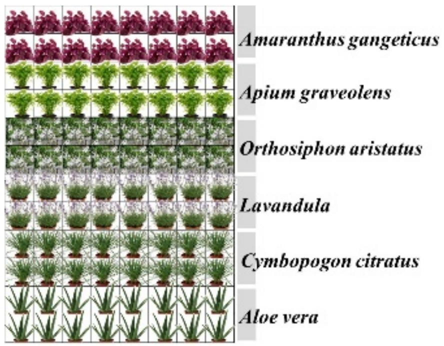
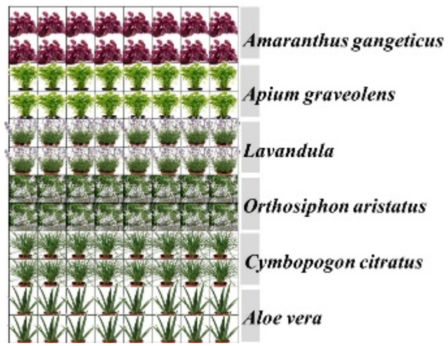
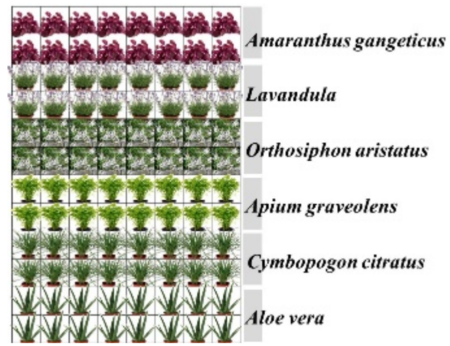
Figure 12. Residents' expectations of the level of improvement in airflow performance based on the position of the room

3.5. LW Model Development According to Residents

The results of field observations show that *Chlorophytum comosum* is the dominant plant species, and most of the reasons are related to beauty and ease of care. Previous research has linked plant species to a decrease in air temperature and humidity, as well as an increase in air quality. This knowledge is being traced by assessing the level of understanding and development desired by residents. According to resident opinions, most residents (87%) are unaware that dark leafy plants can lower the ambient air temperature. Similarly, on the knowledge about the types of plants that can reduce humidity. 91% of residents are also unaware that plants with large stomata can help reduce humidity. Concerning the ability of LW plant species to improve air quality, approximately 84% of residents are unaware that leafy plants can provide freshness to the outside environment, while approximately 16% are aware.

People's expectations for the development of LW based on changes in plant species demonstrate a wait-and-see attitude. The percentage of neutral scale for dark leafy plants is 61%, 60% for moisture-absorbing plants, and 58% for fresh-scented plants. This means that residents continue to require examples of models that demonstrate good performance at a low cost. The biggest percentage for the hope of improvement is for plants that reduce humidity (41%), slightly higher than plants that lower air temperature and increase freshness, which have the same percentage (39%).

Table 1. Code and visualization of plant species arrangement in LW model

Code	Plant arrangement	Code	Plant arrangement	Code	Plant arrangement
A		C		E	
B		D		F	

The LW model (Table 1) was developed to help residents make decisions about plant types, aesthetics, configuration, and ease of arrangement. Residents can choose from six LW models that were developed based on previous research and contain visual and aesthetic information about the composition of the plant species.

Models D and C have more than 15% of the vote, while Models E and F have less than 10% (Figure 13). Residents want lavender plants in the middle area because they provide a sense of beauty and freshness in addition to repelling insects, unlike the E and F models, which plant the cat's whiskers in the center of the LW, which only gives the impression of beauty.

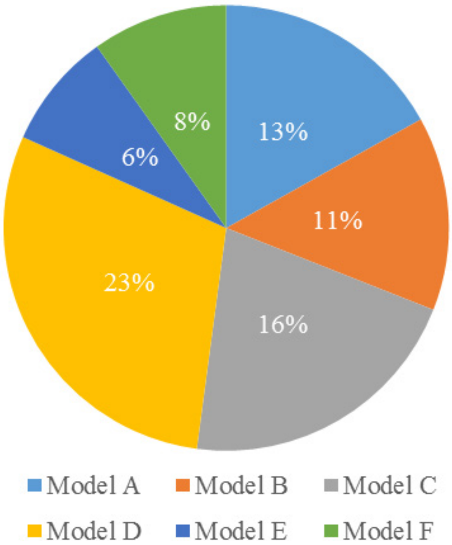


Figure 13. Percentage of LW model selected for each household

The LW model chosen by residents meets the following criteria: First, cooling through LW includes shading and evapotranspiration techniques. Second, the shade by LW is obtained by selecting plants with a solid and dense leaf layer, and the leaf orientation is parallel to the sun's motion. Third, good evapotranspiration can be obtained in the LW model with plants that maximize stomatal opening during the day. Fourth, the plant composition in the selected model includes a variety of leafy plants that cover the plant's back area, pinnate leaves that can increase wind turbulence to transport water vapor, resulting in faster evapotranspiration, and dark leaf colors on top that maximize solar radiation absorption. Finally, the selected LW model does not use plants with the type of Crassulacean Acid Metabolism

Overall, some of the above findings were related to the effect of LW on the comfort of the thermal environment in accordance with the opinion of Cameron et al. [13] and Tan [14]. Cameron et al. [13] specifically stated that the performance of LW can be increased by shading and evapotranspiration, both achieved by selecting plants with large leaf width and shape or leaf area index. Tan et al. [14] demonstrated that plant evapotranspiration and albedo strongly correlate to temperature reduction, particularly in plants with dense layers. The selected LW model (Model D) can be applied especially to Cluster 2, which has the lowest green area (38%) and lowest vertical greenery systems application (0.8%). LW can be applied on both the house walls and street corridors.

4. Conclusions

A study of the condition, performance, quality, and development of LW in Glintung Kultur Village, Malang, found that it significantly impacts thermal comfort. In the case study, LW was used by several houses, with Cluster 1 having the highest percentage (30%). The LW model is a modular tray, with *Chlorophytum comosum* being the most commonly used plant species.

Measurement of air temperature and humidity as the main components of the thermal environment was carried out in the cluster that used the most LW, i.e., Cluster 1. LW can reduce air temperature by 1.7°C and humidity by 32.6%. The average air temperature around LW is the lowest in comparison to the surrounding environment, at 25.9°C, or within the comfortable temperature limits of neutral Malang City (between 22.5°C -27.5°C).

According to residents, the quality of the thermal environment is adequate, but the thermal environment's condition needs to be improved. The terrace has the highest percentages of humidity and airflow suitability, with 58% and 62%, respectively. Meanwhile, the highest level of air temperature suitability was in the outdoor environment (63%). There is a relationship between the perception of the quality of the thermal environment's comfort and the cluster with the highest percentage of houses that have greenery and LW elements. Residents of Cluster 1, in which 74% of the houses have greenery and 30% of which use the VGS system, indicates a comfortable thermal environment. This contrasts with the less comfortable assessment in the other clusters. The majority of residents desire an improvement in the quality of thermal environmental comfort on the terrace: 58% anticipate a decrease in air temperature, 56% a decrease in humidity, and 60% an increase in airflow. Whereas in indoor areas, residents expect a decrease in air temperature of 46%, and humidity of 57%, and an increase in airflow of 56%. In outdoor areas, the expectation for a decrease in air temperature and humidity and an increase in airflow is 53%, 53%, and 59%, respectively.

Although the LW element has been widely applied to the terrace in Glintung Kultur Village, knowledge about the effect of plant species on thermal comfort is still limited. The findings revealed that 87% of the population was unaware that dark leaves can lower temperature and 91% were unaware of the types of plants that reduce humidity. The same thing happened with the types of plants that provide fresh air; approximately 84% were unaware of it.

The LW model is developed by taking into account the different types of plants and residents' opinions on the best configuration. The LW model selected had *Amaranthus gangeticus* and *Apium graveolens* at the top, *Lavandula* and *Orthosiphon aristatus* in the middle, and *Aloe vera* and *Cymbopogon citratus* at the bottom. This arrangement takes several factors into account: the upper plants are chosen to reduce air temperature, the lower plants to reduce humidity, and the middle plants to provide fresh air. The selected LW model can be applied to both the house walls and street corridors. Applications are encouraged, particularly in Cluster 2, which has the least amount of green area (38%) and the fewest applications of vertical greenery systems (0.8%). Further research is needed to determine the performance of the selected LW model in terms of increasing thermal environmental comfort.

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