Thermally regulated green wall façade

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Research Article

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Abstract

Green living walls can improve the aesthetical quality of a building and it can create a temperature moderating effect inside a building. Temperature will be monitored on the outside wall, research, and control areas for a 1-year period that will encompass all seasons, sunny, cold and rain to capture temperature data. The captured data will then be utilized to calculate heat flux of the solar energy that are absorbed through the wall. The amount of energy losses will be determined from the evaporation process taken place during a summer and winter month.

Highlights

- Construction and testing of cement tiles for durability and strength.
- Thermal measurement of a vertical green wall shows promising results.
- Cooling during summer months, isolation during winter months.
- Temperature reductions between 2 – 4 °C were observed all year round.
- It creates a temperature moderating effect inside a building.

1. Introduction

Green façades (Medl et al. 2017) can improve the aesthetical quality of a building and provide a possible cooling solution to the interior of the building in comparison to conventional cooling systems. (Gletter and Bowe, 2006) Direct or indirect green wall façades (Loh, 2008) with vegetation can effectively insulate and cool down the building skin temperature to regulate the interior cooling. (Susrova et al, 2013, Wong and Baldwin, 2016, Radic et al 2019, Roehr and Laurenz, 2008) Living wall systems on the other hand the green vegetations are planted into containers that are adhered to an exterior wall of a building. (Perini and Ottele, 2014) Living wall systems can improve the thermal efficiency of a wall construction by offering extra thermal resistance to the exterior wall. (Fox et al, 2021)

The most important effect provided by green walls is the shading of the building is a clear benefit during the summer months. (Stec et al, 2005, Yin et al, 2017) Green walls could add benefit to energy performance and microclimate mitigation in urban areas. (Riley et al, 2019) Green façades improve indoor comfort by regulating the temperature (Assimakopoulos et al, 2020) and therefore, reducing the energy needs. The other important benefit in using green living wall applications are of economical, social (Perini and Rosasco, 2013) and environmental origin in reducing greenhouse gases (Benjamin et al, 2021), improving of air quality (Fateme et al, 2020), energy saving through insulation (Hoffman et al, 2021) and the overall architectural of the building.

These wall tiles are a robust vertical garden tile with a cup like a normal wall tile that have a flat surface at the back to adhere to a cemented wall. A test wall was prepared in Gqeberha, South Africa a coastal city to investigate the thermal effect of green living wall. Plants chosen for this project because of their hardness and adaptability in a coastal environment were, *Echeveria prolifera*, *Echeveria secunda*, *Sedeveria*

hummelii, Crassula muscosa, and Crassula pudescens. The crassulas plants provide a very good hanging effect that provide additional cooling.

Green living wall systems could provide personal and social benefits to the urban area. (Perini and Rosasco, 2013) The cost benefit analysis have shown that once the initial installation cost have been done, it is only through maintenance and proper irrigation that vertical wall can be sustained. (Perini and Rosasco, 2013, Wong et al 2003)

The aim of this research was to determine the temperature flux observed through a living vertical wall and the cooling or isolating effect inside the building. This was done by connecting various thermocouples to the outside surface of the wall where the tiles containing the plants were situated. A thermocouple measuring device was placed inside the building connected to the green wall tiles. And another thermocouple measuring device was placed in a control area adjacent to the test room. The only difference was that the outside wall was only plastered. From these temperature measurements, profiles were drawn over a month period and over the full year period. The full year period shows the heat flux over summer and winter seasons.

2. Material And Methods

The wall tile was locally manufacture from cement, sand, a plasticizer, and calcium chloride. The normal cement sand combinations were used and combined with the plasticizer and calcium chloride. The plasticizer provide extra strength to the final tile product and the calcium chloride hardens the cement and assist in a quicker curing process.

After the curing process rectangular test samples were selected and send for flexure strength testing to determine strength and breaking point of the cement formula. In this test a specimen rectangular or flat cross-section is placed on two parallel supporting pins. The loading force is applied in the middle by means loading pin. The supporting and loading pins are mounted in a way, allowing their free rotation about:

- axis parallel to the pin axis
- axis parallel to the specimen axis.

This configuration provides uniform loading of the specimen and prevents friction between the specimen and the supporting pins (Fig. 1).

The test wall was plastered to ensure a smooth surface for adhering the wall tiles. The wall dimensions were 3 m height and 6 m wide. The tiles were adhered to the wall using a tile adhesive and covered a 6 m² area. Four LogTag thermocouples were place strategically on the wall and in the flower cavities of the tile to measure the temperature on a 24-hour cycle for 12 months. The readings where recorded over a month period and downloaded using the LogTag analyzer 3 software to analyzed and construct temperature profiles. Figure 2 shows a front view of the modular wall tiles and the positions of the

thermocouples in the tile cavities. A LogTag device with internal sensor was placed in the research area and one in a control environment to measure the temperature inside the buildings.

The case study was performed in the city of Gqeberha (Port Elizabeth) at Nelson Mandela University the latitude 34.00°S, and longitude 25.671°E. A back building was utilized that consist of a storage area adjacent to an open office area of about 12 m² each. The tiles were adhered to the north facing wall for the best solar energy absorption. This provide good sunlight throughout the day so that the plant (*Echeveria prolifia*, *Echeveria secunda*, *sedeveria hummelii*, *Crassula muscosa*, and *Crassula pudescens*) could grow in good sunny conditions. Since this is a coastal city it has a fair amount of humidity during spring and summer months. The winters are not severe although cold nights of 0–2°C have been reported. Generally, the experiments were conducted at different temperature and humidity conditions to determine the impact of green façade on thermal regulation. From Fig. 3 the thermocouple points could be seen from where the measurements for the temperature study was taken.

The insulation of the green wall is caused by the different layers of air cavities formed between the leaves of the plants to the tile cup cavity of the tiles. The temperature is then further reduced as the heat moves through the tile – adhesive – plaster and then finally through the brick wall to reduce the interior of the building. This thermal conductivity could be measured by placing various thermocouples on the outside wall and on the inside. In general, the parameters for the insulation materials are expressed in U, R or λ – values. These parameters are related by the following expression:

$$U = \frac{1}{R} = \frac{\lambda}{d} = \frac{q}{\Delta T}$$
$$q = \frac{\lambda * \Delta T}{d}$$

With U the heat transfer coefficient (W.m²K⁻¹), R the heat resistance coefficient (m²K.W⁻¹), λ the thermal conductivity (W K⁻¹m⁻¹), d the thickness of the vegetation (m), q the heat flux (W m²) and ΔT the temperature difference between the outside green wall and the research or control area (K). Table 1 provide information of the wall composition used to adhere the wall tile on for this research study.

Table 1
Wall composition

Wall composition	
Coating with cement (inner wall)	d = 1.5 cm $\lambda = 0.071 \text{ W K}^{-1}\text{m}^{-1}$
Brick	d = 10.2 cm $\lambda = 0.06 \text{ W K}^{-1}\text{m}^{-1}$
Coating with cement (outer wall)	d = 1.5 cm $\lambda = 0.071 \text{ W K}^{-1}\text{m}^{-1}$
Cement wall 4tile	d = 1.0 cm $\lambda = 0.14 \text{ W K}^{-1}\text{m}^{-1}$
Potting soil cavity of tile	d = 6.5 cm $\lambda = 0.0364 \text{ W K}^{-1}\text{m}^{-1}$

3. Results And Discussions

The cement cup tiles were prepared in-house from Portland cement (strength 42.5 and 52.5N), a plasticizer (provide strength and elasticity), calcium carbonate (hardens the cement), sand and water. This mixture after thoroughly mixing were cast into molds and cured for 10–12 hours. Figure 4 shows the rectangular cement tiles that were made for the 3-point flexure strength testing. This testing was done by means of a 3-point flexure testing as described in the Material and Method section. Table 2 summarizes the results obtained from the flexure testing.

Table 2
Summary of the 3-point flexure testing

Sample number	Sample Name	Strength – Force (N)	Comment
1	Cement, sand water	130	
2	Pearlite	224	Contains pearlite to make the tile lighter.
3	Fiber	225	To bind the cement better and to ensure if cracks do occur that the cub does not fall apart.
4	Slag Ash	420	Very hard and difficult to work with, also heavy tile.
5	Plasticizer	215	Good strength; light weight and durable.
6	Gypsum	28	Brittle, although the tile was light it did not hold together.

Batch samples 3 and 5 in Table 2 were chosen for the green wall façade based on their strength consistency over 200 N and being light weighted to adhered to the wall.

Green living walls need regular watering hence a good reliable irrigation system need to be installed to ensure timeous watering is done through timer-controlled irrigation system. The timer was set to water the wall twice daily once in the morning and once in the evening for 25 minutes to ensure that a good dose of water is provided. Green wall monitoring was performed by the insertion of 4 thermocouples as illustrated in Fig. 2 to measure the temperature on the green living wall at various positions to carried out with the 4 thermocouples (Fig. 3) on the outside wall positioned at top right, right middle, left middle and bottom right direct outside the research area. One thermocouple was placed in the research test area and 1 thermocouple was placed in the control area. This graph shows that over the month period the research area shown a cooling effect of 2–6 °C lower than compared to the outside temperatures. The research area was also 2–4 °C lower compared to the controlled thermocouple in the adjacent room.

The temperature at this coastal city in South Africa fluctuate between 2 and 15 °C during winter months and 18–32°C during summer months. The solar radiation in Gqeberha (South Africa) varies between 230–950 Wm⁻² depending on the weather.

Figure 5A shows a period of 1 month over the period of December 2018 at this coastal city Gqeberha in South Africa the temperature profile taken directly from the LogTag Analyzer 3 software shows temperature fluctuations of the thermocouples on the outside façade at various positions as previously indicated in Fig. 2 as well as the two temperatures measured inside the buildings on at the research area and another in an adjacent room that will indicate an control or a benchmark temperature what to expect without the cooling effect of the green wall façade. In Fig. 5B, a section of a day was taken as an expanded view to illustrate the temperatures observed between these respected thermocouple positions. A significant difference of 2–5°C between the thermocouple inside the research area and those on the outside could be observed. Another significance difference was observed between the research and the

control environment. This indicates that the possibility exists to cool down the interior of the building by place a green façade of living plants in the outside to absorb the heat and provide a cooling effect in the inside.

Heat flux (Φ) can be defined as the rate of heat energy transferred through a given surface (W) and heat flux density (ϕ) is the heat flux per area (Wm^{-2}) this measurement can be useful in determining the amount of heat that passed through the wall or the amount of solar energy transferred to a given area. When water is evaporating from a surface a negative latent heat flux will be observed, while a positive sensible heat flux means heat is flowing from the atmosphere to the surface. In Fig. 6 the heat flux where plotted against 2 days of measurement during the summer month of January 2019. It can be observed that positive sensible heat flux was noted of $20\text{--}30 \text{ Wm}^2$ indicating solar energy flowing from the atmosphere to the green façade. But once it penetrates the green living wall the heat flux is reduce to almost $0 - (-)10 \text{ Wm}^2$ this indicates a cooling effect taken place and hence a drop in temperature between the outside wall and the interior of $2\text{--}4^\circ\text{C}$.

During the winter months an opposite observation was noted the green façade living wall act as an insulator in absorbing the colder winter day temperatures and provide a warmer interior. Day temperatures on the outer green façade increases between $12\text{--}25^\circ\text{C}$ while night temperature falls to $0\text{--}3^\circ\text{C}$. The temperature and exploded view of a winter profile are shown in Fig. 7 below. A maximum interior temperature of 20°C was observed in the research area compare to the control area where the temperature measured was 18°C or below.

The heat flux calculated for this period was considerably lower compared to summer and gave a heat flux range of $(-)4\text{--}6 \text{ W.m}^{-2}$ which implies no heating or cooling penetrates the wall providing a warmer interior from the insulated green wall. Figure 8 show the graphs obtained for the heat flux observed during a winter month.

Figure 9 shows the temperature fluctuations observed during a summer and winter month and its deviation against the control. The average bar-graph for the summer temperatures show a temperature variance of $0\text{--}8^\circ\text{C}$ in comparison to winter months the average temperature fluctuates between $0\text{--}4^\circ\text{C}$ these fluctuations is due to the absorption of the solar energy on the exterior wall provide a cooling or insulating effect to the interior.

A box and whisker plot in Fig. 10 shown the energy heat loss due to evaporation through the green façade during the summer month in comparison to the winter month. The heat loss calculated average between $3\text{--}8 \text{ W.m}^{-2}$ per day loss during summer compared to 0.2 to 2.5 W.m^{-2} per day loss during winter. These small deviances in heat losses during winter created a warmer interior from the insulated green living wall.

4. Conclusions

This paper presents a part of an experimental work performed on a green living façade. For this project various cement mixtures were prepared that contains as a benchmark, cement, sand, and water. In addition, other materials were added such as titanium oxide for a whiter tile, calcium chloride to harden the tile, fibers, and slag-ash to enhance strength and durability. Plasticizers provided some elasticity and better mixture bonding.

The 3-point flexure test provide substantial evidence to which cement mixture would be more than adequate, to have the desired strength and porosity to be used in the wall cup tile manufacturing process. Strengths of over 200 N force was considered and two mixtures one containing the plasticizer and the other a fibrous material to be used in the casting process. Once enough of these tiles were manufactured, they were then adhered to the research wall façade and equipped with suitable plants and irrigation as described above. The 4 thermocouples were installed on the outside in the green living wall, 1 thermocouple was placed in the research area and 1 thermocouple in an adjacent control room. The temperatures were measured and captured by means of LogTags for 30 days over a period of 1-year. The temperature profiles show a significant decrease in temperature between the outside wall surface and the interior wall of 2–6 °C compared to the control area, during summer months. This temperature difference observed in terms of heat losses measured as heat flux, gave an energy loss value of 3–8 Wm⁻² per day this indicates the evaporation taken place through the green living wall. The result being that it provides a cooling effect inside.

During the winter months a smaller evaporation heat loss was observed of 0.5–2.5 Wm⁻² per day, which results in a warmer interior and therefore the green living wall acts as a thermal insulator. The data is valuable and on large surface can be decorative as well as provide a cooling or heating effect that can be beneficial as green thermal energy rather than conventional heating or cooling systems.

Declarations

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Disclosure statement.

The authors report there are no competing interests to declare.

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Figures

Figure 1

An animation of a 3-point flexure test to determine the compression strength.

Sample area dimensions for rectangular ceramic tile for the flexure study was (length, width, height = 110 x 55 x 10mm)

Figure 2

Front view of modular living wall, equipped with pump, tank and irrigation system. T1 – T4 are P100 thermocouples placed in strategic positions

Figure 3

Test wall equipped with 4 thermocouples for temperature measurements.

Figure 4

Rectangular cement test samples for the 3-point flexure test

A

B

Figure 5

A shows the temperature profile for the months of December 2018 this is a summer month, 5B shows the expanded view for the day profile on the 13 December 2018.

Figure 6

Comparison of temperature and heat flux variations at two different heights during a summer month period of January 2019. Please refer to the Figure legend for the color interpretation.

Figure 7

A shows the temperature profile for the months of June 2019 this is a winter month, 7B shows the expanded view for the day profile on the 3 June 2019.

Figure 8

Comparison of temperature and heat flux variations at two different heights during a winter month period of July 2019. Please refer to the figure legend for the color interpretation.

Figure 9

Temperature fluctuation range for the exterior wall

Figure 10

Energy heat loss (W.m^{-2} per day) comparison between a summer and a winter month.

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