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Research paper

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The effect of vertical gardens on temperature and CO_2 levels in urban housing

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ABSTRACT

The city's thermal environment plays an important role in achieving comfort and quality of life, especially during the current global pandemic. Meanwhile, reduction in the green areas has been observed to be continuously causing climate change in cities and one of the proposed solutions to this is by developing a greening system for buildings. This paper, therefore, assessed the ability of vertical garden to decrease air and surface temperatures as well as CO_2 levels. The research involved field measurements of these parameters both inside and outside the building along with the modification of the vertical garden distance at 0.5 m and 1 m as well as the plant type including red spinach or amaranthus hybridus, mustard or brassica juncea, celery or apium graveolens linn, and cat's whiskers or orthosiphon spicatus. The results showed an average decrease of 0.75°C in air temperature, 16.4°C in surface temperature, and 58.8 ppm in CO_2 levels. Moreover, a maximum reduction of 6°C was achieved in air temperature with red spinach plants at 0.5 m, 26.3°C in surface temperature by the red spinach plant, and 124 ppm in CO_2 levels by celery plants. In conclusion, a closer distance and darker color of the leaves as well as the Red Spinach species were found to be the main consideration in the application of vertical gardens in urban homes due to their ability to reduce the temperature on the limited land.

Introduction

Vertical greening systems are increasingly being used due to a continuous decrease in green areas and limited land (Seyam 2019). According to Besir (2018), this involved placing a veil mainly as a growing medium on the walls of buildings (Besir and Cuce 2018). There are two models of vertical greening systems and they include green walls and vertical gardens (Manso and Castro-Gomes 2015; Bustami et al. 2018). Green walls consist of vines placed directly on the wall and indirectly by staying rooted in the earth (Zaid et al. 2018; Riley 2017; Cuce 2017) while vertical gardens involve using groups of plants with their respective media and without dependence on a particular type (Medl, Stangl, and Florineth 2017). The advantage of vertical gardens over green walls is the modularity and flexibility in replacing plants and this makes its application and maintenance easy (Raji, Tenpierik, and van den Dobbelsteen 2015; Zaid et al. 2018; Wang, Er, and Abdul-Rahman 2016). They are, however, classified into modular and continuous (Bustami et al. 2018; Dover 2015; Charoenkit and Yiemwattana 2016).

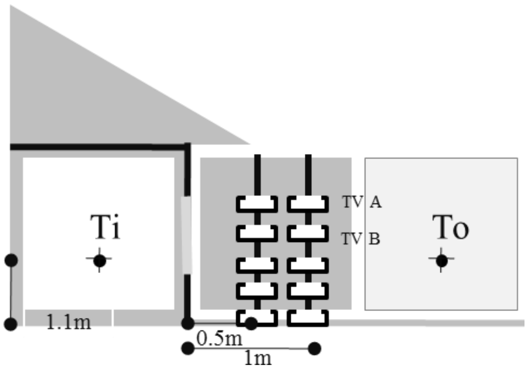
Vertical gardens have many aesthetic and functional benefits such as the reduction in temperature, especially in the afternoon. This study examined the effect of implementing vertical gardens in urban homes to improving the thermal environment, especially air temperature and environmental quality, especially CO_2 levels. The problem formulated was to determine the performance level of vertical gardens in reducing air and surface temperatures as well as CO_2 levels. Moreover, the purpose and benefit were to evaluate the effect of distance and plant species on the thermal environment through field measurements. The research was designed to be in several stages and these include measuring the air temperature difference, plant against surface temperature, and the decrease in CO_2 levels. All these stages were used to determine the effect of plant type and distance on environmental comfort and quality. The novelty of this paper is founded on the fact that limited studies have been conducted on natural cooling and carbon emission reduction through the application of vertical gardens in tropical buildings. Meanwhile, advanced research focuses on applying the vertical garden model as the main component of a house in relation to providing comfort and environmental quality.

Method

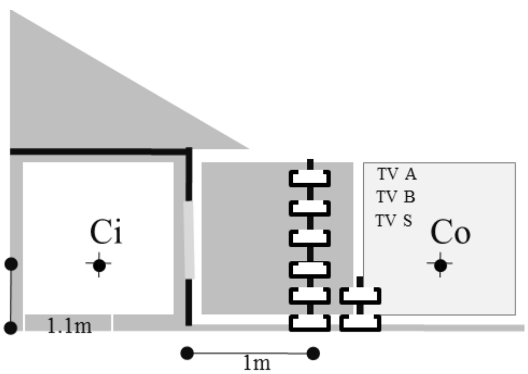
The quantitative approach was employed with an experimental field measurement technique. The research object used was a typical 45-type minimalist house located in Griya Saxofone Housing in Malang, East Java with the vertical garden model placed in the front yard and the side of the bedroom wall. The model was 3 m wide and 3 m high with 6 shelf levels consisting of 36 plant pots. Moreover, the bedroom is 3 x 3 m with one 1 m x 1.1 m window located in the middle of the wall at a height of 1 m opened. The research object is shown in the following figure 1.

Figure 1. Objects of vertical garden research in minimalist urban housing in Malang, East Java

The research instruments and techniques were in line with the stages of the study and these include first measuring air temperature every 15 minutes using the Hobo Data Onset tool placed at the measurement point as shown in figure 2. The performance was determined based on its reduction level outside and inside the building. Second, the performance of the plants was measured against the surface temperature with or without plants using the Flir infrared temperature model i3 at 08.00 am, 10.00 am, 12.00 pm, 02.00 pm, and 04.00 pm. Third, the plant was also measured against CO_2 levels using the GE Telaire 7000 Series every hour starting from 08.00 am to 04.00 pm with the tool positioned as shown in figure 3. The CO_2 performance was determined using the difference between the levels in outdoor and indoor space.



Ti = Indoor air temperature; To = Outside air temperature
T1 A = Vertical garden red spinach/*amaranthus hybridus*
T1 B = Mustard vertical garden/*brassica juncea*
Figure 2. Air temperature measuring instrument position



Ci = CO_2 levels indoor space; Co = CO_2 levels in outdoor space
TV A = Vertical garden red spinach/*amaranthus hybridus*
TV B = Mustard vertical garden/*brassica juncea*
TV S = Celery vertical garden/*apium graveolens linn*
Figure 3. CO_2 measuring instrument position

The modifications made at each stage of the study are shown in the following table 1:

Table 1. Vertical garden modifications at each stage of the field measurement

Modification	Air temperature performance	Surface temperature performance	CO_2 performance
0.5 m distance	√		
1 m distance	√		√
Red spinach plants	√	√	
Mustard plant	√	√	
Cats whiskers		√	
Celery plants		√	

Result and discussion

The effect of vertical garden distance on the temperature of the air in the house

The measurements recorded from 06:00 am to 06:00 pm showed the vertical garden distances decreased the temperature in the space. An average decrease in both distances measured was 1.1ºC in red spinach plants and 0.4ºC in mustard plants. Meanwhile, the maximum reduction of 6ºC occurred at 12.00 pm in spinach plants with 0.5 m and 3.2ºC in mustard plants also at 0.5 m as shown in figure 4.

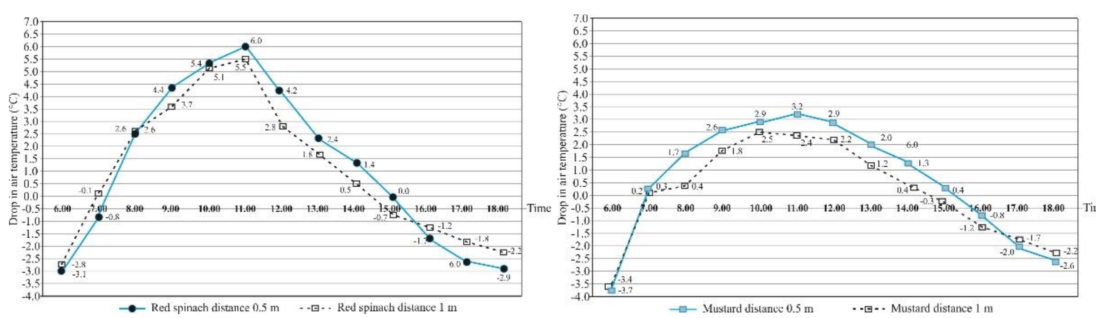


Figure 4. The relationship between the distance of the garden and the decrease in air temperature in the red spinach plant (left) and mustard plant (right)
Source: Field measurements, 2015

Red spinach was recorded to have the maximum air temperature decrease of 6ºC to 5.5ºC as the vertical garden distance changed from 0.5 to 1 m while the average was 1.2ºC to 1ºC respectively. In the mustard vertical garden, the maximum decrease was a difference of 0.7ºC between 0.5 and 1 m. Moreover, the maximum temperature reduction of 3.2ºC to 6ºC recorded was in line with the results of the research conducted by Tan et al (2014) and Widiastuti et al. (2018) on the temperature-reduction performance of vertical garden in Singapore and Indonesia was found to be 0.5 to 10 ºC (Tan, Wong, and Jusuf 2014; Widiastuti et al. 2018). The comparison of the results for both distances showed 0.5 m provided a higher performance compared to 1 m. This means a closer vertical garden has the ability to provide a better natural cooling effect than farther distance. Therefore, a 0.5 m distance is the right strategy to be applied in urban homes with limited land.

The effect of plant types used in the vertical garden on the decrease in the air temperature of the house

The two types of plants, red spinach, and mustard, were compared at 1m to determine the plant with the highest decrease in the room's air temperature and the results showed an average decrease of 1ºC and 0.2ºC, respectively while 1.2ºC and 0.6 were measured at 0.5 m.

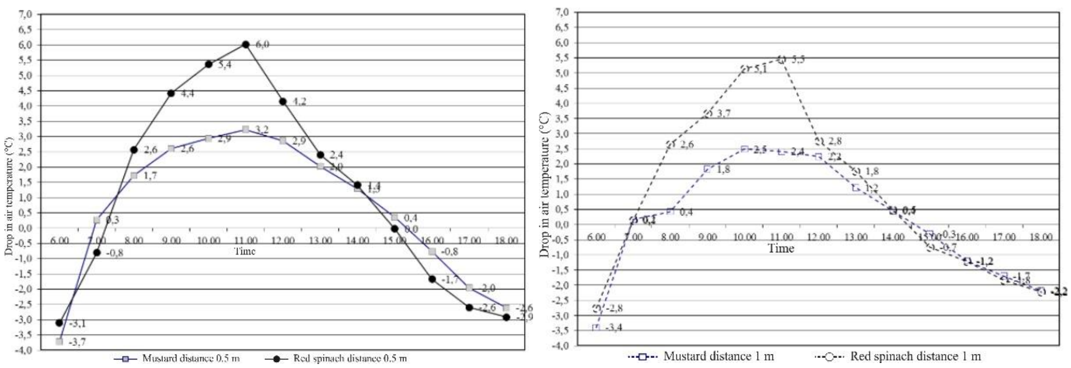


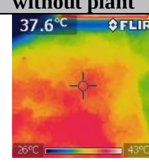
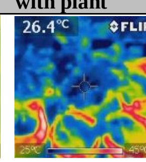
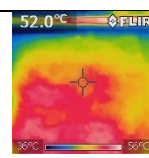
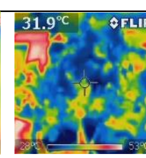
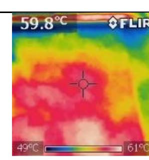
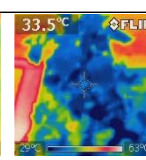
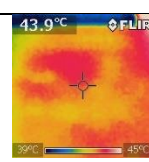
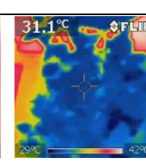
Figure 5. Relationship between types of plants and a decrease in air temperature
Source: Field measurements, 2015

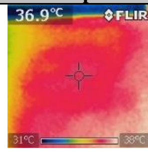
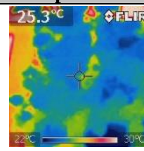
Red spinach Plants were discovered to have reduced the air temperature more compared to mustard. This is evident in the 3ºC difference recorded at 1 m and 2.8ºC at 0.5 m. This performance was associated with the darker color of the red spinach leaves which allows it to absorb higher solar radiation. It has also been reported that plant density factors also affect air temperature reduction (Jim 2015). However, some studies use plants with the same density.

The effect of plant types on the decrease in surface temperature

The values recorded with the Flir i3 series showed a decrease in surface temperature due to the presence of plants in a field as presented in table 2.

Table 2. The effect of red spinach plant on decreasing surface temperature

Time	Temperature without plant	Temperature with plant	Temperature difference
08.00			11.2ºC
10.00			20.1ºC
12.00			26.3ºC
14.00			12.8ºC

Time	Temperature without plant	Temperature with plant	Temperature difference
16.00			11.6ºC

Source: Field measurements, 2015 using the infrared surface temperature tool Flir i3

The red spinach plants were discovered to have significantly decreased the surface temperature as observed with differences measured at 08.00, 10.00, 12.00, 14.00, and 16.00 which were 11.2, 20.1, 26.3, 12.8, and 11.6°C respectively as well as an average value of 16.4°C. These results are consistent with the opinions of He et al (2017) and Tudiver and Korjenic (2017) on the effect of greening a vertical building on heat transfer for building walls (He et al. 2017; Tudiwer and Korjenic 2017). Purwanto (2019) also showed that the heat transfer of a surface is the thermal connector of other building components (Purwanto 2019). Meanwhile, after the surface temperature of the red spinach plants was measured, other types of plants such as mustard, celery, and cats' whiskers were also assessed in relation to color diversity and plant size uniformity.

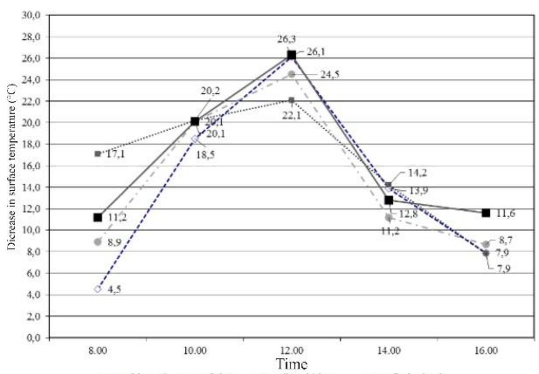


Figure 6. Relationship between plants species and a decrease in surface temperature
Source: Field measurements, 2015

The analysis of infrared images on each plant showed the highest temperature reduction of 26.3°C for red spinach, 26.1°C for mustard, 22.1°C for celery, and 24.5°C for cat whisker at 12 noon. Meanwhile, the highest average decrease in surface temperature for red spinach plant was 16.4°C followed by celery with 16.3°C, cat whisker with 14.7°C, and mustard with 14.2°C.

These results reinforce the notion that plants with dark leaves such as red spinach and mustard plants produce greater performance. Nevertheless, the physiological aspects of plants also have influence and this is in line with the findings of Wong and Baldwin (2016) that the mechanism of evapotranspiration reduces air temperature by releasing water vapor around the plants through the leaf stomata (Wong and Baldwin 2016). Solar radiation is, therefore, absorbed by the water vapor to cause a natural cooling effect (Charoenkit and Yiemwattana 2016). Furthermore, the leaves shading has also been reported to have a significant influence on the cooling performance and energy consumption (Gratani, Varone, and Bonito 2016). It is, however, important to study the components of plant physiology such as stomata, density, and shape of leaves in the future.

The effect of vertical garden on CO_2 levels

The reduction in the CO_2 level was obtained experimentally in red spinach, mustard, and celery and the results showed celery averagely has the highest maximum level of reduction with 124 ppm recorded at 13:00 while mustard and red spinach plants had 73 ppm and 74 ppm respectively at 12.00.

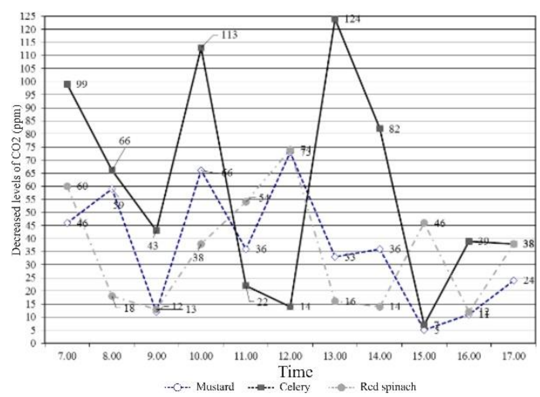


Figure 7. The relationship between plants types and a decreased levels of CO_2
Source: Field measurements, 2015

Figure 8 shows the CO_2 level was reduced more at a greater number of plants and the average significant decrease was from 58.8 ppm to 27.2 ppm due to the reduction in the number of potted plants from 36 to 12. This in line with the findings of Currie and Bass (2008) and Yang et al (2008) that plant area influences the decrease in the CO2 level (Currie and Bass 2008; Yang, Yu, and Gong 2008).

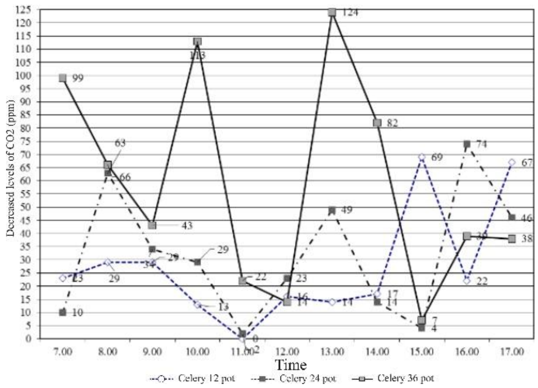


Figure 8. The relationship between the number of plants and a decreased in CO_2 levels
Source: Field measurements, 2015

The performance related to a decrease in air and surface temperatures showed vertical insulation as the heat insulation, especially when solar heat directly affects the building. Lin (2006), however, reported a 1°C reduction in temperature has the ability to decrease the consumption of artificial ventilation by 6% (Lin HT 2006, 16–19).

Conclusion

The main factors of the vertical greening system of buildings aiding the reduction of air temperature include the distance, color, and type of plant. The maximum reduction of 6°C was recorded at a distance of 0.5 m with red spinach plants while the average observed in the two spacing types and plants was 0.75°C. Moreover, the surface temperature was recorded to be majorly reduced by the leaf color with the maximum reduction of 26.3°C found with Red Spinach plants while the average value was 16.4°C. The CO_2 level was discovered to be mainly reduced by the type and number of plants with the average valued recorded to be 58.8 ppm while the maximum of 124 ppm was found in celery plants with 36 pots. Further research is, therefore, required, especially on the aspects of plant physiology and variations in plant geometry. The selection of the right plants such as vegetables, ornamental plants, and herbs as vertical garden elements will improve the quality of life and well-being, especially in this COVID-19 Pandemic period.

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