*Preprints* (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 March 2021

*Article*

# Benefit of Green Roof to Thermal Insulation and Heat Preservation of Sheet Metal Houses

**Tsai-Fu Chuang [1], Yuan-Hsiou Chang [2]*, Hsiao-ling Lu [3], Wen-San Chang [4], Yi-Ying Tsai [5] and Wen-Chi Huang [6]**

[1] Department of Civil Engineering, Feng Chia University, Taichung 40724, Taiwan; tfchuang@fcu.edu.tw
[2] College of Intelligence, National Taichung University of Science and Technology, Taichung 40401, Taiwan.
[3] Department of Biotechnology, National Formosa University, Yunlin 632301, Taiwan; hllu@nfu.edu.tw
[4] Department of Hospitality and Commercial Marketing, Chung Chou University of Science and Technology. Changhua 510, Taiwan; wensan69126@dragon.ccut.edu.tw
[5] Department of Landscape Architecture and Environmental Planning, MingDao University. Changhua 52345, Taiwan; evan@nutc.edu.tw
[6] Center for General Education of China Medical University, Taichung 406040, Taiwan; glavine-huang@mail.cmu.edu.tw
* Correspondence: f89622050@ntu.edu.tw; +886 937523685; fax: +886 4 22195609

**Abstract:** The purpose of this study was to arrange a green roof on a sheet metal house to achieve winter heat preservation and summer thermal insulation using different plants and soil media, and to maintain the advantage of cost-saving and quick installation of sheet metal houses. In terms of the research method, the roof insulation, heat preservation and plant growth index were tested. Plants were grown in 10 container-type green roofs on the sheet metal house roof, and the physical environment of the building was monitored for one year. Five containers of commercially-available culture soil and five containers of sustainable composite were used as the media for growing five kinds of plants, respectively. The control group only had a sheet metal house roof. There were 11 experimental modules for testing whether the green roofs had thermal insulation, heat preservation and plant growth effects on a general sheet metal house. The results showed that, regarding the thermal insulation benefit assessment, the *Sedum acre* cv. robustum of green roof Groups B to D caused the temperature to be 38.29°C lower than the surface of the simple sheet metal house roof in August, showing a temperature difference of 54%.

**Keywords:** Green roof; Sheet metal; Thermal insulation

## 1. Introduction

In recent years, global climate change may result in more severe air temperature increases. Taiwan, located in a subtropical zone, summer is long and hot. Due to their low cost and fast construction, sheet metal houses have become a common building type in Taiwan, but the material is unlikely to insulate from heat, leading to considerable indoor air conditioning power consumption. Due to the heat island effect, it is hard to bear high outdoor temperatures in Taiwan in the summer (Hsieh and Huang, 2016). Taiwan is developing country and its natural environment has been damaged due to incorrect planning and rapid development, and green areas have been lost. Greening the roofs has become one of the management tactics of many developing and developed countries (Rahman et al., 2015).

There are different major terms used for green roofs in the world, such as green roofs, rooftop gardens, planted roofs, eco roofs, vegetated roofs and grassed roofs, wherein “green roof” is the foremost term used (Teemusk, 2009). Heidarinejad and Esmaili (2015) indicated that the fundamental purposes of roof greening are to reduce building energy consumption and to provide shell cooling, and suggested that green roof is an applied technology and should be paid attention to. Among different ecological engineering technologies, green roofs are free from additional land area needs and regarded as a feasible method (Peck, 2003). Green roofs are the result of ecological engineering and provide such

© 2021 by the author(s). Distributed under a Creative Commons CC BY license.

*Preprints* (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 March 2021



environmental benefits as hydrologic conditioning, improving air quality, reducing building energy usage, reducing rainwater from storm, and providing ecological habitats, as well as providing an esthetic appearance (Villarreal et al., 2004; Dunnett and Kingsbury, 2004; Teemusk, 2009). Increasing urban albedo and using green roofs seem to have great potential, presenting relatively higher heat island mitigating capability (Santamouris, 2014). The USEPA (2009) compared the rainfall runoffs of green roofs and asphalt roofs and found that the rainfall runoff of green roofs was apparently lower. Lamera et al. (2014) indicated that green roofs are becoming a popular urban rainwater management technology of SUDS. Heidarinejad and Esmaili (2015) compared the heat transfer rates of green roofs and concrete roofs. The result showed that the heat flux of green roofs is lower than that of concrete roofs by 77%.

Berardi (2016) indicated that the evapotranspiration cooling effect of increasing the LAI on air temperature is 0.4°C, that green roofs can reduce a building's energy needs by 3%, and that increasing the soil depth is more important than increasing the LAI for cooling. According to Taiwan's Bureau of Energy (2016), whenever the preset temperature for air conditioning is increased by 1°C, the air conditioning power usage can be reduced by about 6%, representing a considerable energy saving effect. According to the New Effective Temperature (ET * or NET) described by Chen (2000), a room temperature of 25°C, an air velocity lower than 0.25 m/s, a RH of 50% and a humidity of 40%~60% are the most comfortable conditions for the human body, indicating that buildings in Taiwan must be equipped with air conditioning for cooling in summer.

Ku (2003) calculated the power consumption proportions for Taiwan in the summer and found that apartment-type household appliances account for 41%, air conditioning accounts for 41%, and lighting and others account for 18% of the total power consumption. Meanwhile, townhouse-type household appliances account for 36%, air conditioning accounts for 32%, and lighting and others account for 32% of the total. The monthly air conditioning power consumption increases by 300 kWh on average during the air conditioning season, and the air conditioning energy consumption is high.

Driscoll et al. (2013) used Builder software to develop a calculation model for simulating the energy consumption of a container and environmental parameters, so as to compare simulated data with that from a true environment. The study found that eco-roofs are effective in subtropical climates, as they can save about 13% of the energy use, matching the simulation results. Anwar et al. (2013) studied the thermal insulation and energy-saving benefits of roof greening systems in Queensland, Australia (a subtropical zone). The study found that in the subtropical climate of Queensland, the temperature was reduced by as much as 4°C in March, and the temperature difference was 11.7%.

A field measurement was conducted in Singapore to investigate the thermal impacts of rooftop garden. From the derived data, it has been confirmed that rooftop gardens contribute thermal benefits to both buildings and their surrounding environments (Wong, et.al., 2003). Piero et al. (2017) present an extensive analysis of the surface temperature of an experimental green roof located in southern Italy. The surface thermal performance of both green and traditional roof was analyzed in a very concise manner through proper defined indexes. The results of the analysis showed how the traditional roof in June reached a peak of 74.3 °C with a daily excursion of 51.5 °C; whereas green roofs were able to produce a surface temperature from 0.57 to 0.63 times lower. A study conducted by Morakinyoa et al. (2017) presents a parametric study on the effect of four green-roof types on outdoor/indoor temperature and cooling demand under four different climates and three urban densities using co-simulation approach with ENVI-met and EnergyPlus. Results reveal an outdoor nighttime warming effect of not more than 0.2 ◦C which is most obvious with the semi-extensive while the outdoor and indoor cooling effect ranges between 0.05–0.6 ◦C and 0.4–1.4 ◦C, respectively depending on the green-roof type, urban density and time of the day.

The objective of this study was to arrange a green roof on a sheet metal house to achieve winter heat preservation and summer thermal insulation. This study hoped to

*Preprints* (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 March 2021



achieve thermal insulation and heat preservation effects for sheet metal houses and mitigate the urban heat island effect, so as to provide a design reference for architects and landscapers. The paper is organized as follows: section 2 describes the materials and methods, study area, experiments; section 3 reports the results of the study while section 4 concludes.

## 2. Materials and Methods

### *2.1. Study area*

The experimental site was located on the campus of Taiwan's MingDao University, located at E23°86'66", N120°49'73". The sheet metal house dimensions were 275 cm (length) × 145 cm (width) × 165 cm (height). The walls and roof were made of steel sheets with Al-Zn baked painting, with a thickness of 0.726 mm. The inclination of the roof was 25°, and the roof edges project 17 cm outward, respectively.

### *2.2. Materials*

#### 2.2.1. Sustainable green landscape building shell integrated system

The sustainable green landscape building shell integrated system won the international IF invention design award in 2016. Each year, iF International Forum Design GmbH organizes one of the world's most celebrated and valued design competitions: the iF DESIGN AWARD. Recognized as a symbol of design excellence around the world, the iF DESIGN AWARD welcomes over 5,000 submissions from 70 countries every year. It is based on the concept of modular combination, in which turf, bushes, arbores, agricultural vegetables and flowers, and solar power systems are provided on building roofs to enhance roof greening and reach the daily energy saving index, site greening, and biodiversity index of green building indexes of Taiwan, as well as achieve the function of on-site water retention, reduce labor and construction costs, mitigate the heat island effect, reduce the indoor temperature, and implement solar-powered automatic sprinkler systems for vegetation and night LED illumination. The system comprises five units: 1) a turf unit; 2) a flower unit; 3) a bush unit; 4) an arbor unit; and 5) a solar landscape power supply system unit. There are five layers inside Unit 1 to Unit 4, which are a planting soil layer (for placing the culture soil), a nonwoven fabric layer (the first filtering layer, which is used to prevent soil loss and filter impurities), a cotton fabric layer (the second filtering layer, which is used for water retention), a plastic plate layer (to prevent soil settlement and infiltration into the water storage and drainage layer), and a dock (a water storage and drainage layer and structure), as shown in Figure 1.

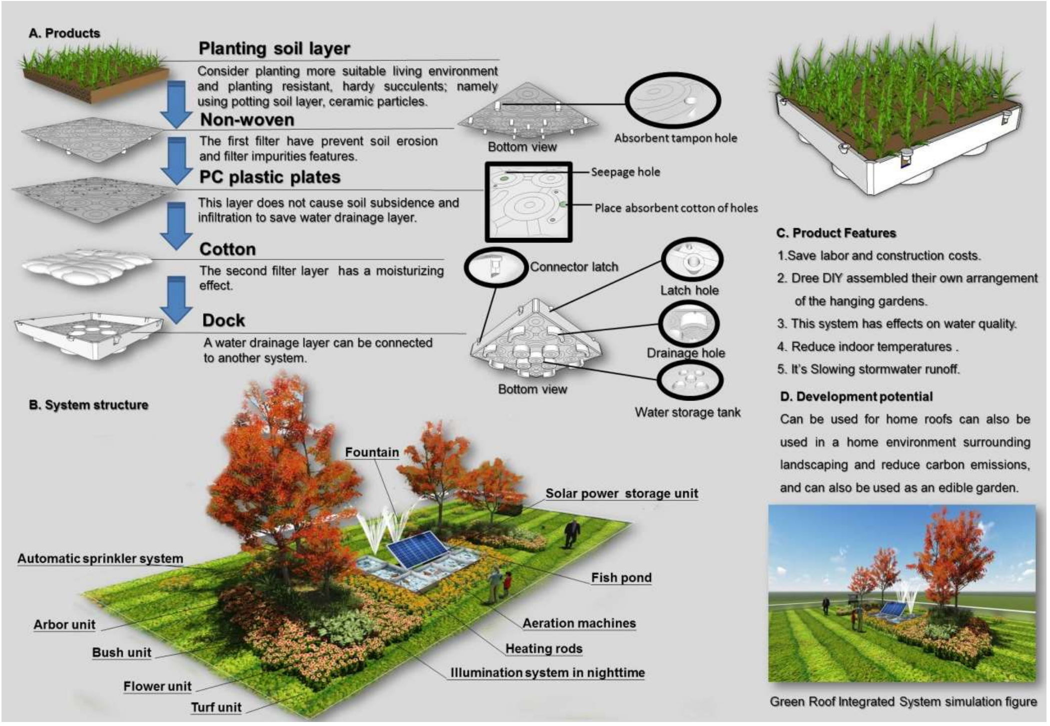
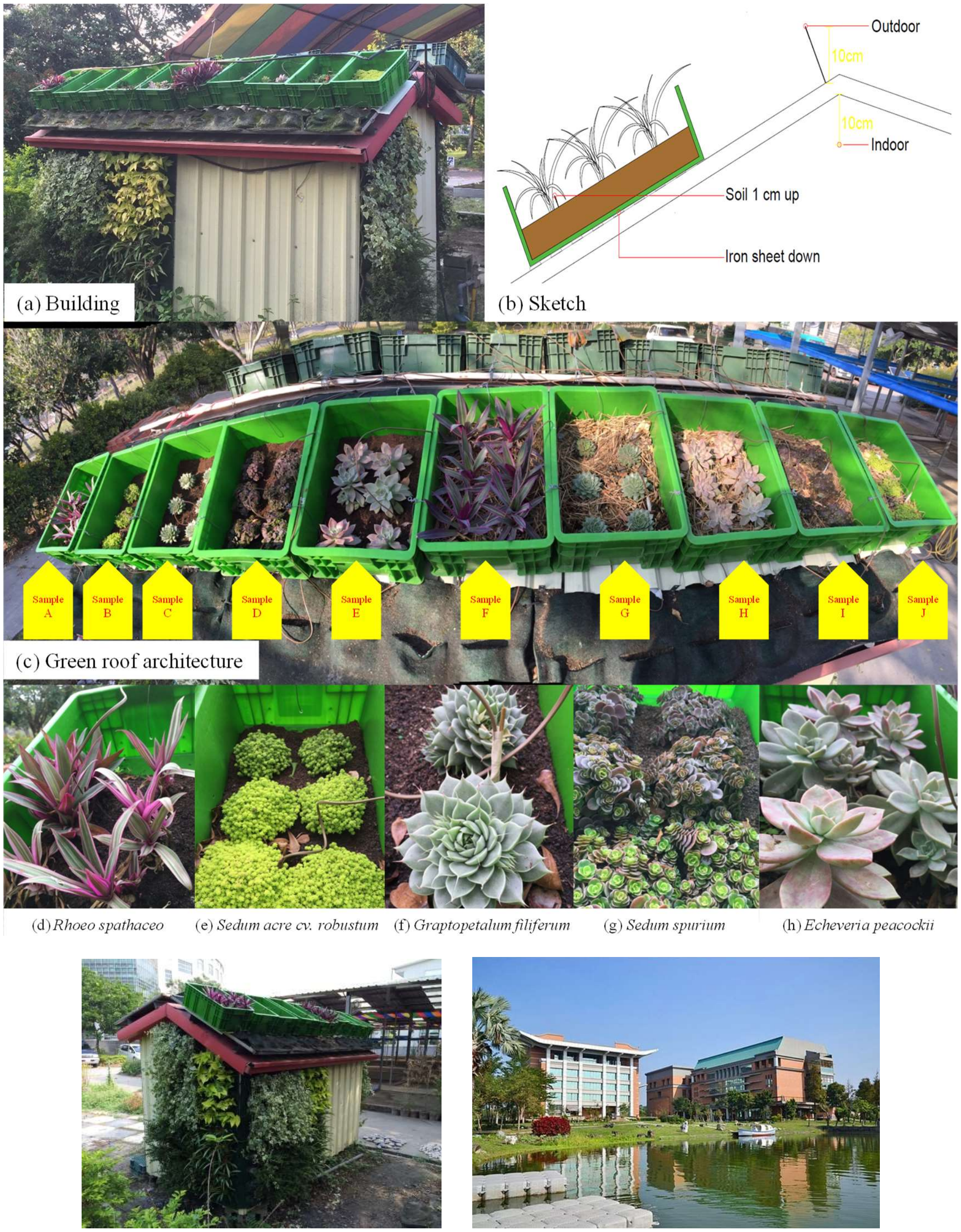



**Figure 1.** Sustainable green landscape building shell integrated system (2017 iF international design award).

2.2.2. Flower and plant materials and arrangement mechanism

There were 10 sustainable green landscape building shell integrated system units placed on the roof of the sheet metal house. The size of each unit was 49 cm × 33 cm × 17 cm. Plants were put in units A to J, culture soil was placed in samples A to E, and sustainable composite was placed in samples F to J, as shown in Figure 2(a)-2(c). The medium in each of samples A to E was 2500 g of culture soil, and the raw materials of the culture soil included mushroom-growing wood chips (70%) and coconut fiber (30%). The medium in samples F to J was sustainable composite, which was composed of sediment (1000 g), culture soil (500 g), waste cotton (200 g), rice hull (100 g), rice straw (100 g) and tea dregs (50 g). Five kinds of plants, including *Rhoeo spathacea, Sedum acre* cv. robustum*, Graptopetalum filiferum, Sedum spurium* and *Echeveria peacockii* were planted in the two groups of samples A to E and samples F to J, as seen in Figure 2(d) to 2(h). In addition, a control group was arranged on the corrugated roof of the sheet metal house.




(i) Image of the study area  (j) MingDao University

**Figure 2.** Experimental mode field.

2.2.3. Measuring instruments

1. Climatological station

The climatic data collection (Fig. 3(a)) recorder was comprised of an atmospheric pressure meter with a measurement range of 500 to 1100 hPa (mBar) and an aerodromometer with a measurement range of 0 to 60 m/s, and accuracy of ±1 m/s (0~20 m/s) or 5% (>20 m/s), a resistance to gusts of up to 70 m/s, and a wind direction measurement range of 0 to 360 degrees.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 March 2021



2. HL20 Data Logger

The data logger was connected to a thermocouple T-type wire and connected to a computer to obtain the temperatures at all points and for integrated management. The output range was 0 to 3.8 VDC, the accuracy was ±2 mV (0°C to ±40°C), ±5 mV (-25°C to +60°C), and the resolution was 1 mV.

3. Thermocouple temperature sensor wire

The sensor wire was a T-type thermocouple temperature sensor wire with a temperature range of -160°C to 400°C, ±0.5°C.

4. Digital hygrothermograph

The digital hygrothermograph (Fig. 3(b)) was a CENTER-314 with a humidity measuring range of 0 to 100% RH and temperature measuring range T1 of -20 to 60°C.

5. Hot wire anemometer

The hot wire anemometer was an Anemomaster Lite model 6006 with a storage environment of -10 to 50°C, an accuracy of ± -0.015 m/s ± 5%, and an air velocity range of 0.01 to 20.0 m/s.

6. Black-bulb thermometer

The black-bulb thermometer was a model JC-3500, with a measurement range of 0 to 100°C, an accuracy of 1°C, and a diameter of 15 cm.

7. Faucet controller

The faucet controller was a model 9001D series, with a starting frequency of four times/day, a spray time of one minute to 12 hours, and good weather resistance and impermeability.

8. Israeli drip irrigation pipe

The Israeli drip irrigation pipe was a model GB83233 consisting of a 1/2" pipe with a labyrinth path, certain pressure compensation functions, and a pitch of 30 cm.

(a) Climatological station (b) The digital hygrothermograph

**Figure 3.** Measuring instruments.

*2.3. Methods*

The experimental period lasted for one year, from March 1, 2015 to February 29, 2016. The test time was 13:00~17:00 every Wednesday and included direct readings of the ambient air temperature, humidity and wind speed, as well as a field plant growth survey.

2.3.1. Climatological observation station measurement

According to the data from the micro climatological observation station, which were recorded at a rate of one group of data every 10 minutes for one year, five kinds of physical environment data were monitored, including humidity, solar radiation, illumination, rainfall and temperature.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 March 2021



2.3.2. Humidity and wind speed instrumentation

The physical environment measurements included physical environment monitoring of the noise, humidity, wind speed and globe temperature and were collected from 13:00 to 17:00 every Wednesday. The measurement positions were at 10 cm on the internal and external north-facing wall surfaces of the building, and the height was 160 cm.

2.3.3. Temperature measurement

One of the measuring points, made of thermocouple wire T-type, was placed 1 cm above the surface of the soil in each box, and one was placed on the corrugated board under each box of plants. The control group had one measuring point on and under the surface of the metal sheet, respectively, one at a height of 10 cm outdoors, and one measuring point that was suspended 10 cm from the midpoint indoors (Figure 2(b)). There were 23 measuring points. Using the HL20 temperature data processor, the temperature at each measuring point could be measured instantly on the computer. The faucet controller and drip irrigation pipe system were used for irrigation. There were three irrigation periods every day: 06:00, 15:00, and 22:00. Each period lasted five minutes, and the flow rate was 60 cc per minute. There were 23 measuring points on the green roof and inside the room for measuring the temperature (Table 1). A T-type thermocouple was combined with an HL20 data processing controller, and data was recorded automatically every 10 minutes at each measuring point during the entire year of the study.

**Table 1.** Codes and locations of measuring points.

| **Soil group** | | | **Composite materials group** | | |
|---|---|---|---|---|---|
| **Number** | **Code** | **Location** | **Number** | **Code** | **Location** |
| **1** | **A-U** | *Rhoeo spathacea (Up)* | **13** | **F-U** | *Rhoeo spathacea (Up)* |
| **2** | **A-D** | *Rhoeo spathacea (Down)* | **14** | **F-D** | *Rhoeo spathacea (Down)* |
| **3** | **B-U** | *Sedum acre* cv. robustum *(Up)* | **15** | **G-U** | *Graptopetalum filiferum (Up)* |
| **4** | **B-D** | *Sedum acre* cv. robustum *(Down)* | **16** | **G-D** | *Graptopetalum filiferum (Down)* |
| **5** | **C-U** | *Graptopetalum filiferum (Up)* | **17** | **H-U** | *Echeveria peacockii (Up)* |
| **6** | **C-D** | *Graptopetalum filiferum (Down)* | **18** | **H-D** | *Echeveria peacockii (Down)* |
| **7** | **D-U** | *Sedum spurium (Up)* | **19** | **I-U** | *Sedum spurium (Up)* |
| **8** | **D-D** | *Sedum spurium (Down)* | **20** | **I-D** | *Sedum spurium (Down)* |
| **9** | **E-U** | *Echeveria peacockii (Up)* | **21** | **J-U** | *Sedum acre* cv. robustum *(Up)* |
| **10** | **E-D** | *Echeveria peacockii (Down)* | **22** | **J-D** | *Sedum acre* cv. robustum *(Down)* |
| **11** | **Iron heet** | Iron heet (Up) | **23** | **Iron heet** | Iron heet (Down) |
| **12** | **Outdoor** | Outdoor | **24** | **Indoor** | Indoor |

2.3.4. Plant growth benefit measurement

The test plant growth efficiency is mostly analyzed by plant evaluation method to determine the growth difference among plants. The common evaluation method is growth index for evaluating the external dimensions of plants (Rowe et.al., 2006; Monterusso et al., 2005; Nagase and Dunnett, 2010; Bousselot et al., 2011), expressed as Eq. 1. The maximum length, width and height (in cm) of each plant were measured using vernier calipers every week during the test period, and the length, width and height were added up and divided by three to obtain the growth index of the plant (Rowe et al., 2006). The growth index was quantified by measuring each plant's height and width in two

*Preprints* (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 March 2021



perpendicular directions. A growth index was calculated for each plant by averaging the three individual growth measurements.

## 3. Results

The maximum values of the daily radiation and sunshine were 100.84 W/m² to 137.01 W/m² from May to September. The daily rainfall changed obviously during April to August. The daily rainfall was up to 121.2 mm in August due to the occurrence of typhoons. The peak average air temperature was about 35.1°C from June to September. The annual maximum temperature was 36°C in July, which was higher than the annual minimum temperature of 6.5°C in February by 29.5°C. The annual humidity was almost 100% due to the observation station being located near the water (Figure 4(a)). The maximum wind speed was about 1.96 m/s during July to September, and the wind direction was 147.46 to 180.53 deg.

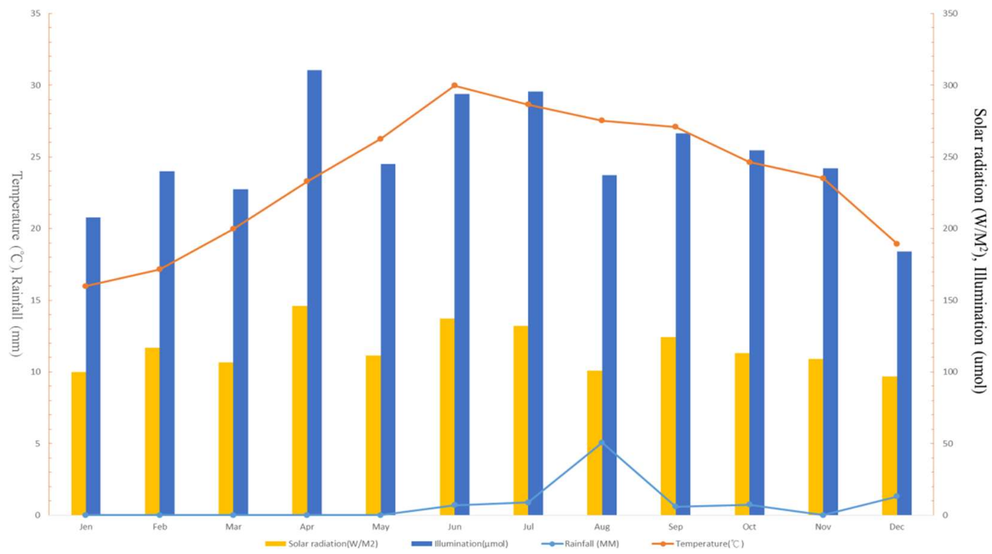



***Figure 4(a).*** *Climatic conditions*

### *3.1. Thermal insulation analysis*

3.1.1. Thermal insulation difference for same soil quality but different plants

According to the annual temperature trend, the temperature rose gradually in May, and the roof surface temperature reached its maximum in August during the summer. The temperature dropped gradually after October and reached its minimum in January. According to the thermal insulation difference based on the same soil quality but different plants, the roof temperature difference was the most significant in summer. The outdoor temperature was as high as 43.83°C on August 11, the temperature of metal sheet was 71.10°C, and the B-D *Sedum acre* cv. robustum was 32.81°C. The temperature difference was 38.29°C, i.e. 54%, indicating an excellent cooling effect. The outdoor temperature was 6.45°C on January 24, the temperature of the metal sheet was 5.99°C, and the temperature of the J-U *Sedum acre* cv. robustum was 5.39°C, lower than that of the metal sheet, that of A-D *Rhoeo spathacea* is 6.90°C, the temperature difference from iron sheet is 0.91, i.e. 13%, meaning the heat preservation benefit of the green roof was not obvious (Figure 4 (b)).

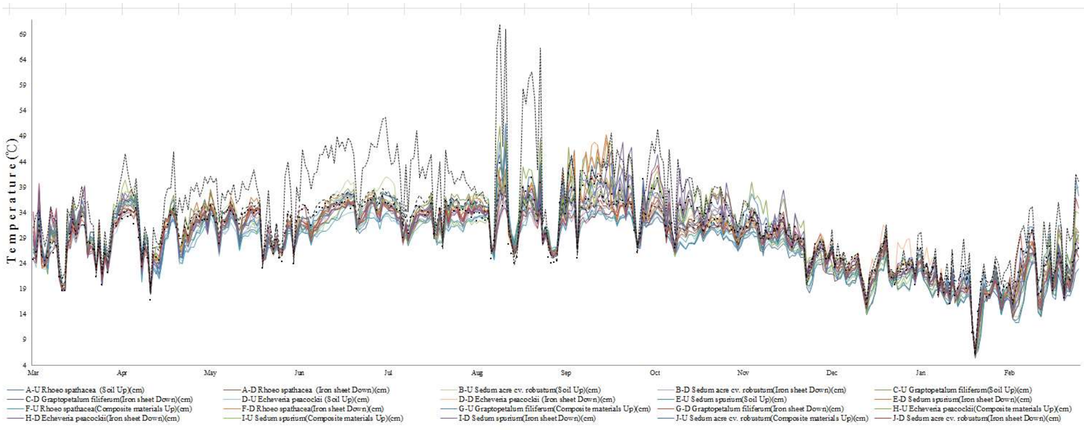



**Figure 4 (b).** Annual temperature chart.

1. Upper layer of the culture soil group (Soil Up)

The maximum temperature during the year (71.10°C) occurred at the measuring point on the metal sheet at 13:00 on August 11, while the minimum temperature was 35.61°C for D-U, indicating a difference of about 34.49°C. In addition, the worst thermal insulation benefit of the different plants was C-U, at 43.07°C, while the best was D-U. The temperature difference between the two plants was 7.46°C. The metal sheet had the maximum temperature of 49.73°C at 13:00 on September 19, while the minimum temperature was 32.30°C for D-U, indicating a difference of 17.43°C. In terms of the thermal insulation benefit from different plants, C-U had the maximum temperature of 47.28°C and D-U had the minimum temperature of 32.3°C, indicating a temperature difference of 14.98°C. It was observed that the metal sheet had the maximum temperature, while the A-U and D-U plants resisted the direct irradiation of sunlight most effectively. According to the temperatures measured from the plants, *Echeveria peacockii* had the minimum temperature due to its big and thick leaves, which were sufficient to shield the direct irradiation of sunlight. *Graptopetalum filiferum* had the maximum temperature due to its small leaves that could not shield sunlight and caused the sunlight to directly irradiate the measuring sensor. It had the highest temperature among the five plants (Figure 5(a)).

*Preprints* (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 March 2021



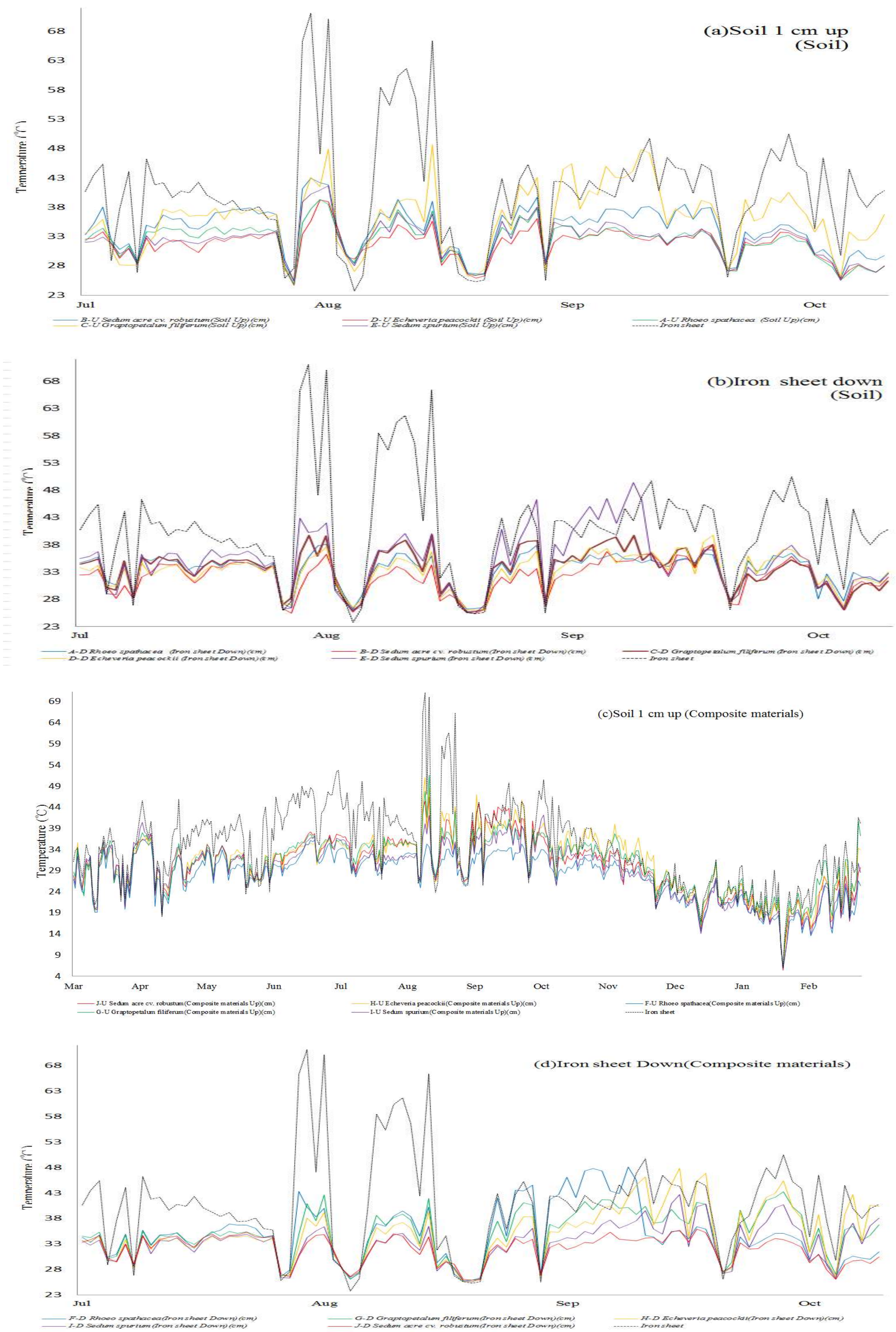



**Figure 5.** Upper and lower temperature charts of different plants.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 March 2021



2. Lower layer of the culture soil group (Soil Down)

At 13:00 on August 11, the maximum temperature was as high as 71.00°C at the measuring point under the metal sheet. According to the comparison of the measuring points under the five boxes of the culture soil group, measuring point B-D had the minimum temperature, which was as low as 32.81°C, indicating a difference of about 38.19°C. At 13:00 on September 19, the maximum temperature was 49.70°C under the metal sheet. Measuring point E-D under the five boxes of the culture soil group had the minimum temperature of 35.06°C, indicating a difference of 14.64°C. Therefore, B-D, C-D and E-D had better thermal insulation benefits in the lower layer of soil. The description of Moran et al. (2005), who stated that enlarging the green areas in a city will influence its urban climate, was thus validated (Figure 5(b)).

3. Upper layer of the composite group (Composite Up)

At 13:00 on August 11, the maximum temperature was 71.10°C at the measuring point on the metal sheet, while the minimum temperature was 33.27°C for F-U, indicating a temperature difference of 37.83°C. At 13:00 on September 19, the maximum temperature was 49.73°C at the measuring point on the metal sheet, while the minimum temperature was 34.41°C for F-U, indicating a temperature difference of 15.33°C. At 13:00 on October 5, the maximum temperature was 50.49°C at the measuring point on the metal sheet, while the minimum temperature was 33.91°C for F-U, indicating a temperature difference of 16.58°C. Therefore, F-U shielded the direct irradiation of sunlight most effectively and provided good plant growth, long leaves and big plants that could obstruct more sunlight from directly irradiating the building surface (Figure 5(c)).

4. Lower layer of the composite group (Composite Down)

At 13:00 on August 11, the maximum temperature was 71.00°C at the measuring point under the metal sheet, while the minimum temperature was 33.36°C for J-D, indicating a temperature difference of 37.64°C. At 13:00 on September 19, the maximum temperature was 49.70°C for the metal sheet, while the minimum temperature was 34.17°C for J-D, indicating a temperature difference of 15.53°C. At 13:00 on October 5, the maximum temperature was 50.40°C at the measuring point of the metal sheet, while the minimum temperature was 33.84°C for J-D, indicating a temperature difference of 16.56°C. Therefore, J-D had the best thermal insulation benefit in the lower layer of the composite. In addition, the difference between the air temperature and the green roof temperature was 37°C in August, validating the description of Santamouris (2014), who stated that green roofs have great potential. If they are developed and popularized in cities in the future, the impact of the heat island effect could be minimized, which would be helpful for ecological restoration (Fig 5(d)).

3.1.2. Thermal insulation difference based on the same plants but different soil matrix materials

1. (a) *Sedum acre* cv. robustum

At 13:00 on August 25, the maximum temperature was 66.37°C at the measuring point of the metal sheet, compared with 34.30°C for B-D, indicating a temperature difference of 32.07°C. In addition, the temperature at measuring point B-U, located 1 cm above the soil in the flower pot, was 43.75°C, while that at J-U was 39.06°C, indicating a temperature difference of 4.69°C. At 13:00 on September 18, the maximum temperature was 46.88°C at the measuring point of the metal sheet, while the difference between B-D (36.14°C) and J-D (33.60°C) was 2.54°C. The temperature difference between the metal sheet of the control group and measuring point J-D with the lower temperature was 13.28°C. In addition, the temperature of B-U (38.00°C) was higher than that of J-U (43.18°C) by 5.18°C. At 13:00 on October 3, the maximum temperature was 47.99°C at the measuring point of the metal sheet, and the difference from J-D (33.34°C) was 14.65°C. In addition, the temperature difference between B-U (33.82°C) and J-U (38.07°C) was 4.25°C.

Therefore, *Sedum acre* cv. robustum could effectively reduce the high temperature induced by vertical incident solar rays, and the temperature measured from the soil of the composite group was higher than that of the culture soil group (Figure 6(a)).

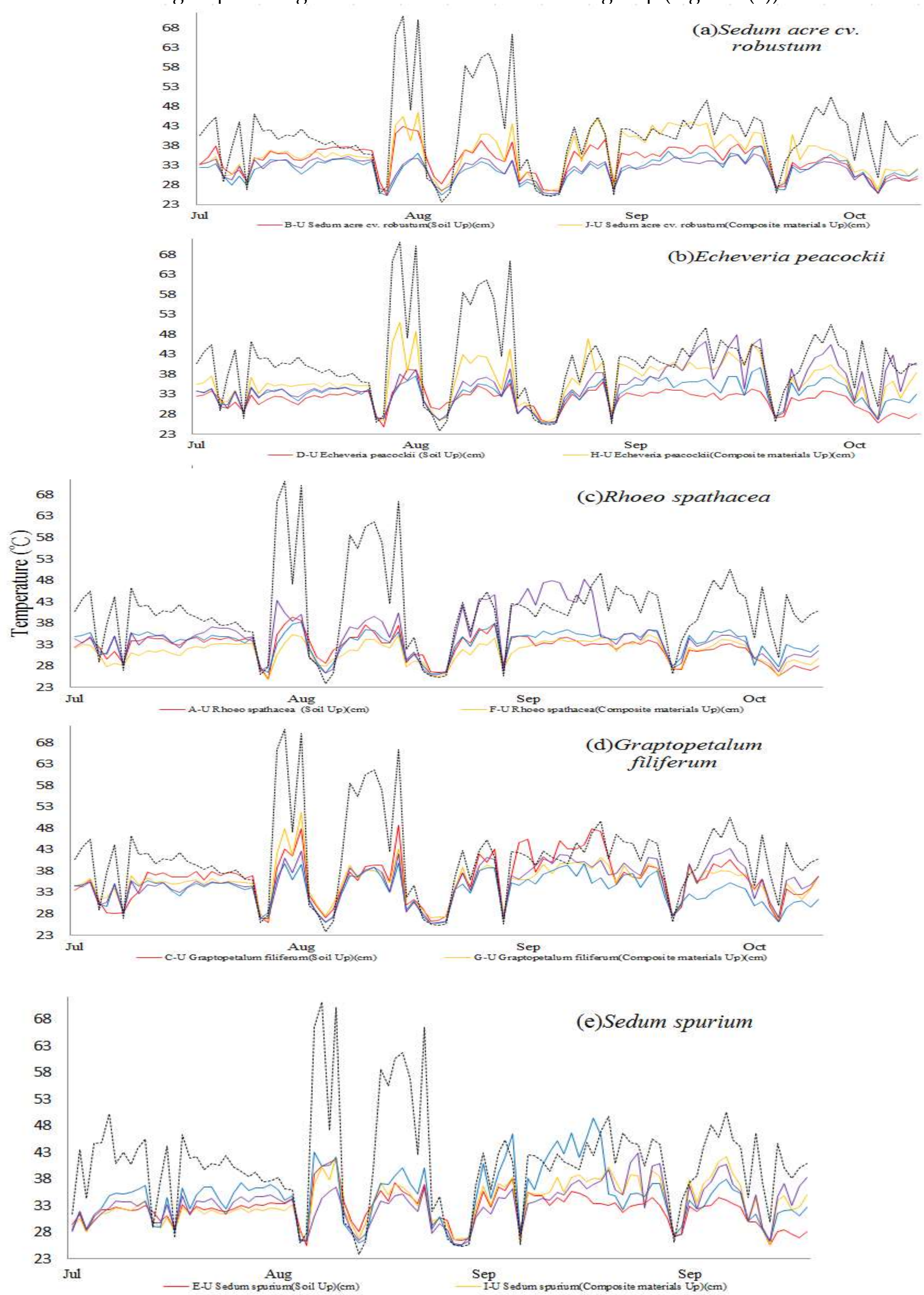



**Figure 6.** Temperature chart of the same plant with different measuring points.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 March 2021



2. (b) *Echeveria peacockii*

At 13:00 on August 25, the maximum temperature was 66.37°C for the metal sheet, and the difference from D-D was 29.63°C. In addition, the temperature of D-U (35.66°C) was higher than that of H-U by 8.54°C. At 13:00 on September 18, the maximum temperature was 46.88°C at the measuring point of the metal sheet, and the difference from D-D was 10.81°C. In addition, the temperature of D-U (32.57°C) was higher than that of H-U by 6.74°C. At 13:00 on October 3, the maximum temperature was 47.99°C at the measuring point of the metal sheet, and the difference from D-D was 12.68°C. In addition, the temperature of H-U was higher than that of D-U (31.91°C) by 7.16°C. According to the aforesaid results, planting *Echeveria peacockii* could effectively reduce the high temperature induced by vertical incident solar rays. In addition, in August, September and October, measuring point D-U had a lower temperature, due to the fleshy and big leaves of *Echeveria peacockii*, which shielded the sunlight and reduced the temperature. This species had a higher cooling effect on the culture soil group than that on the composite group (Figure 6(b)).

3. (c) *Rhoeo spathacea*

At 13:00 on August 25, the maximum temperature was as high as 66.37°C at the measuring point of the metal sheet, and the difference from A-D was 30.39°C. In addition, the temperature of A-U (37.36°C) was higher than that of F-U by 2.25°C. At 13:00 on September 18, the maximum temperature was 46.88°C at the measuring point of the metal sheet, and the difference from A-D was 12.20°C. In addition, the temperature difference from A-U (33.15°C) and F-U was 0.43°C. At 13:00 on October 3, the maximum temperature was as high as 47.99°C at the measuring point of the metal sheet, and the difference from F-D was 13.83°C. The temperature of F-U was higher than that of A-U (31.74°C) by 0.98°C. According to the above results, planting *Rhoeo spathacea* could effectively reduce the high temperature caused by vertical incident solar rays, because *Rhoeo spathacea* has long leaves that can shield the sunlight. This plant had a higher temperature drop benefit in the culture soil group than in the composite group (Figure 6(c)).

4. (d) *Graptopetalum filiferum*

At 13:00 on August 25, the maximum temperature was as high as 66.37°C at the measuring point of the metal sheet, and the difference from C-D was 26.55°C. In addition, the temperature of G-U was higher than that of C-U (48.71°C) by 5.53°C. On September 18, the maximum temperature was as high as 46.88°C for the metal sheet, and the difference from C-D was 11.79°C. The temperature of C-U (47.82°C) was higher than that of G-U by 9.30°C. On October 3, the maximum temperature was as high as 47.99°C for the metal sheet, and the difference from C-D was 14.69°C. *Graptopetalum filiferum* could effectively reduce the high temperature caused by vertical incident solar rays, but its effect was worse than that of the other plants, because *Graptopetalum filiferum* has smaller leaves that are worse for shielding the daily radiation. The culture soil group had a higher cooling effect than the composite group (Figure 6(d)).

5. (e) *Sedum spurium*

At 13:00 on August 25, the maximum temperature was 66.37°C for the metal sheet, and the difference from I-D was 30.47°C. In addition, the temperature of E-U (36.86°C) was higher than that of I-U by 0.96°C. On September 18, the maximum temperature was as high as 46.88°C for the metal sheet, which was higher than that of I-D by 9.29°C. On October 3, the maximum temperature was as high as 47.99°C for the metal sheet, which was higher than that of E-D by 12.97°C. In addition, the temperature of I-U was higher than that of E-U (34.01°C) by 8.12°C. *Sedum spurium* could effectively reduce the high temperature caused by vertical incident solar rays, because *Sedum spurium* has small but dense leaves that can shield sunlight. The culture soil group had a higher cooling effect than the composite group (Figure 6(e)).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 March 2021



3.1.3. Thermal insulation benefit

The maximum temperature was 71.1°C on August 11, and *Sedum acre* cv. robustum had the best thermal insulation benefit among the plants used in this study. After the thermal insulation benefit of the five plants was analyzed, it was obvious that the thermal insulation benefit of *Sedum acre* cv. robustum was higher than that of the other plants by 54%. *Sedum acre* cv. robustum had the best thermal insulation benefit in July, September and October, proving that *Sedum acre* cv. robustum had a wide planting area for shortness and denseness, shielding daily radiation. Therefore, this experiment proved that *Sedum acre* cv. robustum had the best thermal insulation benefit (Figure 7).

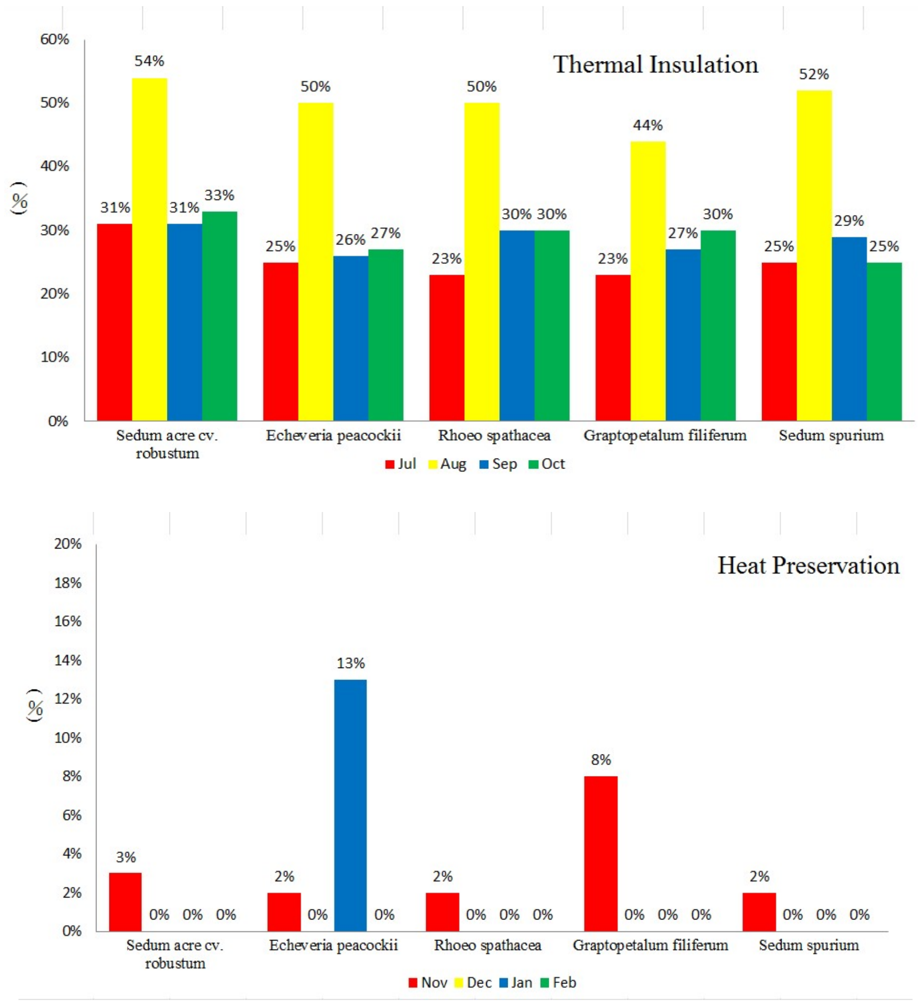



**Figure 7.** Thermal insulation benefit and heat preservation benefit charts.

3.1.4. Heat preservation benefit

In November, *Graptopetalum filiferum* had the best heat preservation benefit of 8%, higher than the other four plants by 5%. In addition, on January 24, which had the lowest air temperature, only *Echeveria peacockii* reached a heat preservation effect of 13%, the reason could be that cold wave in February in Taiwan, the heat preservation effect is particularly good; the other plants failed to achieve a heat preservation effect. *Sedum acre* cv. robustum, *Rhoeo spathacea, Graptopetalum filiferum and Graptopetalum filiferum* had heat preservation effects of 3%, 2%, 8% and 2% in November, but they had no heat preservation effect in the other months. The experimental results showed that the plants used in this study had minimal heat preservation effect on the sheet metal house (Figure 7).

### *3.2. Growth index*

According to the findings of the growth index, the plants grown in the composite had better growth. The *Sedum acre* cv. robustum was planted in culture soil and had a height of 1.9 cm, which was higher than the 0.9-cm high plants in the composite; however, the composite group had better plant width than the culture soil group. The plants in the culture soil group were 1.4 cm long and 1.7 cm wide, while the plants in the composite group were 5 cm long and 2.3 cm wide. In terms of the growth index of *Rhoeo spathacea*, the monthly average of the plants in the composite group was larger than that of the culture soil group by 1.93 cm. The *Sedum acre* cv. robustum of the composite group had better growth than the *Sedum acre* cv. robustum of the culture soil group, and its monthly average was larger than that of the culture soil group by 1.07 cm. The growth indexes of *Echeveria peacockii, Graptopetalum filiferum* and *Sedum spurium* in the composite group were slightly different from those in the culture soil group. According to the comparison of the same species in different soil qualities, the growth index of *Rhoeo spathacea* in the two different soils was 14.00 on April 27; the index of the composite group was 19.47 on February 26, whereas the index of the culture soil group was only 17.50, indicating a difference of 1.97, so the new use of the composite materials made of scraps may be in green roofs (Figure 8).

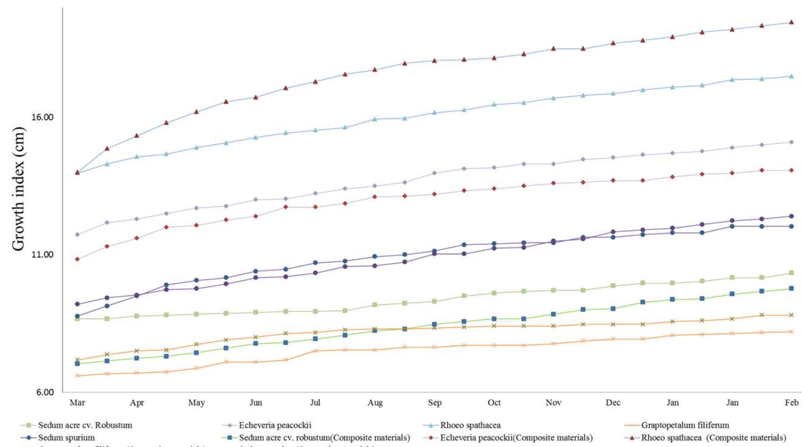



**Figure 8.** Plant growth index diagram.

## 4. Conclusions

The objective of this study was to arrange a green roof on a sheet metal house to achieve winter heat preservation and summer thermal insulation. This study hoped to achieve thermal insulation and heat preservation effects for sheet metal houses and mitigate the urban heat island effect.

According to the comprehensive analysis, container-type green roofs were found to have an apparent cooling effect on the peculiar metal sheet building material used in Taiwan in the summer, as the temperature was reduced by 35.61°C. However, the heat preservation effect of plants on metal sheet was limited in winter, because the sheet metal house had high heat capacity and the temperature of the metal sheet varied with the outside ambient temperature. Arranging a container-type green roof is suitable for the hot environment of Taiwan. On the one hand space can be economized, while on the other hand the urban heat island effect can be mitigated effectively and the urban green area can be enlarged. The test plant growth efficiency is mostly analyzed by plant evaluation method to determine the growth difference among plants. The growth index for five

*Preprints* (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 March 2021



plants in the two different soils was compared. The growth index of *Rhoeo spathacea* in the two different soils was compared and the results indicated that the new use of the composite materials made of scraps may be in green roofs. For the future research, it is suggested that it aquatic plants can be planted on the sheet metal house. For one reason, it can increase the ecology and improve the microclimate of the building. The heat insulation and heat preservation effect should also be better.

**References**

1. Berardi, U., 2016, "The outdoor microclimate benefits and energy saving resulting from green roofs retrofits", Energy and Buildings,121, pp. 217-229.
2. Bousselot, J., M., Klett, J., E., Koski, R., D., 2011, "Moisture Content of Extensive Green Roof Substrate and Growth Response of 15 Temperate Plant Species during Dry Down", HORTSCIENCE, 46(3), pp.518-522.
3. Dunnett, N., Kingsbury, N., 2004, Planting Green Roofs and Living Walls. Portland (OR), Timber Press.
4. Durhman, A. K., Rowe, D., B., Rugh, C., L., 2007, "Effect of substrate depth on initial growth, coverage, and survival of 25 succulent green roof plant taxa", HortScience, 42(3), pp.588-595.
5. Heidarinejad, G., Esmaili, A., 2015, Numerical simulation of the dual effect of green roof thermal performance., 106, pp. 1418-1425.
6. Hendel, M., Gutierrez, P., Colombert, M., Diab, Y., Royon, L., 2016, Measuring the effects of urban heat island mitigation techniques in the field: Application to the case of pavement-watering in Paris., 16, pp. 43-58.
7. Hsieh, C, M., Huang, H, C., 2016, Mitigating urban heat islands: A method to identify potential wind corridor for cooling and ventilation., 57, pp. 130-143.
8. Kikon, N., Singh, P., Singh, S, K., Vyas, A., 2016, Assessment of urban heat islands (UHI) of Noida City, India using multi-temporal satellite data., 22, pp. 19-28.
9. Lamera, C., Becciu, G., Rulli, M., C., Rosso, R., 2014, Green roofs effects on the urban water cycle components., 70, pp. 988-997.
10. Monterusso, M., A., Rowe, D., B., Rugh, C., L., 2005, "Establishment and Persistence of Sedum spp. and Native Taxa for Green Roof Application", HortScience 40(2):391-396.
11. Moran, A., B. Hunt., Smith., J., 2005, Hydrologic and Water Quality Performance from Green roofs in Goldsboro and Raleigh. Paper Presented at Third Annual Greening Rooftops for sustainable Communities Conference, Washington, D.C. USA.
12. Nagase, A., Dunnett, N., 2010, Drought tolerance in different vegetation types for extensive green roofs: Effects of watering and diversity., 97, PP. 318-327.
13. O'Malley, C., Piroozfarb, P., Farr, E, R, P., Gates, J., 2014, An Investigation into Minimizing Urban Heat Island (UHI) Effects: A UK Perspective., 62, pp. 72-80.
14. Peck, S., W., 2003, Towards an Integrated Green Roof Infrastructure Evaluation for Toronto. Green Roofs Infrastructure Monitoring, Vol. 5, No. 1, pp 4-5.
15. Rahman, S., R., A., Ahmad, H., Mohammad, S., Rosley, M., S., F., 2015, Perception of Green Roof as a Tool for Urban Regeneration in a Commercial Environment: The Secret Garden, Malaysia., 170, pp. 128-136.
16. Ramamurthy, P., Sangobanwo, M., 2016, Inter-annual variability in urban heat island intensity over 10 major cities in the United States., In Press, Accepted Manuscript - Note to users.
17. Rowe, D., B., Monterusso, M., A., Rugh, C., L., 2006, "Assessment of Heat-expanded Slate and Fertility Requirement in Green Roof Plant Substrates", HortTechnology, 16(3):471-477.
18. Santamouris, M., 2014, Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments., 103, pp. 682-703.
19. Sendo, T., Kanechi, M., Uno, Y., Noboru, I., 2010, "Evaluation of Growth and Green Coverage of Ten Ornamental Species for Planting as Urban Rooftop Greening", Journal of the Japanese Society for Horticultural Science, 79 (1): 69-76.
20. Teemusk, A., 2009, Temperature and Water Regime, and Runoff Water Quality of planted roofs., Ph. D. Dissertation,Department of Geography, University of Tartu, Tartu, Estonian. http://hdl.handle.net/10062/10279.
21. USEPA (2009) Green Roofs for Storm water Runoff Control, EPA/600/R-09/026 | February 2009 | www.epa.gov/ord.
22. Villarreal, E., L., Semadeni-Davies, A., Bengtsson, L., 2004, Inner city stormwater control using a combination of best management practices. Ecology Engineering, Vol. 22, pp 279-298.
23. Abowei, J. F. N., 2010. Salinity, Dissolved Oxygen, pH and Surface Water Temperature Conditions in Nkoro River, Niger Delta, Nigeria. Advance journal of food science and technology, 2(1), 36-40.
24. Alvarez, G., Palacios, M. J., Flores, J. J., 2000. A test method to evaluate the thermal performance of window glazings. Applied Thermal Engineering, 20, 803-812.
25. Antonie, R. L., Kluge, D. L., Mielke, J. H., 1974. Evaluation of a rotating disk wastewater treatment plant. Water Pollution Control Federation. 46 (12), 2792-2795.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 March 2021




26. Anwar, M., Rasul, M. G. and Khan, M. M. K., 2013. Air Conditioning Energy Saving by Rooftop Greenery System in Subtropical Climate in Australia. International Scholarly and Scientific Research & Innovation, 7 (7), 427-433.
27. Arasteh, D. K., Reilly, M. S., Rubin, M. D., 1989. A Versatile Procedure for Calculating Heat Transfer through Windows. ASHRAE, 755-765.
28. Araujo, R. S., Senner, R., 1979. *Eichhornia Crassipes*, a pollution remover. An Assoc Bras Quim, 30 (3-4), 111-112.
29. Berardi, U., 2016. The outdoor microclimate benefits and energy saving resulting from green roofs retrofits. Energy and Buildings, 121 (1), 217-229.
30. Bousselot, J. M., Klett, J. E., Koski, R. D., 2011. Moisture Content of Extensive Green Roof Substrate and Growth Response of 15 Temperate Plant Species during Dry Down. HORTSCIENCE, 46(3), 518-522.
31. Brix, H., Schierup, H.H., 1990. Soil oxygenation in constructed reed beds: the role of macrophyte and soil-atmosphere interface oxygen transport. In: Cooper, P.F., Findlater, B.C. (Eds.), Constructed Wetlands in Water Pollution Control. Pergamon Press, New York, USA, 22 (1), 27–42.
32. Chang, Y. H., Ku, C. R., Lu, H. L., 2014. Effects of aquatic ecological indicators of sustainable green energy landscape facilities. Ecological Engineering, 71, 144-153.
33. Dai, Q., Chen, Y., Pi, Y., 1991. Study on the accumulation amount of silver in waste water and its utilization by water hyacinth. Chin. J. Appl. Ecol., 2 (2), 159-167.
34. Davis, K., Anderson, M. A., Yates, M. V., 2005. Distribution of indicator bacteria in Canyon Lake California, Water Research. 39, 1277-1288.
35. Driscoll, M. O., Anwar, M., and Rasul, M. G., 2013. Eco-Roof Systems in Subtropical Climates for Sustainable Development and Mitigation of Climate Change. International Scholarly and Scientific Research & Innovation, 7(7), 395-403.
36. Durhman, A., Rowe, K. D. B., Rugh, C. L., 2007. Effect of substrate depth on initial growth, coverage, and survival of 25 succulent green roof plant taxa. HortScience, 42(3), 588-595.
37. Environmental Protection Administration, R.O.C., 2013. Water Quality Monitoring Project and its Significance, http://wqp.epa.gov.tw/ecological/ClassRoom.aspx?Num=01.
38. Garcia, M., Soto, F., Juan, M. A comparison of bacterial removal efficiencies in constructed wetlands and algae-based systems. ecological Engineering, Vol. 32, pp. 238-243, 2008.
39. Gustavo, G., Henry-Silva, F. M., Camargo, M., 2008. Growth of free-floating aquatic macrophytes in different concentrations of nutrients, Hydrobiologia. 610, 153-160.
40. Heidarinejad, G., Esmaili, A., 2015, Numerical simulation of the dual effect of green roof thermal performance., 106, pp. 1418-1425.
41. Hendel, M., Gutierrez, P., Colombert, M., Diab, Y., Royon, L., 2016. Measuring the effects of urban heat island mitigation techniques in the field: Application to the case of pavement-watering in Paris. 16, 43-58.
42. Hsieh, C, M., Huang, H, C., 2016. Mitigating urban heat islands: A method to identify potential wind corridor for cooling and ventilation. 57, 130-143.
43. Huilong X., Xiangjuan Ma., 2006. Phytore-mediation of ethion by water hyacinth (*Eichhornia crassipes*) from water. Bioresource Technology, 97 (8) 1050-1054.
44. Kalff, J., 2002. Limnology: inland water ecosystems. Upper Saddle River, NJ: Prentice Hall.
45. Karim, M. R., Glenn, E. P., Gerba, C. P., 2008. Pathogen removal in wetlands. International Water Association. 21, 71-85.
46. Kikon, N., Singh, P., Singh, S, K., Vyas, A., 2016. Assessment of urban heat islands (UHI) of Noida City, India using multi-temporal satellite data. 22, 19-28.
47. Kivaisi, A. K., 2001. The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review. Ecol. Eng., 16(4), 545-560.
48. Lamera, C., Becciu, G., Rulli, M., C., Rosso, R., 2014, Green roofs effects on the urban water cycle components. Procedia Engineering, 70, 988-997.
49. Larsson, U., Moshfegh, B., 2002. Experimental investigation of downdraught from well-insulated windows. Building and Environment, 37, 1037-1082.
50. Larsson, U., Moshfegh, B., Sandberg, M., 1999. Thermal analysis of super insulated windows numerical and experimental investigations. Energy and Buildings, 29, 121-128.
51. Lewitus, A. J., Brock, L. M., Burke, M. K., 2018. Lagoonal storm water detention ponds as pro-moters of harmful algal blooms and eutrophica-tion along the South Carolina coast. Harmful Algae, 8, 60-65.
52. Merritt, R. W. and Cummins, K. W., 1996. An introduction to the aquatic insects of North America. 3 ed. Kendall/Hunt Publ. Iowa.
53. Metcalf, & Eddy, Inc., Revised by Tchobananoglous, G. & Burton, F.L., 1991. Wastewater engineering: treatment, disposal and reuse. McGraw-Hill, McGraw-Hill series in water resources and environmental engineering, New York, USA, 927-952.
54. Monterusso, M. A., Rowe, D. B., Rugh, C. L., 2005. Establishment and Persistence of Sedum spp. and Native Taxa for Green Roof Application, HortScience, 40 (2), 391-396.
55. Moran, A., B. Hunt., Smith, J., 2005. Hydrologic and Water Quality Performance from Green roofs in Goldsboro and Raleigh.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 March 2021



Paper Presented at Third Annual Greening Rooftops for sustainable Communities Conference, Washington, D.C. USA.
56. Nagase, A., Dunnett, N., 2010. Drought tolerance in different vegetation types for extensive green roofs: Effects of watering and diversity. 97, 318-327.
57. O'Malley, C., Piroozfarb, P. A. E., Farr, E., R., P., Gates, J., 2014. An Investigation into Minimizing Urban Heat Island (UHI) Effects: A UK Perspective. Energy Procedia, 62, 72-80.
58. Peter, R. L., Arasteh, D., Huizengan, C., 2000. Window Performance for Human Thermal Comfort. ASHRAE, 594-602.
59. Petter, W., 2001. Convective heat transfer coefficients in a full-scale room with and without furniture. Building and Environment, 36, 743-751.
60. Rahman, S. R. A., Ahmad, H., Mohammad, S., Rosley, M. S. F., 2015. Perception of Green Roof as a Tool for Urban Regeneration in a Commercial Environment. The Secret Garden, Malaysia, 170, 128-136.
61. Ramamurthy, P., Sangobanwo, M., 2016. Inter-annual variability in urban heat island intensity over 10 major cities in the United States. Sustainable Cities and Society, 26, 65-75.
62. Reddy, K. R., Sutton, D. L., 1984. Water hyacinths for Water Quality Improvement and Biomass Production. Journal of Environmental Quality, 13 (1), 1-8.
63. Rowe, D., B., Monterusso, M., A., Rugh, C., L., 2006. Assessment of Heat-expanded Slate and Fertility Requirement in Green Roof Plant Substrates. HortTechnology, 16 (3), 471-477.
64. Santamouris, M., 2014. Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. 103, 682-703.
65. Saso, M., Novak, P., 1998. Heat transfer through a double pane window with an insulation screen open at the top. Energy and Buildings, 28, 257-268.
66. Sendo, T., Kanechi, M., Uno, Y., Noboru, I., 2010. Evaluation of Growth and Green Coverage of Ten Ornamental Species for Planting as Urban Rooftop Greening. Journal of the Japanese Society for Horticultural Science, 79 (1), 69-76.
67. Sooknah, R. D., Wilkie, A. C., 2004. Nutrient removal by floating aquatic macrophytes cultured in anaerobically digested flushed dairy manure wastewater. Ecol. Eng., 22 (1), 27-42.
68. Sutherland, W., 1996. Ecological census techniques: a handbook. Cambridge University Press, Cambridge.
69. Tanner, C. C., 2001. Plants as ecosystem engineers in subsurface-flow treatment wetlands. Water Sci. Technol., 44 (11–12), 9–17.
70. Teemusk, A., 2009, Temperature and Water Regime, and Runoff Water Quality of planted roofs. Ph. D. Dissertation, Department of Geography, University of Tartu, Tartu, Estonian.
71. US Environmental Protection Agency, 2000. Constructed Wetlands Treatment of Municipal Wastewater: Manual. Office of Research and Development, National Risk Management Research Laboratory, Cincinnati, OH, 166.
72. USEPA, 2009. Green Roofs for Storm water Runoff Control. EPA/600/R-09/026, www.epa.gov/ord.
73. Watson, J. T., Reed, S. C., Kadlec, R. H., Knight, R. L., Whitehouse, A. E., 1989. Performance Expectations and Loading Rates for Constructed Wetlands. In: Hammer, D.A. (Ed.). Constructed Wetlands for Wastewater Treatment, Michigan.
74. Ding, Y. Y., Lee, W. H. (1991), Biological Illustrated Handbook of Common Seawater Shrimps CAPD Fisheries SeriesNo. 37, Council of Agriculture.
75. Ding, Y. Y., Lee, W. C. (1988), Illustrated Handbook of Common Planktons in Culture Ponds in Taiwan, CAPD Fisheries Series No. 14, Council of Agriculture.
76. Yamagishi, T. (1992), Plankton algae in Taiwan, Uchida Rokakuho, Tokyo.
77. Central Weather Bureau (2016), http://www.cwb.gov.tw/V7/index.htm.
78. Construction and Planning Agency of Minister of the Interior (2016), Building Technical Regulations, Construction and Planning Agency of Minister of the Interior.
79. Tien, C. J., Li, W. W., Kuo, Y. C., Wong, H. C., Wang, P. H. (2001), A Method for the Observation of Freshwater Algae in Our Environment, Science Education Monthly, 259.
80. Shih, F. C., 2005, Water Quality Analysis Principles and Standard Methods, New Wun Ching Developmental Publishing Co., Ltd.
81. Environmental Protection Administration, Executive Yuan (2014), Nationwide ambient water quality monitoring infonet, http://wq.epa.gov.tw/Code/Business/Vocabulary.aspx.
82. Lu, K. Y., Chen, T. H., Kao, C., Sun, C. C., Chu, C. M., Tsai, T. S., Ho, Y. H., Cheng, C. K. (1996), Taiwan wildlife resource survey ~ amphibian resource survey handbook, Council of Agriculture, Executive Yuan.
83. Lu, C. H. (2001), Study on Nitrification and Denitrification of Wastewater Containing Organic Nitrogen, master's thesis, Bioengineering Institute, Tatung University.
84. Lee, C. H. (2010), Study on Treatment of Livestock Wastewater by Aquatic Plants, master's thesis, Graduate School of Environmental Engineering, Kun Shan University.
85. Lee, P. F., Liang, S. H. (2003), Study of Animal Ecology Assessment Technology and Validation of Assessment model, Environmental Protection Administration, Executive Yuan.
86. Ke, T. Y. (2010), Algal Growth Control and Water Quality Enhancement within Natural Water Purification Systems, master's thesis, National University of Kaohsiung.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 March 2021



87. Hsu, M. K. (2011), Wetland Algae, Wetlands TaiwanNo.64, Taiwan wetlands magazine.
88. Hao, D. M. (2000), Outline of Ecology, Xushi Culture & Education Foundation, Taipei.
89. Chang, W. L. (1979), Research Questionnaire About *Eichhornia Crassipes* Ecology and Water Quality, master's thesis, Department of Agricultural Engineering, National Taiwan University.
90. Chang, W. L. (2006), Evaluation and Management of Water Purification Effect of Aquatic Plants on Constructed Wetlands, Seminar on Planning and Design and Construction of Natural Purification Engineering for River Water Quality.
91. Chang, Y. H., Lin, P. Y., Ku, C. R., Wang, Z. Y., Wu, Z. Y., Lin, S. F. (2013a), Performance Evaluation of Water Purification of Solar Power System Equipment Combined *Eichhornia Crassipes*, Journal of Taiwan Agricultural Engineering, 59 (3), 22-31.
92. Chang, Y. H., Lin, P. Y., Ku, C. R., Wu, Y. T., Chen, Y. J., Fu, Y. R., Zhong, P. Y. (2013), The Study of Six Aquatic Plants on Water Purification Efficiency Comparison of Winter Season in Taiwan, Journal of Taiwan Agricultural Engineering, 59 (4), 33-41.
93. Chang, S. Y., Chen, C. T, Chen, L. D. (2006), Practical Discussion About Common Problems in Biological Wastewater Treatment Process, Industrial Pollution Control.
94. Chen, C. C. (2012), Facility and Environment Engineering, BSE Lab, National Chung Hsing University, http://bse.nchu.edu.tw/new_page_370.htm.
95. Chen, Y. C. (2005), Ecological Engineering of Wetlands, Tsanghai Book.
96. Chen, C. C. (2000), Outline of Building Physics, Chans Book.
97. Chen, M. Y. (2007), Evaluation of the Antipollution Potential of some Aquatic Plants in an Artificial Wetland: *Eichhomia crassipes (Mart.)* Solm. - Laub., Pistia stratiotes L., Ipomoea aquatica Forsk, and *Hygrophila pogonocalyx Hayata*, Department of Environmental Engineering, Da-Yeh University.
98. Shan, M.Y., Lee, J. C. (2006), River Water Quality Purification Engineering Benefit Analysis, Seminar on Technology and Management, Hsing Kuo University of Management.
99. Moriwaka, M. (1992), Taiwan Floating Algae, Uchida Rokakuho, Tokyo.
100. Moriwaka, M., Chi, C. (1996), Illustrated Handbook of Reservoir Planktonic Algae in Taiwan, Environmental Analysis Laboratory, Environmental Protection Administration, Taipei.
101. Yang, Y. X. (1979), Feasibility Study of Treating Heavy Metals with *Eichhornia Crassipes*, master's thesis, Graduate Institute of Environmental Engineering, National Taiwan University.
102. Bureau of Energy, Ministry of Economic Affairs (2016), http://www.moeaboe.gov.tw/ecw/populace/content/Content.aspx?menu_id=460.
103. Liao, Y. W., Hsu, S. T., Lin, M. H., Hsieh, Y. H., Wu, H. D., Chung, R. B. (1999), Plant Physiology, Top Ching Culture, Taipei.
104. Ku, H. W. (2003), A Study on the Record of Observing and Analysis of Electrical Consumption of Residential Building, master's thesis, Department of Architecture, NCKU.
105. Morakinyo, T.E., Dahanayake, K.K.C., Ng, E.; Chow, C.L. Temperature and cooling demand reduction by green-roof types in different climates and urban densities: a cosimulation parametric study. Energy Build. 2017, 145, 226-237.
106. Bevilacqua, P, Mazzeo, D.; Bruno, R., Arcuri, N. Surface temperature analysis of an extensive green roof for the mitigation of urban heat island in southern mediterranean climate. Energy Build. 2017, 150, 318–327
107. Wong, N.H., Chen, Y.; Ong, C.L., Sia, A. Investigation of thermal benefits of rooftop garden in the tropical environment. Environ. 2003,38, 261-270