Performance Analysis of Green-Wall Infrastructure Using IoT Devices

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Abstract. Urban populations grow consistently from year to year and their infrastructure has been developed rapidly. Due to population density and the rapid increase of the use of electronic applications, it is common to find the urban heat island effect in these areas where average temperatures have risen significantly. The changes in temperature of urban areas contribute to global warming and are believed to lead to unavoidable natural disasters. Green-wall infrastructure is a popular environmental-friendly method used to reduce the average temperature in urban areas by curbing the urban heat island effect and improving air-quality at the same time. However, a standard monitoring system is lacking as well as statistical data that depicts the efficiency of the green-wall method. This paper proposes to use the emerging Internet of Things (IoT) and cloud technologies to investigate the efficiency of the green wall system in reducing the average temperature of the urban infrastructure. Numerical analysis illustrates the effectiveness of the proposed IoT design in monitoring the performance of the green-wall method.

1. Introduction

In the past decades, many countries have been transformed by the urbanisation with the aim to increase mobility and to improve the quality of the life of their citizen. However, this rapid urbanisation development lead to a major environmental challenge such as global warming that will increase the average temperature [1] [2] [3]. The inland urban areas are also more prone to the urban heat island effect due to the greater proportion of impervious surfaces and concrete structures [4].

Recently, the concept of green walls (GW) infrastructure is increasingly popular to tackle the urban heat issue. Using this green infrastructure concept, it will not only reduce the temperature and mitigate the urban heat island effect but also save the energy in the buildings. In this paper, we focus on the green walls concept where the infrastructure is the self-sufficient vertical gardens that are mounted on the inner or outer parts the walls of a building [5].

There are two main alternatives to integrate the green infrastructure to the building and they are green facades and living walls [6]. The green facades refer to the use of climbing or hanging plants along the wall which can be located naturally (direct method) or through a created frame (indirect method). Living walls, on the other hand, refer to a system of planter boxes arranged in specific patterns that each contain the necessary elements for plant life and support [7]. Thus,
they can be used to cover a larger surface area compared to green facades. This project will use the green facades and the frame structures within them.

For many years, green walls method have been integrated in urban infrastructures. However, there is lack of accurate performance measurement of the impact of the green walls methods regarding the efficiency of the energy saving and the efficiency of the heat reduction. The lack of statistical data leads to an overall inability to effectively monitor and analyse the impact of the green walls in the urban infrastructure. This paper proposes to use smart IoT (Internet of Things) devices to analyse the performance of the green walls. The proposed IoT devices and setup are illustrated and numerical analysis are presented to show the efficiency of this proposed method.

The remainder of this paper is structured as follows. Section II presents the introduction of the IoT and M2M communication systems. In Section III, the overview of the green wall infrastructure is presented. In Section IV, the smart IoT design for green wall monitoring is presented. The numerical results and analysis are discussed in Section V. Finally, the concluding remarks are drawn in Section VI.

2. IoT and M2M communications systems
Fast and better data sensing method is required in detecting changes in temperatures as manual measurement is inefficient and sensitive to human errors. Machine-to-Machine communication M2M technologies enable the reliable and fast data sensing.

The recent development of the Internet of Things IoT devices enable the efficient Machine-to-Machine communication M2M to collect data remotely and process the data in real-time [8] [9].

For this project, the CSM-XM1000 will be used. The XM1000 is an embedded system equipped with temperature, light and humidity sensors. It is also capable of wireless communication and configured using the Contiki linux-based operating system on a virtual machine.

3. OVERVIEW of GREEN WALL INFRASTRUCTURE
Green Walls (GWs) are self-sufficient vertical gardens that are mounted on the inner or outer parts the walls of a building [5]. In other words, they are capable of supporting the materials necessary for plant growth (soil, water, etc.) along vertical structures. The concept of GW is not in any way new. It dates back to the tenth century where the early inhabitants of Greenland and Canadian inhabitants used sod houses to keep warm during winter and cool in summer [10]. Through the centuries and even more so today, they are becoming more prominent due to their potential to curb the growing global crisis of climate change and global warming. Several factors are considered when setting up GWs with regards to the way the plants are arranged, the type of plants used, maintenance cost and durability [11].

There are two general types of GW systems. The types are green facades and living walls [6]. Green facades refer to the use of climbing or hanging plants along the wall either naturally (direct method) or through a created frame(indirect method). They usually involve climbing plants that are rooted to the ground or in pots suspended on the wall. Living walls on the other hand refer to a system of planter boxes arranged in specific patterns that each contain the necessary elements for plant life and support [7]. Thus, they can be used to cover a larger surface area compared to green facades.

3.1. Facade for Climbing or Hanging Plants
A cable and wire-rope net system independent of the building are used to support climbing plants [12]. Climbing plants supported by this system have their roots at the base of the wall in the ground. Plants with a high foliage density are supported with cables. However, for plants
that grow slowly, shorter intervals are required thus, wire-rope net supports are used. Wire-rope net structures resemble a grid.

Ivy is a common climbing plant with a fast growth rate that uses a cable and wire-rope net support.

3.2. Modules for short Plants

Modules are structures implemented for plants on Living Walls [13]. Each module contains trays or vessels or pots to contain plants within. Modules are made to interlock with other modules. These allow the installation of several plants in each element along the same row as modules are mounted onto vertical supports connected to the wall [6]. They are often made up of polymeric materials or substrates that support a hydroponic system.

These facades and arrangements are means to optimize the green wall as well as preserve the integrity of the structures they are mounted on. Two main factors are considered when setting up green walls - temperature and humidity. Different means can be used to measure the effect they have on the temperature and humidity of the buildings they setup on. With the recent advances in technology and research in wireless sensor networks, the Internet of Things is yet another tool that has been added to the arsenal in a bit to optimize the process data sourcing and analysis.

4. Smart IoT Design for Green Wall Monitoring

This paper designs the smart monitoring system as illustrated in Fig. 1. The combination of IoT within a WSN means that the statistics measured for the GW system can be analysed in real time remotely.

The observations of the temperature and the humidity were taken from three different locations based upon the following: (i) A wall without any greenery, (ii) A wall with partial greenery and (iii) A wall with a facade and greenery. For each parameter, two sensor nodes will be placed at different points on the walls. One sensor will be placed on a wall exposed to
incident sun light and the other will be placed behind the green wall. The difference between these two readings will be correlated with the current temperature and humidity data of that day to prove accuracy as well as consistency in result. The readings will be taken remotely via the network for 5 to 10 minutes at different times of the day (morning, afternoon, night) and sent to a cloud for analysis. After the data has been processed, further instructions can be sent to either the sensors or other IoT devices within the same network that would "react" or respond to the observed change.

Temperature readings would reflect the effectiveness of a GW compared to a wall without one. For instance, if a building’s normal temperature at night is 28°C without a GW and is 25°C with a GW, the 2°C difference would mean that there would be no need for central cooling at night and an instruction could be forwarded to an air conditioning unit to be turned off. However, if the humidity is low, an instruction could be forward to switch on an air humidifier. This directly affects the amount of energy consumed and at a larger scale, slows down global warming. Being able to get this data and interpret it real time would require low power sensors capable of running for extended periods of time.

In order to optimize the analysis of the GW system, the current temperature and humidity of the day have to be taken and compared with the readings from the sensors placed behind the GW. An online weather forecast will be used which gives a close average of the temperature and humidity at the time of the day that readings were taken. Most of the time, the readings from the sensors placed on the exposed surfaces will vary due to external sources of heat from other equipment or human activity around the structure. This external factor may lead to a slight increase or decrease in the temperature and the humidity. The accumulated difference in the readings of the sensors on a surface exposed to incident light and the sensors behind the GW will be averaged. Furthermore, the plant type, plant density, or type of facade used can then be adjusted to see which has a higher impact.

The temperature and humidity readings from the sensors from different walls will be analyzed according to the following formula.

\[ T_d = T_{w1} - T_{w2} \]  \hspace{1cm} (1)

where \( T_d \) represents the temperature change, \( T_{w1} \) represents the temperature of the wall with greenery and \( T_{w2} \) represents the temperature of the reading gotten from the exposed surface of the structure.

\[ H_d = H_{w1} - H_{w2} \]  \hspace{1cm} (2)

where \( H_d \) represents the humidity change, \( H_{w1} \) represents the humidity of the wall with greenery and \( H_{w2} \) represents the initial humidity reading of the exposed surface of the structure.

\[ T_{av} = (T_{d1} + T_{d2} + \ldots + T_n)/(n) \]  \hspace{1cm} (3)

where \( T_{av} \) average temperature change for a specific range of days to show the efficiency of a particular type of green wall. \( T_n \) represents the temperature change for a number of \( n \) days.

\[ H_{av} = (H_{d1} + H_{d2} + \ldots + H_n)/(n) \]  \hspace{1cm} (4)

where \( H_{av} \) average humidity change for a specific range of days to show the efficiency of a particular type of green wall and \( H_n \) represents the temperature change of a number of \( n \) days.

5. Numerical Results and Analysis

In this simulation, three XM1000 embedded with temperature and humidity sensors were used. Two of these sensors were configured as sensor nodes and the other was configured as a sink node. The sink node received temperature and humidity readings from both sensors wirelessly
via queued unicast messages sent from each of the sensor nodes. The Sensors that are not the sink node were placed on the wall as illustrated in Fig.1.

ThingsSpeakIoT was used as the cloud platform. A unique API key was also configured to allow the data to be sent to the cloud for further analysis. A single channel could accommodate 8 data fields and each sensor used two fields for humidity and temperature, respectively. It was configured that the data are constantly updated.

The XM1000 sensor nodes were placed on a wall covered partially by greenery and one exposed to direct sunlight respectively. Elevation of each sensor from the base of the building varies on the elevation of the plant / green wall structure. For this simulation, the plant type used had a maximum height of 6 to 8 feet thus the sensor was placed below that range at about 4 feet. For walls without any greenery, sensor elevation can vary. The sink node as shown in 2, was placed in range of both sensors at the doorway. Each sensor has an outdoor range of 100m for wireless communication.

![Figure 2. Sensor Placement](image)

The parameters that were analysed include the time periods, distance between sensors, initial temperature and humidity of the day, distance of the greenwall from the building, the type of plants and the structure material.

In this paper, the readings were taken in period of three days in the afternoon with varying temperature and humidity as shown in Table 1.

| D | Sensor | T(°C) | R.H | DT(°C) | DH |
|---|--------|-------|-----|--------|----|
| 1 | 1      | 38.5  | 49.4| 31     | 77 |
|   | 2      | 30    | 72.2|        |    |
| 2 | 1      | 40    | 44  | 33     | 63 |
|   | 2      | 32    | 68  |        |    |
| 3 | 1      | 37    | 52.2| 32     | 68 |
|   | 2      | 30.7  | 72.2|        |    |
Comparing the temperature and humidity values of the wall shielded by the plants in Table 1 with the initial values of the day in Table 2, there is a degree of difference in temperature. The humidity behind the particular plant (pink bougainvillea) used is high. High humidity levels...
over time are known to do some damage to a wall. This means that ample ventilation distance between the wall and the facade is needed. The plants absorbed most of the heat incident heat which maintained the temperature of the wall at a slightly lower degree than the temperature of the day. However, the plant itself is not on a facade so its efficiency is low. Thus it only maintained the initial temperature of the day with a single degree difference. It was observed that the surface temperature of the surface of the walls without greenery for all three days was an average of 7.6°C hotter compared to that of the walls covered by plants. The data gathered also showed that the relative humidity behind the plants was slightly higher by 23%.

It can be seen that the sensor nodes worked better when it was placed indoor or not under
direct sun. This may be due to the type of the battery used to power the sensors. When a node connected to the sink node, the other would be disconnected or stopped sending the readings. Swapping the batteries to an industrial grade type improved the performance. Another reason was that the radios required an antenna. The one on board without an antenna was unidirectional and couldn’t pick the signals once the sink node was adjacent to it. It was observed that attaching a few coiled wires helped to boost the signal.

6. Conclusion
It can be shown that the performance of the green wall can be analyzed effectively using IoT sensor network. Data can be monitored in real time and the designed hardware can be easily installed in various type of structures.

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