**Thermal Environment Control of Buildings using Installation of Plants and Metal Panels on Brick Walls**

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**Abstract.** One of the thermal behaviors of bricks on building walls might store heat in large amounts and delay it to be re-released. This performance will consequently prevail over the building’s environment, comprising the Urban Heat Island (UHI) phenomenon. Hence mitigation technology for controlling and managing heat gain is required to reduce the effect of UHI. Various research has studied this phenomenon mainly from orientation and the several types of wall insulation for sundry types of climates. However, it has not been significantly scrutinized from the green wall and metal panel wall viewpoint. This study aims to discern the thermal behavior of regular building brick walls using 3 (three) types of walls, i.e., conventional brick walls, metal-panel wall technology such as Aluminum Composite Panel (ACP) without air gap, and green walls technology by planting the vines in a trellised container with a sandy loam substrate. ENVI-met V4 software is performed for simulation by modeling a house building measuring 8 meters long, 6 meters wide, and 5 meters high. Metal panels and green walls are installed on all brick walls on the building's west and east sides. The parameter observed was the surface temperature of walls and the air temperature pattern by introducing fixed wind speed (0.1 m/s). In the daytime, the results showed that using the technology intervention with ACP provided better results in terms of lower surface temperature than other types with a 0.6 – 6.7 % difference due to its conductive properties in storing heat. Moreover, green wall intervention utilizing vegetation yields better performance in the nighttime with a 0.3 – 3% difference as the Ivy Hadera is holding the heat during that time. Green wall intervention also evinces significant temperature rising at 09.00 – 16.00 since the Ivy Hadera vegetation has relatively sparse leaf
space; hence there is a considerable amount of heat radiation reaching through the walls, and there is evapotranspiration of the vegetation causing heat release to the atmosphere.

1. Introduction

Brick as a building wall material in urban areas shows a higher number than other heavy building materials, such as concrete, glass, metal coating, and asphalt. This is due to the bricks' strength, high social class image, and thermal comfort [1,2,3]. Furthermore, the perception of thermal comfort is immensely correlated with the type of climate in a place, in this case, countries that have a hot-humid climate such as Indonesia with a tropical climate which has a comfortable temperature ranging from 24°C - 26°C, while in a country that experienced 4 (four) seasons, the perceived comfort temperature was equal to 28°C [4]. On the other hand, the use of bricks as building walls has an impact on environmental warming [5,6] and has been proclaimed to be a substantial factor in the formation of the Urban Heat Island (UHI) [7].

In terms of the material's thermal characteristics, brick walls have different thermal behavior throughout the day [8,9,10]. One of the thermal behaviors of brick walls is to garner considerable heat and tends to delay it from being re-released, as shown in Figure 1 [11]. At 08.00 am, the brick walls receive heat, but at 10.00 am, the heat received will be re-released. During the daytime, the temperature will drop and rise again at 14.00-15.00, while at nighttime, the brick walls will re-release the heat. Therefore, mitigation technology is needed to control heat gain from the sun and manage the heat from the building so as not to heat the building's brick walls to reduce UHI's effect. Mitigation can be in thermal behavior intervention on brick walls comprising heat gain, heat storage pattern, and heat release pattern.

![Figure 1. Temperature pattern of inside and outside brick wall material.](image)

Numerous studies studying the phenomenon of heat exchange have also been conducted, subsuming the orientation and ratio of width to height of buildings for various climates [12,13]. Besides, several mitigation strategies to deal with the UHI phenomenon have been developed in the form of shading the building skin through shading [14], self-shading [15], vegetation techniques, and adding building skins [16]. Mitigation strategies by replacing building skins are replacing heavy building materials with lightweight building materials with lower heat capacity, replacing glass opening materials that perform well, and using Double Skin Façade [17,18,19]. Mitigation strategies with thermal insulation techniques
include placing thermal insulation on the building skin, glass wool and rock wool, and cellulose fibers [20]. Another strategy is building envelope engineering to reduce surface temperature through vertical greening systems, tree canopy systems, and reflective layers [21].

The use of vegetation serves as an insulating layer providing a shading effect and an evaporative cooling effect [22]. Vegetation ingests substantial solar radiation amid plants’ evapotranspiration can further reduce it, indicating escalated humidity and lower surface temperatures of hard surfaces. Recent studies have demonstrated that green wall techniques might steer heat circulation, improve indoor thermal comfort, and temper heating or cooling energy [23]. The use of green walls also proves that some green wall systems can reduce environmental loads by conferring to the walls' thermal resistance, introducing reduced energy demand [24].

Apart from vegetation, Aluminum Composite Panel (ACP) for UHI mitigation can be installed on the facade of any building to enhance the aesthetic appearance at the various height of the building. ACP is the most suitable material for maintenance and renovation of building facades because it is lightweight, easy to maintain, flexible, easy to install, and does not add to the dead load of the building and can be installed in any form because it is a flexible material [25]. However, for UHI, the use of ACP has not been studied significantly from the intervention of building material composition; hence this study aims to compare the thermal behavior of conventional brick walls without and with interventions consisting of conventional brick walls (without intervention), bricks with green wall intervention in the form of vegetation’s installation on the walls/facades of buildings and brick walls with the intervention of Aluminum Composite Panel (ACP) on the east and west wall orientation.

2. Methodology

2.1. Material specification

This study brings out material composition interventions on conventional brick walls consisting of plastered bricks, painted and painted white. The layer thickness of each arrangement on the brick wall is as in figure 2. The first intervention approach, green wall, is to green the walls with Ivy Hadera vines with a 30 cm diameter without the air gap. Moreover, the plants are planted in sandy loam with a substrate (sandy loam soil) by applying a modular trellis along the wall, as shown in figure 3. The last material intervention using material insulation, Aluminum Composite Panel (ACP), is applied by installing aluminum material with a 4 mm thickness, as shown in Figure 5.
Figure 3. The thickness of the green-wall layer.

Figure 4. The Ivy Hadera. [26]

Figure 5. Brick wall and additional of the aluminum composite panel (without air gap).
2.2. Climatological conditions

| Time  | Weather       | Air temperature (°C) | Humidity (%) | Windspeed (Knot) |
|-------|---------------|-----------------------|--------------|------------------|
| 00.00 | Sunny Cloudy  | 25                    | 75           | 5                |
| 06.00 | Light Rain    | 36                    | 55           | 10               |
| 12.00 | Cloudy        | 25                    | 80           | 5                |
| 18.00 | Cloudy        | 24                    | 90           | 2                |
| 23.59 | Sunny Cloudy  | 24                    | 70           | 2                |

The climatological data at the measurement location are presented in table 1. Weather records throughout the day fluctuate from sunny to cloudy, cloudy to local rain. The air temperature varies from 23°C to 36°C. While the humidity also ranges throughout the day from 55% to 90%, with wind speeds between 2 to 10 knots. Meanwhile, direct Shortwave radiation or solar radiation value ranges from 449.13 W/m² to 628.78 W/m² due to the bright sky conditions that are not clear throughout the day because it is influenced by weather conditions that vary throughout the day.

2.3. ENVI-met modeling

A simulation of ENVI-met V4 (2020) with a student license is performed in this study. The location/area setting used in modeling is public housing. The simulation model is a simple house with a length of 8 meters and a width of 6 meters with an area of 48 m² with four units houses equipped with a garage and a 2 meter high of dense hedge tree in front and back of the building and surrounded by concrete pavement gray and asphalt road as shown in figure 6.

Figure 6. (a) Building plan; (b) Master plan of the area; (c) Simulation model of ENVI-met 3D.
The geometric model settings were x-Grids 50, y-Grids 50, and z-Grids 40 with the two units size of grid cells for each dx, dy, and dz. Besides, nesting grids' soil profile is loamy soil. Top of the building or element 5 meters from ground level to the end of the roof. Meanwhile, ENVI-guide data input was carried out on August 24, 2004, for 24 hours starting from 06.00 am to 06.00 am with a warm temperature, minimum air temperature (night time) of 23°C and maximum temperature (day time) of 36°C, slow winds speed with of 0.1 m/s and wind direction from the east (90°).

Material intervention simulation is executed by attaching the green wall and ACP material to all east and west orientation wall surfaces. All simulation results will be analyzed using the Leonardo feature on the ENVI-met to capture the surface temperature results on the east wall orientation and the west wall orientation, presented in graphs and hourly temperature contour drawings 24 hours. The three brick walls material (1 non-intervention and two interventions) will be compared based on the surface temperature to discern the UHI effect in both east and west orientation.

3. Results and discussion

3.1. Results

The results of ENVI-met simulation on brick wall material intervention show that the thermal behavior pattern of heat exchange on brick walls varies every hour. The surface temperature values for conventional brick walls, brick walls with green wall material intervention, and ACP for east and west wall orientation are shown in Table 2.

Table 2. Surface temperature (°C) of wall material intervention.

| Time  | Brick wall | Brick wall with green wall | Brick wall with ACP |
|-------|------------|----------------------------|---------------------|
|       | East       | West                       | East                |
| 07.00 | 25,0       | 24,6                       | 27,1                |
| 08.00 | 27,5       | 26,6                       | 33,8                |
| 09.00 | 29,1       | 28,8                       | 34,5                |
| 10.00 | 30,3       | 30,0                       | 35,3                |
| 11.00 | 31,2       | 30,9                       | 35,9                |
| 12.00 | 31,7       | 31,6                       | 36,2                |
| 13.00 | 32,3       | 32,2                       | 36,6                |
| 14.00 | 33,1       | 32,8                       | 34,0                |
| 15.00 | 33,8       | 33,4                       | 34,4                |
| 16.00 | 34,5       | 33,8                       | 34,5                |
| 17.00 | 34,0       | 33,5                       | 33,4                |
| 18.00 | 33,4       | 32,9                       | 32,4                |
| 19.00 | 32,8       | 32,4                       | 31,6                |
| 20.00 | 32,1       | 31,9                       | 30,8                |
| 21.00 | 31,3       | 31,4                       | 30,0                |
| 22.00 | 30,5       | 30,8                       | 29,1                |
| 23.00 | 29,6       | 30,3                       | 28,2                |
| 00.00 | 28,7       | 29,6                       | 27,4                |
| 01.00 | 27,9       | 29,0                       | 26,5                |
| 02.00 | 27,1       | 28,3                       | 25,6                |
| 03.00 | 26,2       | 27,5                       | 24,8                |
| 04.00 | 25,4       | 26,8                       | 24,0                |
| 05.00 | 24,6       | 26,0                       | 23,1                |
| 06.00 | 23,9       | 25,2                       | 22,3                |
Figure 7. Comparison surface temperature of the conventional brick wall with east and west orientation.

Figure 8. Surface temperature comparison of the green wall for east and west orientation.

As shown in figure 8, a comparison of hourly surface temperature values for the orientation of the east and west walls of the brick walls with green wall intervention is presented. For east orientation, there is a significant increase in surface temperature from 27.1 °C to 34.5 °C at 07.00 - 09.00, and then it rises moderately to 36.6 °C until 13.00. Subsequently, the surface temperature decreased until it reached 22.3 °C at 06.00 in the morning. However, in west orientation, the striking increase occurred between 07.00
and 11.00, from 23.5 °C to 35.7 °C, then it appears a slight increase to 37.1 °C in the afternoon. Then, the temperature decline with the slope as in east orientation reached 23.4 °C at 06.00.

Later, the surface temperature of brick walls with ACP intervention is introduced in figure 9. It can be seen that, in general, the hourly trend of ACP intervention is similar to conventional brick walls for both orientations. For east orientation, from 07.00 to 17.00, the temperature increased significantly and fell off between 17.00 and 06.00, varied from 24.5 °C to 33.9 °C in the daytime and drop until 23.7 °C in the following morning. On the other hand, the west side temperature ranged from 24.5 °C and hit a maximum temperature of 33.6 °C at 16.00. Subsequently, the temperature on the west side then decreased to 24.8 °C in the morning.

By collating every intervention in the same orientation, the heat performance comparisons among three types of walls are presented in Figures 10 and 11. As demonstrated in figure 10, from 07.00 to 18.00 (day time), brick walls with ACP intervention suggested a lower surface temperature than conventional brick walls and walls with green wall intervention. Conversely, from 18.00 to 06.00 (night time), the surface temperature for green wall intervention implied a lower value than brick walls and walls with ACP intervention. Furthermore, for ACP intervention walls, the value is lower than that of brick walls.
For west orientation (figure 11), it can be seen that the time range between 07.00 and 19.00 for brick walls with ACP intervention shows a lower surface temperature compared to brick walls and walls with green wall intervention. The surface temperature value for walls with green wall intervention at 10:00 - 16:00 increased significantly; then, after 17.00, it decreased again. Meanwhile, at 18.00 - 06.00, the surface temperature for walls with green wall intervention denoted a lower value than conventional bricks and walls with ACP intervention. Likewise, with ACP intervention walls in east orientation, the surface temperature value is lower than that of brick walls.
Figure 12. Direct shortwave radiation.

Figure 12 shows one of the direct shortwave radiation values in brick wall interventions with Aluminum Composite Panel (ACP) at 09.00 with a value between 449.26 W/m² and 628.96 W/m². The value of solar radiation is relatively low because the sky’s bright conditions influence it at that time, where clouds partially cover the sky and even light rain occurs. This also affects the surface temperature value, especially for the orientation of the east wall. The value of the surface temperature in the east wall's orientation in the morning should be higher, but because the sky is covered in clouds, even rain causes the lower surface temperature.

Table 3. Contour surface temperature (°C) of wall material intervention.
Table 3 shows how the type of wall intervention will affect the environment regarding the urban heat island issue. For conventional brick walls, at 07.00, 12.00, 17.00, and 22.00, the same contour surface temperature for the east wall orientation and the west wall orientation. In the intervention of brick walls with green wall material, the contour surface temperature for 07.00, 12.00, and 17.00 also showed the same contours, both for the east and west wall orientation. While the contour surface temperature for 22.00 shows a difference where the east wall's orientation shows that the surface temperature value is lower than the west wall's orientation. Meanwhile, based on the contour surface temperature for wall material intervention with ACP shows that at 07.00 am and 12.00, the east wall orientation is higher than the west wall. On the other hand, at 17.00, the surface temperature contour on the east wall orientation was lower than the west wall orientation, while at 22.00, the surface temperature contour for the east wall orientation and the west wall orientation remained similar.

3.2. Discussion
Based on the results of brick wall interventions in tropical climates, it reveals that the trend of thermal behavior between building walls with and without intervention is assorted. The thermal behavior pattern of conventional brick is receiving heat at 07.00 - 08.00, releasing heat at 10.00 - 12.00, re-receiving heat again at 14.00 - 17.00, and releasing the heat that has been previously received at 22.00. Naturally, as the brick wall's surface increases in temperature due to solar radiation, some of the heat was absorbed into the wall's inner layers, and some were ejected outside, causing an increase in air temperature. At 1 cm from the wall's surface, the proximity to the wall's surface causes the air temperature to increase significantly within a short period. The temperature reaches a peak of around 45°C and occurring from 9 am to 10 am. The heat continues to spread to a 30 cm distance from the wall's surface, causing a maximum increase in temperature of around 33°C and occurring from 10 am to 11 am. At a 60 cm distance, the temperature increase is lower than the previous points due to more excellent proximity, where the maximum temperature reaches around 29°C and occurs from 11 am to 1 pm. The temporal delay of temperature peaks between each measurement point shows the heat transfer process between the wall's surface and the outdoor air.
Comparing the maximum surface temperature values for the east wall's orientation on the intervention wall with ACP 34.3 °C, then with the green wall intervention 36.6 °C and conventional brick walls 34.5 °C. Meanwhile, the surface temperature with west wall orientation shows that conventional brick walls
are 33.8 °C, walls with green wall intervention are 37.6 °C, and ACP intervention walls are 33.6 °C. From the maximum value of surface temperature for the orientation of the east wall and the west wall's orientation, it can be seen that the surface temperature of the wall with green wall intervention is higher than that of conventional brick walls and walls with ACP intervention. This is due to the type of vines used in the green wall system using *ivy Hadera*, which has a diameter of 30 cm, where the density is slightly tenuous so that solar radiation more easily enters the surface of the material.

On a wall with green wall intervention, the morning's surface temperature shows a significant increase, then drops dramatically and gives the lowest surface temperature than other walls at night. This is due to the influence of the vegetation used on the walls with green wall intervention, wherein the morning. During the day, plants undergo a photosynthetic process, wherein the photosynthesis process evaporation occurs through evapotranspiration to increase the air temperature on the wall. However, during night time, the secured heat is stored by the vegetation to decrease the surface temperature. On ACP-intervening walls, the morning to evening's surface temperature is lower than the other walls and lower than conventional brick walls at night. This is due to ACP's material properties, where the composition of the constituent matrix provides a practical thermal conduction pathway for heat storage in the material so that it does not release heat [27]. Moreover, in this simulation, ACP is stuck to the wall without a gap, where it is used to be installed with an air gap around 4 cm. With a more extended wall width, it will reduce heat to be released in the atmosphere. From the three wall interventions, the surface temperature value of wall intervention using ACP is lower than the surface temperature of conventional brick walls and walls with green wall intervention in the morning to evening, with a difference in efficiency ranging from 0.6 to 6.7% per day. For east wall orientation and west wall orientation. Meanwhile, at night, ACP efficiency is around 0.3%, and green wall efficiency is 3% compared to conventional brick walls.

4. Conclusion

Utilization of bottom ash with local waste, i.e., sago husk, could be established in housing sectors since all properties are well satisfied, both structural and non-structural components. 10% and 20% composition of bottom ash in these admixtures might yield better requirements for light and strong building due to their result on bulk density and compressive strength. However, workability in the molding process should be vigilantly executed as cracks are comfortable to occur provided water distribution is not uniform in bricks body.

From the results of ENVI-met simulation and analysis on conventional brick walls, brick walls with green wall intervention, and brick walls with ACP intervention, it can be concluded that:

- The brick walls tend to show different diurnal thermal behavior patterns for heat gain, heat storage, and heat release. The pattern is also influenced by its east or west orientation due to different radiated time and radiation power.
- The simulation results show that the addition of ACP on the brick wall surface affects a little bit lower surface wall temperature than the conventional brick walls (without intervention). In comparison, the addition of the green wall on the brick wall surface shows higher air temperature on both of east and west wall. However, the addition of the green wall shows significantly lower surface temperature during night time. The additional greeneries on the wall surface changes the brick wall's thermal behavior that its thermal mass effect decrease significantly, indicated by lower surface temperature during night time. On the other side, it could be understood that the conventional brick wall harms the night thermal environment.
- The simulation of additional greeneries on the wall surface affects a higher surface temperature during the day hours. Its condition due to the *ivy Hadera* vegetation consists of cellulose, low in thermal mass material.
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