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Effect of Coconut Fiber Wall Panels on Humidity Conditions in a Tropical House

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Abstract

Houses in warm and humid tropical regions, like Indonesia, often experience uncomfortable conditions due to high temperatures aggravated by high humidity. With its adsorptive characteristics, natural coconut fiber can be utilized as wall panels and assigned to regulate house humidity levels. Research focusing on investigating the adsorptive capability of the natural coconut fiber in controlling humidity is widely available, but that specifically examines the effect of the surface area of the material on air humidity conditions in humid tropical extant houses is still limited. A field experiment was conducted in a small Surabaya house. The study analyzes the impact of coconut fiber (CF) wall panels on humidity conditions in each house room and the optimal surface area of the wall panels. CF wall panels were found to reduce the indoor relative humidity (RH) significantly. The optimal surface area varied depending on room characteristics. The optimal surface area of the wall panels for the living room is six (6) m² with a 28% RH reduction, for the bedroom is six (6) m² with a 27% reduction, and for the kitchen is five (5) m² with a 27% reduction.

INTRODUCTION

Coconut fiber (CF) is a natural substitute for eco-friendly building materials (Avubothu et al., 2022). It can absorb and retain moisture in a room (Pramitasari, 2016), making it an ideal option for controlling relative humidity (RH). Additionally, CF offers excellent sound and thermal insulation properties (Husein, 2018; Mintorogo et al., 2015; Simanjuntak & Mahda, 2019). Therefore, CF wall panels can be used as an alternative building material to regulate room humidity levels. Previous studies have explored the use of CF wall panels as RH controllers, but these studies only explored uniform size of CF wall panels and experimented with a limited number of treatments (Pramitasari, 2012; Sales et al., 2021).

Current studies already propose several materials that can be used to control room humidity, such as gypsum board and fiber cement. Based on the studies, these materials have properties that function as a room humidity controller (Ren et al., 2020; Shang et al., 2017; Y. Yang et al., 2022). However, aside from its advantages, using such materials can negatively affect the environment and human health. Consequently, there is a need for environmentally friendly alternatives that effectively control room humidity levels (Khoshnava et al., 2020). As distinct from the previously mentioned materials, CF is an environmentally friendly material with few adverse effects on health.

Humidity control is important when constructing a house (Cheekatamarla et al., 2022). It is especially vital in small houses with poor ventilation and arid land in humid tropical regions (Alfrida & Putranto, 2017). This is because high RH levels can lead to discomfort and structural damage to the building (Lucas et al., 2002). One effective method for controlling humidity levels is utilizing building material that has adsorption capability. In this regard, the properties of CF are worth further exploration and can be the basis for investigating CF as an agent for controlling indoor humidity levels.

Adsorption refers to the phenomenon wherein water vapor is sequestered into the porous structure of a solid material, leading to a decline in the ambient humidity levels within a given space (Chi Tien, 2019). The efficacy of the adsorption process is subject to diverse factors associated with the material, encompassing its physical attributes like thickness, surface area, type, and density. Concurrently, external environmental parameters, including temperature, humidity, and air circulation, exert discernible influences on the state of adsorption equilibrium (Crittenden & Thomas, 1998). Because of these interactive influences, adsorption represents a multifaceted interplay between the properties of the adsorbent material and the surrounding atmospheric conditions.

Many studies have been carried out concerning the use of CF wall panels. The study generally only explored the utilization of CF wall panels of uniform size and experimented with the wall panels with a limited number of treatments. In some studies, CF and recycled materials have been used as alternative building materials (Avubothu et al., 2022; Danso, 2017; Indahyani, 2011; Leão et al., 2015; Mintorogo et al., 2015; R & Maitra, 2020; Rafiqi & Mahjoeddin, 2022; Randi & Yovial, 2022). None of these studies have examined the influence of the surface area of a CF wall panel on the indoor RH and considered the application of the panels in an extant house.

This study aims to fill a gap in knowledge by exploring the optimal surface area of CF as a wall panel for humidity control in small houses. The study delves into various aspects, such as the adsorption capacity of CF as a wall panel, the extent of temperature conditions and RH reduction in internal spaces, and the ideal wall panel surface area required to achieve optimal humidity control. Aside from that, the study also proposes natural and eco-friendly wall panels that can reduce thermal discomfort due to high humidity and those that have minimal adverse effects on health.

METHODS

This study aims to investigate the influence of wall panels made of CF on indoor humidity levels and explore the optimal wall panel surface area to control RH. A small house with an area of 36 m2 in Surabaya is chosen as the locus of an experiment. The experiment was conducted by observing the moisture adsorption of the CF wall panels in three house rooms: the living room (LR), bedroom (BR), and kitchen (KT). Field observation and measurement are used following previous studies, such as RH and air temperature (T) measurements (Moon et al., 2014) and water content measurements in absorbent materials (Yang et al., 2012; Zhang et al., 2017).

To simplify the testing process and determine sizes based on surface area variations, this study uses a module of CF wall panels as a specimen. The module has dimensions of 50 cm x 50 cm and a thickness of approximately 1 cm, with a density of 0.05 gr/cm3. The specimen is produced in the factory with the addition of 10% latex and will be installed on the walls of the room under study. Before installing CF as a wall panel in a room, it is essential to test its adsorption performance. This test ensures that each material has the same level of adsorption performance. The adsorption performance validation test consisted of two stages in this study: 1) comparison between sample modules and 2) between points within one module.

Three module samples were taken and compared in the first validation test stage. A meter measured the moisture levels every three hours (Figure 1.a). In addition, the weight of the material at both the initial and final positions was measured using a digital scale (Figure 1.b). The validation test was conducted in a controlled and enclosed room to create the same testing environment for each sample.


Moisture Level Material’s Weight

Fig. 1. Measurement of the CF Wall Panel

One specimen module was divided into nine grids to compare points within one module. The moisture level of the material was measured every three hours from each of the nine grid areas. Like the previous validation stage, this test was conducted in a controlled, enclosed room to determine the material's performance similarity in each part.

After all materials are assessed to have the same level of adsorption performance, the experiment in the existing space can be carried out. The house used for the experiment is a typical developer’s house. It employs common building materials for standard housing, such as tiled floors, light brick walls, and a clay tile roof. The dimension of the LR is 3 m x 3.5 m x 4.4 m, the BR is 3 m x 3 m x 3.7 m, and the KT is 2 m x 3 m x 3.7 m. The LR has a 1.1 m x 3 m window at the top of the wall, while the BR has no direct external window. The KT has transparent glass roof tiles in the center of the room (Figure 2).

CF panel modules are installed as interior finishing materials on walls without doors or windows (Figure 3). These panels were tested in natural settings with no occupants and ventilations. To prevent water seepage, the panels were layered with polyethylene plastic (Figure 4). The wall panels are set to have different surface areas for the experiment. The area ranges from 1 m2 to 7 m2. A room with no wall panels is assigned as the group control (Table 1).

Table 1. Experimental Setting for the Study

Internal Space	Room Area	Controlled Group	Experimental Group
Living room (LR)	13.5 m2	No CF panels	CF panels with areas of 1, 2, 3, 4, 5, 6, and 7 m2
Bedroom (BR)	9 m2	No CF panels	CF panels with areas of 1, 2, 3, 4, 5, 6, and 7 m2
Kitchen (KT)	6 m2	No CF panels	CF panels with areas of 1, 2, 3, 4, 5, 6, and 7 m2

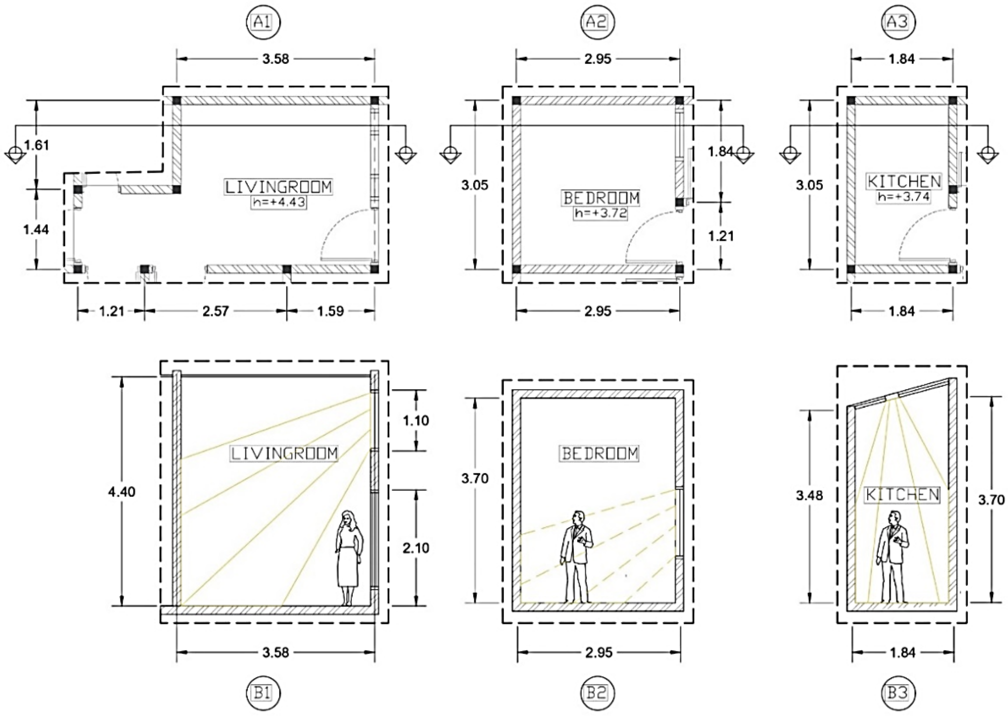

Fig. 2. Description of the room under study with the Placement of Glass Windows: Plans of the Living Room (A1), Bedroom (A2), Kitchen (A3), and Section of the Living Room (B1), Bedroom (B2), Kitchen (B3)

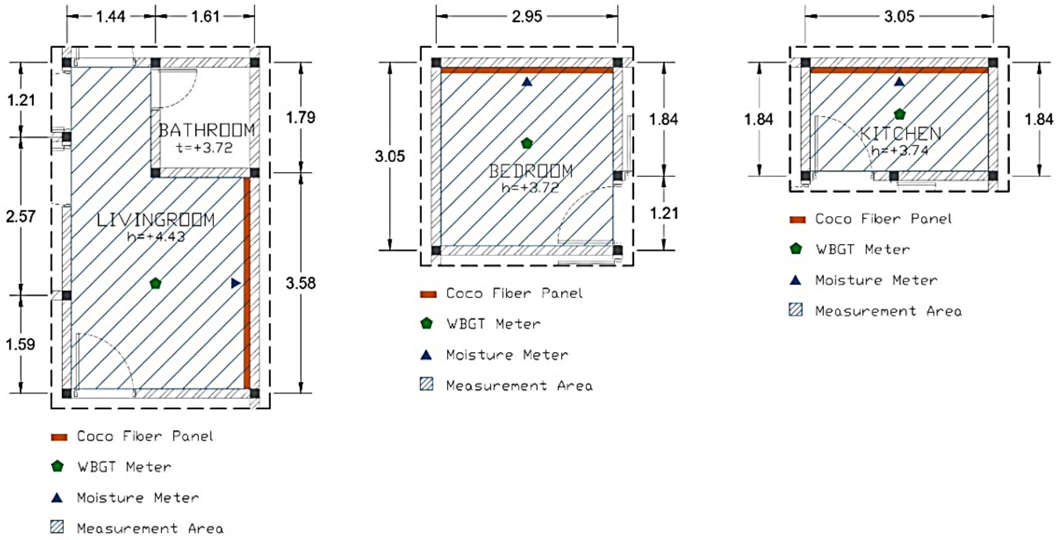

Fig. 3. Allocation of Measurement Tools and Specimens in Each Room

WBGT and moisture meters were used to measure the temperature and water content of the panels, respectively. WBGT meter is positioned at a height of 1 meter in the center of the room to measure the T and RH. A WBGT meter is also placed outdoors to record the external T and RH. A moisture meter measures the CF specimens' water content. The moisture measurements were taken at three measuring points on each CF panel (Figure 5). The measurements of each room for each surface area were taken hourly for a 24-hour duration.

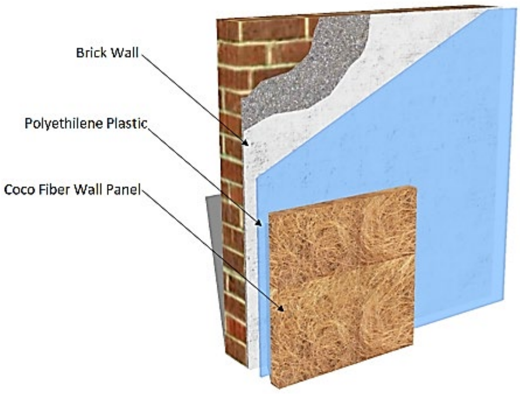

Fig. 4. Installation of CF Panel on the Wall


Living Room

Bedroom

Kitchen

Fig. 5. Visualization of the Measurement in the Three Rooms Under Study

Two analyses were set for the study. The first analysis was carried out to determine the relationship between the adsorption of CF panels and room RH. The data collected was used to perform a simple linear regression analysis between the moisture content of the material, measured by a moisture meter (i.e., Mastech, MS6900), and the indoor RH, measured by a WBGT meter (i.e., Lutron, 2010SD). A coefficient determination (R-value) exceeding 0.5 indicates the CF panels affect indoor RH levels. The results of the regression analysis are descriptively presented. The second is a comparative analysis adopted to examine the reduced humidity values across different experimental treatments, i.e., surface area variability. The indoor-to-outdoor RH ratio was calculated to enable comparison because different wall panel treatments were measured on different days. Values higher than 1 indicate increased humidity in the internal spaces; conversely, values less than 1 indicate humidity reduction. The performance of the experimental models was calculated based on the percentage of RH ratio reduction between the experimental models and the control group. The model with the highest percentage RH ratio reduction determines the optimum surface area of the CF panels.

RESULTS AND DISCUSSION

Adsorption Performance Test of Coconut Fiber Wall Panel Modules

Preceding the experiment, a validation test regarding the adsorption performance of the specimens was carried out. This validation test is divided into two. The first involves comparing one sample module to another, and the second comparing points within one module. The test is set five times with three-hour intervals, i.e., 9 a.m., noon, 3, 6 and 9 p.m. The objective of the test is to ensure the slight density variation in the specimen modules occurring in the fabrication process does not affect the adsorption level consistencies of the specimen and is thus valid for the experiment.

Table 2 displays the outcomes of the first validation test. The results indicate that the moisture content in the specimen modules increases gradually during the testing course. The recorded moisture content differences are within 0.2-0.3 % within the same time setting. The values increased from about 11.3% at 9 in the morning to 13.5% at 9 in the evening. The highest moisture content of the three specimens was recorded at 9 p.m. and ranges from 13.3% - 13.5%. The moisture adsorption capacity of the specimens after twelve-hour exposure in each room varies from 1.71% to 1.97%. The validation results show the moisture content level in the specimen modules can impact the weight gained by the materials. As shown in Table 2, the specimen modules gain weight after several hours of exposure. These findings align with previous research demonstrating that moisture content, like CF, can affect lignocellulosic materials' physical and mechanical features (Das & Biswas, 2016). These characteristics encourage the material to absorb the moisture, which subsequently increases its weight. The test also shows no significant performance differences among the specimen modules within the same time setting. Variation only occurs at different test times, which is a consequence of the gradual adsorption process from the environment to the material.

Table 2. Validation Test Results of the Specimen Modules

Specimens	Weight (gr) Before	Moisture Level (%) by Time					Weight (gr) After
		09.00	12.00	15.00	18.00	21.00	
A	386.6	11.3	12.4	11.9	13.0	13.5	393.2
B	386.0	11.5	12.2	11.8	12.9	13.3	393.6
C	387.0	11.6	12.5	12.0	13.2	13.5	394.0

The second validation test evaluated the adsorption performance of nine points in the same module. The results in Table 3 revealed that the nine measurement points have similar moisture levels within the same time setting. The recorded differences were between 0.3% and 0.7%. Like the previous tests, the moisture level varied between different time settings, ranging from 11.1% at 9 a.m. to 13.7% at 9 p.m. The test suggests that small variability in specimen module densities does not significantly affect moisture levels at different points in the modules.

Table 3. Validation Test in Nine Measurement Points of the Specimen Module

Time	Moisture Level (%)								
	X1	X2	X3	X4	X5	X6	X7	X8	X9
09.00	11.1	11.5	11.3	11.2	11.5	11.5	11.4	11.5	11.6
12.00	12.2	12.4	12.5	12.2	12.2	12.5	12.4	12.2	12.5
15.00	11.5	11.7	12.1	11.9	11.8	12.2	11.9	11.8	12.2
18.00	13.1	12.8	13.1	13	12.9	13.2	13	12.9	13.2
21.00	13.7	13.4	13.5	13.5	13.3	13.5	13.6	13.3	13.5

Based on the results, it can be inferred that the specimen of the CF wall panels has consistent adsorption performance across different specimen modules and measurement points in the modules. This result also indicates that the wall panel module is sensitive to moisture content and performs well at each measurement point tested. The wall panels can, therefore, be used for further data collection and valid for the experiment.

Relation between Indoor Relative Humidity and CF Wall Panel's Moisture Content

The relationship between the CF wall panel's moisture content and indoor RH was analyzed using simple linear regression (Table 4). The results show that all coconut fiber CF wall panels' coefficient of determination (R-value) exceeds 0.5, indicating good relationships. Of all the cases, 47.7% have an R-value of more than 0.8, 14.3% between 0.7 and 0.8, 19% between 0.6 and 0.7, and 19% between 0.5 and 0.6. The analysis indicates a direct and positive correlation between the indoor RH and the moisture content of CF wall panels. High indoor RH indicates high moisture content in the room. Installing CF wall panels in the room can facilitate moisture adsorption, thus reducing the humidity. The condition owes to the excellent moisture adsorption properties of the materials (Pramitasari, 2016). The experiment also confirms that with a 10% latex mixture, CF can still adsorb excess moisture in the air. Based on this simple regression analysis, the study suggests that installing CF wall panels can be a practical alternative to reduce indoor RH, especially in small houses in Surabaya.

Table 4. Results of Simple Linear Regression Analysis on the Adsorption Performance of the Wall Panels

Rooms	Coefficient of Determination by CF Wall Panel Area						
	1 m2	2 m2	3 m2	4 m2	5 m2	6 m2	7 m2
Living room (LR)	0.738	0.825	0.845	0.836	0.779	0.609	0.616
Bedroom (BR)	0.834	0.519	0.854	0.782	0.682	0.878	0.584
Kitchen (KT)	0.681	0.848	0.894	0.813	0.856	0.529	0.597

Indoor Thermal Conditions in Each Room During the Experiment

Indoor thermal conditions covering T and RH measured in the three rooms under study are illustrated in Figures 6 and 7. Indoor T was generally slightly lower than outdoors, especially when the CF wall panels were installed in the rooms (Figure 6.a). An exception was recorded in LR and KT, where most of the average indoor T was like or higher than the average outdoor T. Indoor RH in the room without the CF wall panel, i.e., the control model, was generally higher than outdoors (Figure 6.b). On the contrary, rooms with CF wall panels possess low RH.

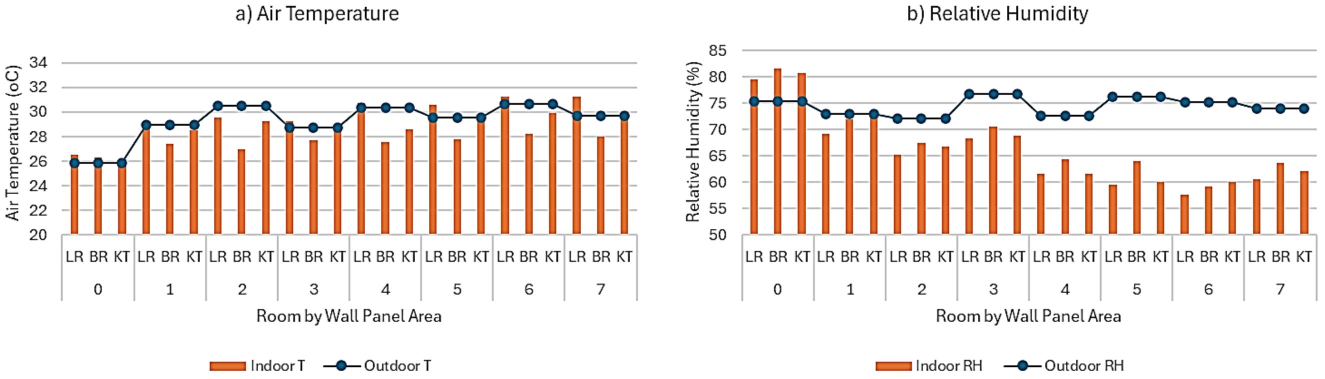

Fig. 6. Average Indoor and Outdoor T and RH in the Rooms Under Study

Looking closely at hourly indoor RH in some cases of the experiment, indoor RH narrowly fluctuates, and the values spread between 75-85% in the controlled spaces (Figure 7.a). The profile of the indoor RH mimics the night outdoor RH pattern. During the day, the indoor RH was much higher than the outdoors. When the CF wall panels were installed, indoor RH gradually decreased (Figures 7.b, c, and d). The range between minimum and maximum indoor values was about 15%. This range is much lower than the outdoor RH range, which is between 25 and 40%. From the three experimental samples presented here, i.e., 1, 4, and 7 m2, in 1 m2 wall panel area, the indoor RH drops in the range of about 60-75%, in 4 m2 wall panel 55-70%, and 7 m2 wall panel area 55-60%. Indoor RH reaches around 60%, the same as outdoor RH, especially towards higher wall panel areas.

Figure 7 also shows that the indoor RH is generally lower during the night and higher during the day than outdoor RH. CF wall panels absorb substantial moisture from the air during the night, thus lowering indoor RH. High temperatures during the daytime accelerate the desorption process of the CF wall panels. Desorption is releasing the previously absorbed water vapor back into the air when the environmental conditions change. The increased temperature provides the energy needed for the water molecules to break free from the material's pores more rapidly, allowing the material to be ready for another adsorption cycle sooner. It causes water vapor on the surface of the CF to evaporate into the air and trap in the room. This moisture is confined because the experiment does not allow ventilation. The conditions were explained in the previous research that in closed spaces (i.e., no ventilation), the air conditions will remain the same (Khumaira & Hendrawati, 2022). From this explanation, it can be said that the desorption process contributes to the high RH experienced in internal spaces during the day.

The above analysis and discussion show that indoor T generally does not vary compared to outdoor T during the experiment, where the rooms are empty and under limited ventilation. Indoor RH, conversely, decreases substantially compared to outdoor RH when rooms are equipped with CF wall panels. The study found that indoor T can affect indoor RH, especially during the daytime. From those mentioned above, the study suggests that installing absorptive wall panels is beneficial in buildings located in high humidity conditions, especially during the night. During the day, indoor RH is thermally acceptable as it approaches the outdoor RH, which is around 55-60%.

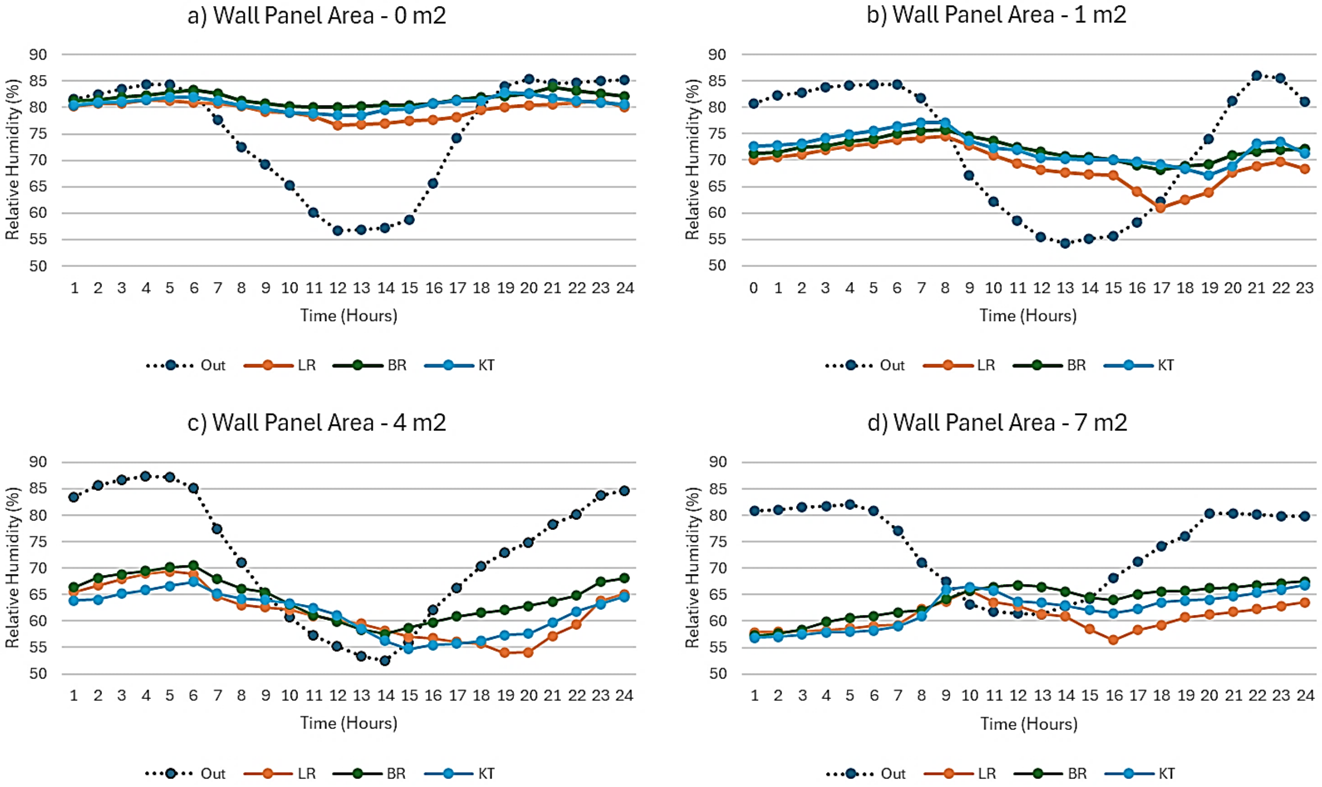

Fig. 7. Hourly Indoor and Outdoor RH in the Rooms Under Study

The Influence of Wall Panel Surface Area on Air Humidity Reduction

Figure 8 displays the evaluation of the adsorption capacity for each room. As previously mentioned, the assessment of the adsorption capacity of the wall panels was based on the indoor-outdoor RH ratio, which was calculated for each panel in each room. Values lower than 1 indicate the wall panel's capacity to reduce moisture. This method was used to allow comparison among experimental models, i.e., models with different surface areas.

As shown in Figure 8, indoor RH conditions in the control model, i.e., rooms with no CF wall panel installed are generally higher than outdoors, where the average RH ratio is between 1.08 and 1.11. Conversely, indoor RH conditions are typically lower in experiment models (i.e., the ratio is less than 1). There is a tendency for the RH ratio to decrease towards a larger wall panel area. LR experiences drier conditions than the other two across different wall panel areas. Adsorption capacity in BR and KT is almost the same. As underlined before, the analysis suggests that installing CF wall panels can reduce indoor air humidity. The larger the wall panel, the higher the humidity reduction capacity.

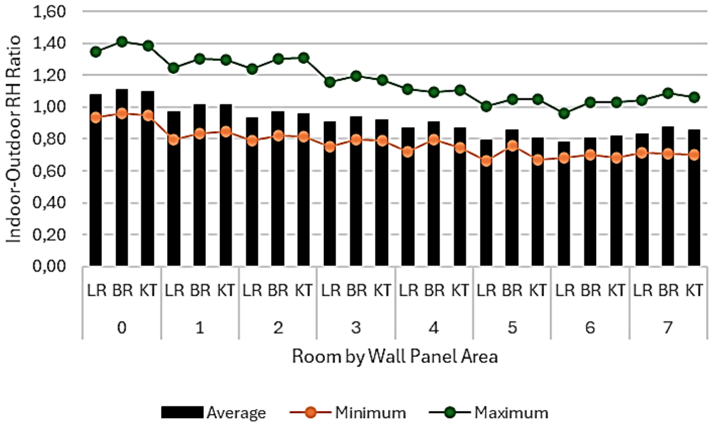

Fig. 8. Comparison of Indoor-Outdoor RH Ratio in Each Room

The humidity reduction performance of the CF wall panel is depicted in Figure 9. The performance is defined, as previously stated, by RH ratio reduction between the experimental and control models, represented in percentage (%). Higher values point to higher RH reduction performance. Figure 9 shows that increasing the wall panel area will reduce indoor RH in the room, as previously underlined. The performance ranges from 7% to 28%, describing the wall panel's capacity to reduce the air humidity from 7% to 28% compared to the control model. Generally, the humidity reduction is marked in the wall panel with a 1 m2 area up to 6 m2. The performance decreases in the wall panel with a 7 m2 area.

Indoor RH reduction in LR is the highest compared to the other two rooms (Figure 9). 10% reduction for 1 m2 wall panel area and gradually increase up to 28% for 6 m2 wall panel with an average reduction of 18.8%. Extending the wall panel area to 7 m2 conversely decreases the performance to 23%. In the BR, the performance ranges from 9% to 23%, that is, for a 1 m2 to 6 m2 wall panel area. The average value is 17.6%. Like the LR, the performance drops to 21% when the wall panel area increases to 7 m2. Posing a slightly different pattern, increased performance in the KT only occurs in the room with a wall panel area of 1 m2 to 5 m2. It ranges from 7% to 27%, with an average value of 16.7%. Adding an adsorption area of up to 7 m2 decreases the performance to 22%.

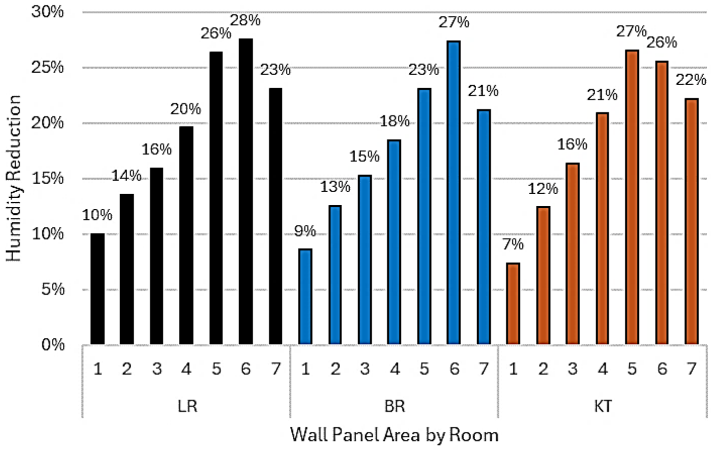

Fig. 9. Performance of Humidity Reduction of the CF Wall Panel by Room

The above description shows that extending the CF wall panel area will result in higher humidity reduction. Increasing the adsorption surface area increases the wall panel's capacity to adsorb moisture in the room. However, the wall panel no longer absorbs moisture in certain wall areas, such as 7 m2 in LR and BR and 6-7 m2 in KT. The surface of the CF wall panel is saturated in this case, and the moisture adsorption process stopped. The reverse process, i.e., desorption, occurs mainly during the day when the temperature elevates.

As highlighted above, LR is experiencing more significant relative humidity reduction than BR and KT. The relative humidity reduction can be attributed to the temperature disparity between rooms. As previously observed, KT has a higher indoor T than BR, while LR has the highest indoor T. This phenomenon can be explained by the impact of air temperature on relative humidity, as observed on a psychrometric diagram (Parsons, 2014). When the air is warm, its capacity to carry moisture increases, thus lowering RH. Since indoor T in LR and KT are higher than BR, RH will be lower in LR and KT than BR under similar moisture content in each wall panel. The decreasing performance in the wall panel area of 6 and 7 m2 can be connected to saturation on the surface of the wall panel.

Regarding the high temperatures in LR and KT, the role of windows in the room is worth noting. The LR and KT have external windows, i.e., glass windows and glass roof tiles, that can elevate indoor air temperatures. The glass windows allow solar radiation to enter the room and increase indoor T. Since ventilation is restricted in the experiment, the heat quickly builds up indoors and causes the temperature to rise. In this condition, the longwave radiation has difficulty passing back through the glass, causing it to be trapped inside the room (Raval & Ramanathan, 1989). In addition, as demonstrated by previous research on the impact of windows and doors on room temperature, installing glass windows can raise room temperature by 2°C (Ma et al., 2015).

High indoor T in the KT can also be attributed to the application of ceramic wall claddings. Installing ceramics on the wall can raise the room temperature (McNaney et al., 1999). Ceramic tiles have properties that can influence the temperature of a room. Ceramics can absorb and retain heat. Ceramic tiles have low thermal conductivity, which means they are not good conductors of heat (Shariff et al., 2020). If the room is heated, the ceramic tiles can act as an insulating layer, preventing the heat from escaping and keeping the room warmer. The increase in air temperature shortens the adsorption time and causes a more significant reduction in the relative humidity in the room (Mohan et al., 2015). Heating the absorbent material can result in a greater and quicker reduction in RH.

The above analysis shows that different CF wall panel areas influence humidity reduction in each room under study. Indoor RH will be significantly reduced when the wall panel area is increased, as previously mentioned. The analysis also shows that humidity reduction among the three rooms slightly varies. Furthermore, the analysis indicates that high indoor T in the room can accelerate the adsorption and desorption, reducing humidity. However, the study found that the influence was not significant. Although it is inconclusive and requires further validation, increasing indoor T might be associated with applying glass windows and roof and wall ceramic tile cladding in the room.

CONCLUSION

A series of experiments on controlling room RH by installing CF wall panels of different surface areas were conducted in a small house in Surabaya. The experiments showed that installing CF wall panels could significantly reduce indoor RH, but the reduction varied depending on the wall panel's surface area. The model revealed that the moisture adsorption and desorption of hygroscopic materials in each room increased in parallel with surface area, ranging from 7% in 1 m2 wall panel area and 28% in 6 m2. The surface of the CF wall panels will be saturated for the LR and BR after installing 6 m2 of wall panel areas. For the KT, the ideal surface area was 5 m2. The study also found, although it requires validation, that building material specification of the room, such as glass roof or windows and ceramic wall cladding, might influence indoor T but only contribute little to indoor humidity reduction.

The study underlines the benefits of adsorptive material and recommends using CF wall panels for humidity control in the building, especially in humid environments like Surabaya. Further studies are proposed to investigate the more detailed performance of CF wall panels by extending the observation period of the experiment. The study also plans to use a building mock-up that allows the influence of building material specifications to be comparatively investigated, and a controlled environment can be easily applied.

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