The Application Air-Plant Green Roof for Residential Building in Hot-Humid Climate

Tachaya Sangkakool

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Environmental Management
Prince of Songkla University
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Major Program	Environmental Management

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บทคัดย่อ

หลังคาสีเขียวเป็นแนวทางการออกแบบที่ผสมผสานวิธีการทางธรรมชาติที่คำนึงถึงประโยชน์ด้านสิ่งแวดล้อม หลังคาเขียวช่วยลดพื้นที่ในการเก็บสะสมความร้อนในเวลากลางวัน และสะท้อนความร้อนในเวลากลางคืน ช่วยลดค่าการถ่ายเทความร้อนเข้าสู่อาคารและลดภาระการใช้งานพลังงานอย่างมีประสิทธิภาพถือเป็นกลยุทธ์สำคัญในการแก้ปัญหาภาวะโลกร้อนอย่างยั่งยืน การวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาประสิทธิภาพพลังงานของหลังคาสีเขียวกรณีศึกษาพืชอากาศสำหรับอาคารอยู่อาศัยในสภาพภูมิอากาศร้อนชื้น ณ อำเภอหาดใหญ่ จังหวัดสงขลา ละติจูด 60 55N และลองติจูด 1000 26E อยู่สูงจากระดับน้ำทะเลประมาณ 34 เมตร ทำการทดลองในช่วงเดือนเมษายนถึงเดือนพฤศจิกายน พืชที่ใช้ในการศึกษาวิจัยนี้เป็นพืชอากาศ 2 ชนิด คือ เคราฤาษี (*Tillandsia usneoides L.*) และทิลแลนเซียพันธุ์โคลน (Tillandsia Cotton Candy) ซึ่งเป็นพืชใบเลี้ยงเดี่ยวในวงศ์สับปะรด (Bromeliaceae) สกุล Tillandsia มีคุณลักษณะเป็นพืชทนแล้ง ดูแลรักษาง่าย น้ำหนักเบา ไม่อาศัยดินในการเจริญเติบโต พื้นผิวใบมีไทรโคม (Trichome) ปกคลุมช่วยดักไอน้ำ ก๊าซ และสารในอากาศ และการสังเคราะห์แสงแบบ Crassulacean Acid Metabolism ในงานวิจัยนี้มีการสร้างห้องทดลอง 3 ห้อง โดยศึกษาประสิทธิภาพการลดอุณหภูมิจากความหนาแน่นใบ (Density) และศึกษาประสิทธิภาพการลดอุณหภูมิจากช่องว่างอากาศ (Air gap) ซึ่งทำการเปรียบเทียบกับพืชอากาศ 2 ชนิด และห้องทดลองที่ไม่ใช้พืชอากาศ โดยทำการวัดอุณหภูมิทั้งช่วงกลางวันและกลางคืน จากผลการทดลองประสิทธิภาพการลดอุณหภูมิจากความหนาแน่นใบพบว่าปัจจัยหลักที่มีผลต่อการลดลงของอุณหภูมิคือค่าความหนาแน่นใบ ในช่วงกลางวันความหนาแน่นใบที่ 1500 g/0.144m^3 ต้นเคราฤาษีสามารถลดอุณหภูมิได้มากกว่าต้นทิลแลนเซียโดยสามารถลดอุณหภูมิได้ถึง 8.1 และ 6.87 องศา ตามลำดับ ส่วนในช่วงกลางคืนต้นทิลแลนเซียที่ความหนาแน่นใบ 1,500 g/0.144m^3 สามารถลดอุณหภูมิได้มากกว่าต้นเคราฤาษีที่ความหนาแน่นใบ 500 g/0.144m^3 โดยมีอุณหภูมิที่ลดได้คือ 4.20 และ 3.43 องศา ตามลำดับ และจากการศึกษาประสิทธิภาพการลดอุณหภูมิจากช่องว่างอากาศพบว่าในช่วงกลางวันช่องว่างอากาศ 30 เซนติเมตร ที่ความหนาแน่นใบ 1,500 g/0.144m^3 ต้นเคราฤาษีสามารถลดอุณหภูมิได้มากกว่าต้นทิลแลนเซียโดยมีอุณหภูมิที่ลดได้คือ 8.1 และ 6.87 องศา ตามลำดับ และในช่วงกลางคืนต้นทิลแลนเซียสามารถลดอุณหภูมิได้มากกว่าต้นเคราฤาษี ที่ช่องว่างอากาศ 40 เซนติเมตร และความหนาแน่นใบ 1,500 g/0.144m^3 โดยจะลดอุณหภูมิได้ถึง 4.20 และ 4.10 องศา ตามลำดับ จากงานวิจัยสรุปได้ว่าชนิดพืช ความหนาแน่นใบ และช่องว่างอากาศจะมีผลต่อการลดอุณหภูมิผิวอาคาร และอากาศภายในอาคาร โดยความหนาแน่นใบที่ 1,500 g/0.144 m^3 จะสามารถลดอุณหภูมิได้ที่สุดทั้งในช่วงกลางวันและกลางคืน ส่วนช่องว่างระหว่างอากาศ ในช่วงกลางวัน ที่ช่องว่างอากาศ 30 เซนติเมตร สามารถลดอุณหภูมิได้ดีที่สุด ที่ความหนาแน่นใบที่ 1,500 g/0.144 m^3 และในช่วงกลางคืน ที่ช่องว่างอากาศ 40 เซนติเมตร สามารถลดอุณหภูมิได้ดีที่สุด ที่ความหนาแน่นใบที่ 1,500 g/0.144 m^3 เช่นกัน

Thesis Title The Application Air-Plant Green Roof for Residential Building in Hot-Humid Climate
Author Miss Tachaya Sangkakool
Major Program Environmental Management
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ABSTRACT

The idea of green roof can be developed into a design guideline. It composes of natural methods that benefit to the surrounded environment. According to the experiment, green roofs can reduce thermal storage space during daytime. Moreover, it can also reflect heat at night. With that reason, green roofs can reduce solar heat transmission of buildings as well as energy, which leads to sustainable solutions toward global warming. This research aims at studying green roofs energy efficiency by growing air plants on residential building in tropical climate area. The experiment was conducted in Songkhla, situated in the South Thailand at latitude 60° 55N and longitude 100° 26E, during April to November. There were two main types of air plants used in the study, Spanish moss and Tillandsia Cotton Candy. Both of them are monocotyledon plants in family of Bromeliaceae and Genus of Tillandsia. Air plants are easy to maintain and can tolerate to various weather conditions. In addition, it also has lower weight and does not need soil too. The leaf surface has tri-chrome cover as to help vapor gas and other substances trap. This research has set up three different mocked up rooms for the temperature test. The temperature performance study decreased according to density and air gap of air plant. The temperature comparison of two air plants and fiber cement roofs was measured in both day and night time. The result from the temperature performance study has decreased depending on the density of air plants. The main factors which influencing the decrease in temperature were leaf area density. According to the study, the result from temperature performance study revealed that the density of air plant decreased the day time (1,500 g/0.144 m^3). Moreover, Spanish moss can reduce temperature more than Tillandsia Cotton Candy. The temperature can be reduced up to 8.1 to 6.87 degree respectively. During the night time, Tillandsia Cotton Candy at density of 1,500g/0.144m^3 can reduce the temperature more than Spanish moss at density of 500g/0.144m^3. The temperature can be reduced up to 4.20 and 3.43 degrees respectively. The result from temperature performance shows that the decreased temperature on the 30 cm air gap during the day time at density of 1,500g/0.144m^3 of Spanish moss was more than Tillandsia Cotton Candy. It can reduce the temperature up to 8.1 and 6.87 degree respectively. During the night time, Tillandsia Cotton Candy can decrease roof temperature more than Spanish moss in 40 cm air gap and density of 1,500g/0.144 m^3. The decreased temperature are up to 4.20 and 4.10 degrees, respectively. The research can be concluded that air plant species, density and air gap all affect the decreasing temperature of the surface and ambient in residential buildings. Green roof at the density of 1,500g/0.144m^3 can reduce the highest temperature during day and night time. The 30 cm air gap and density of 1,500g/0.144 m^3 air plants can decrease the temperature at its highest during night time. The 40 cm air gap and density of 1,500g/0.144 m^3 green roof can reduce the highest temperature.

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NOMENCLATURE

$C_{e,r}$	latent heat flux bulk transfer coefficient at roof layer
C_f	bulk heat transfer coefficient
C_{hr}	sensible heat flux bulk transfer coefficient at roof layer
$C_{p,a}$	specific heat of air at constant pressure
F_f	net heat flux to foliage layer (W/m^2)
F_g	net heat flux to roof surface (W/m^2)
h	effective heat transfer coefficient with convection + radiation
h_{fr}	latent heat of evaporation
H_f	foliage sensible heat flux (W/m^2)
H_r	roof sensible heat flux (W/m^2)
$I_s^{\downarrow}$	total incoming short-wave radiation (W/m^2)
$I_{ir}^{\downarrow}$	total incoming long-wave radiation (W/m^2)
l_f	latent heat of vaporization at foliage temperature (J/kg)
l_g	latent heat of vaporization at roof temperature (J/kg)
K	total thermal conductivity
L	characteristic depth of air plant green roof
L_f	foliage latent heat flux (W/m^2)
L_r	roof latent heat flux (W/m^2)
LAI	leaf area index (m^2/m^2)
m	evaporation flow rate
q_{af}	mixing ratio for air within foliage canopy
$q_{f,sat}$	saturation mixing ratio at foliage temperature
$q_{r,sat}$	saturation mixing ratio at roof temperature
Q_{cond}	conduction heat
Q_{irr}	radiation heat
Q_{conv}	convection heat
Q_{evap}	evapotranspiration heat
r''	surface wetness factor
T_{af}	air temperature with in the canopy
T_f	foliage temperature
T_r	roof surface temperature
T_S	temperature of air plant green roof surface
T_∞	ambient temperature
V_∞	air velocity

W_{af}	wind speed within the canopy
α_f	albedo (short-wave reflectivity) of the canopy
α_r	albedo (short-wave reflectivity) of roof surface
ε_f	emissivity of canopy
ε_r	emissivity of the roof surface
ε_1	$\varepsilon_g + \varepsilon_f - \varepsilon_g \cdot \varepsilon_f$
φ_∞	relative air humidity
ρ_{af}	density of air at foliage temperature
ρ_{ar}	density of air at roof surface temperature
θ	moisture content
σ	Stefan–Boltzmann constant
σ_f	fractional vegetation coverage
E	Evapotranspiration, kg m^{-2} s^{-1}
F	Leaf area index
h	Height, m
H	Sensible heat flux, W m^{-2}
k	Thermal conductivity, W K^{-1} s^{-1}
l_v	Latent heat of vaporization, J kg^{-1}
L	Latent heat flux, W m^{-2}
r_c	Resistance to heat flow from roof surface displacement height, s m^{-1}
r_{sub}	Substrate surface resistance to mass transfer, s m^{-1}
S_r	Saturation ratio
T	Time, s
T	Temperature, K
u	Wind speed, m s^{-1}
z	Altitude or depth, M

Subscripts

a	Air
b	Bottom of the substrate
c	Leaf canopy
f	Foliage
r	roof (material) surface
s	Solar/shortwave
sat	Saturation value
sky	Sky/longwave
w	Water

List of Published Papers

List of Publication

Thomas Brudermann and Tachaya Sangkakool*, Green roofs in temperate climate cities – An analysis of key decision factors, Urban Forestry & Urban Greening 21 (2017): 224–234

Tachaya Sangkakool and KuaananTechato, Life cycle cost of air plant green roofs in hot and humid climate, International Journal of Applied Business and Economic Research 2016 (IJABER), Vol. 14, No. 10 (2016): 7145-7160

Tachaya Sangkakool and KuaananTechato, Environmental Benefits of Air Plant Green Roofs in Hot and Humid Climate, ADVANCED SCIENCE LETTERS ISSN: 1936-6612 (Print): EISSN: 1936-7317 (Online) Copyright © 2000-2016 American Scientific Publishers

Tachaya Sangkakool, Kuaanan Techato and Thomas Brudermann*, Prospects of Green Roofs in Urban Thailand, Submitted to Journal of Cleaner Production (Submitted to Journal of Cleaner Production in publication process)

List of Conference paper

Tachaya Sangkakool and KuaananTechato,Environmental Benefits of Air Plant Green Roofs in Hot and Humid Climate, International Conference in Environmental and Civil Engineering Technology (ENVICET 2016) on Oct 4 – 6, 2016, Malaysia

Tachaya Sangkakool and KuaananTechato,Heat reduction by using of Spanish mosses as green roof with zero maintenance in hot and humid climate, International Conference on Architecture, Landscape and Built Environment (ICALBE 2016), The New Zealand Academy of Applied Research Limited (NZAAR), June 25-26, 2016, Malaysia

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Paper I

Urban Forestry & Urban Greening journal

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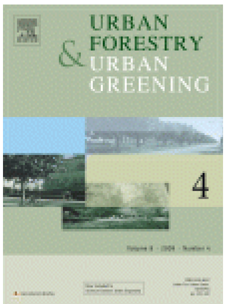

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Journal of Applied Business and Economic Research

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CHAPTER I

INTRODUCTION

Green roofs are commonly demonstrated toward the performance of energy efficiency and the resolving of the lack of green area in urbanization. The efficiency of energy consumption on green roofs could provide the development of sustainable architecture. Green roofs are passive cooling designs. The major of vegetation layer and photosynthesis process on final layers of green roofs contributed low solar absorption, indoor cooling temperature. It could be provided evapotranspiration, shadow and insulation and created other the numerous of environmental benefits.

1. The background of green roofs
2. The classification and technology of green roofs
3. The contribution of thermal transfer on green roofs
4. The environmental benefits of green roofs
5. The variables to affect the architectural design
6. The Crassulacean Acid Metabolism (CAM) plants
7. The policies for green roofs

1.1 The background of green roofs

1.1.1 The history of green roofs

Vegetation technologies on rooftop have since the prehistoric times. Since 590 B.C., Hanging Gardens of Babylon were built to improve aesthetic value and human activities. In ancient Mesopotamia, green roofs had integrated in the ziggurats area and also roof gardens had represented by Roman architect for Villa (Vijayaraghavan, 2016). Vernacular architecture in Viking ancient covered green roofs with natural materials which are sod roof, turf roof and grass roof. Several countries in Northern European and especially Norway utilized the advantage of soil in order to increase thermal insulation and shield building envelope in vernacular house during the 1600s to 1800s (Getter & Rowe, 2006). Le Corbusier distinctly rediscovered roofs garden in the five points towards modern architecture and formulated the roofs gardens movement of the modernist architectural in the twentieth century. In the 1930s, Walter Gropius and Frank Lloyd Wright and Modernist architects widely designed roof gardens and in the same time, include the unique modern Roof Gardens in Kensington, London and the five rooftop gardens terraces in Rockefeller Center, New York. In the 1960, the developments of vernacular roof to reinforced structural concrete roof were diffused green roofs in modern architecture to perform aesthetic, human wellbeing and energy performance (Ascione, Bianco, de' Rossi, Turni, & Vanoli, 2013).

Table 1.1 The history of green roofs in the ancient Mesopotamia, the 21st and modern green roofs

Timeline	**Pre-modern green roofs**
The 20st century BCE.	The Ziggurat, Iraq in the ancient Mesopotamia originated tree and flower gardens on the terrace and massive structure.
The 8th and 10th centuries	The Hanging Gardens of Babylon built living roofs which included the abundant roof forest of perennial plants and lush grass.
The 10th century	Vikings created vernacular architecture with the natural sheltered materials such as turf, birch, grass and sod roofs in Canada, North America, Ireland, Scotland and Greenland.
Around the 60th and 40th centuries	The villa of mysteries, Pompeii created the terraced arcade of roof gardens for the social rest activity and the supported structure with the arched stone colonnade.
In 1459	The palazzo Piccolomini, Pienza Italy built the original concept of manmade landscape design on roof gardens.
In 1890	The casino theatre in New York city was the first of garden rooftop which became the popularity of green roofs.
In 1896	The vernacular architecture in Norwegian provided the technique of sod roofs for insulation layer and weighted structure balance. USA and Canada adopt the concept by Norwegian immigrant.
Timeline	**Modern green roofs**
In the early 20th century	Le Corbusier became the famous of roof garden design and defined in the five points towards of modern architecture.
In 1930-1940	Modernists architects such as Le Corbusier, Frank Lloyd Wright and Roberto Burle Marx designed roof landscapes in Brazil for example ministry of education building, Brazilian press association building.
In the early 1970-1972	The new principle of modern green roofs were introduced in Germany and Hans-Joachim Liesecke summarized the basic of vegetation roofs, intensive green roofs and landscape planning.
In 1974-1980	The acceptance of green roofs in Germany developed green roof technology in European market and originated Optigrün and ZinCo corporations for the marking of green roofs.
Since the early 1990	The blossomed becoming of green roofs in in the United States such as Portland, Washington, D.C., New York, London, Toronto and Chicago.
Since 1992	The faced challenging of green space in Singapore increased the area of green footprint in city and become sustainability in city for example the famous covering of green roofs at the Parkroyal hotel, the school of art, design and media at the Nan yang technological university and Marina Barrage.

Source: (Berardi & GhaffarianHoseini, 2014), (Getter & Rowe, 2006), (Ascione et al., 2013) and (Vijayaraghavan, 2016)

In temperate climate, especially Europe and North America, the exponential increased of implementation and interesting in green roofs was widely recognized during the last decade (Williams, Rayner, & Raynor, 2010)(Volder & Dvorak, 2014). In Germany, the increased of green roofs area was extended approximately 13.5 million m2 per year in 2007 (Oberndorfer et al., 2007). In 2010, the rooftop area of semi-intensive and extensive green roofs in France which the depth of the surface of less than 20cm came up 1 million m^2 and the forecast in 2015 will increase to 1.5 million m^2(Rowe, Getter, & Durhman, 2012).

The development of modern green roofs on a larger scale in market was designed and developed in Germany (B. S. Lin, Yu, Su, & Lin, 2013). Multiple monitors have been conducted with an emphasis on thermal performance, biological diversity, growing media, roof construction and design approach. Most of the beginning of the green roofs was research in German, since the first initiative was introduced it by Germany and later in neighboring countries in Europe. Green roofs were become increasingly popular in the rest of the world.

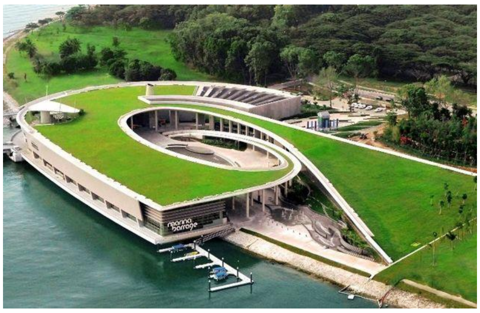
1.1.2 Green roofs research scope on thermal point view in tropical climate

Currently, the researched investigation on thermal performance in tropical climate was obviously conducted in many countries such as Singapore, Japan, Hong Kong, South Korea, Taiwan, Malaysia and China (see in table 1.1). In Japan, Tokyo Prefecture enacted the regulations for making green roofs to newly construction buildings with land area ≥1000 m^2 (B. S. Lin et al., 2013).

In Singapore, many researchers distinctly published the energy efficiency of green roofs since 2003. The measurement on landscaping rooftop in Singapore was explained that the LAI density of vegetation can contributed the direct and indirect benefits of thermal comfort at indoor area and outdoor environment (Hien, Chen, Leng, & Sia, 2003). The simulation of energy with DOE-2 program on the roof garden with shrub plants on commercial building showed the significant decrease in the heat transfer by the roof in peak times as saving of 15% in annual energy consumption and 79% in the cooling load and 79% in the peak load (Wong et al., 2003). The preliminary study of greenery surface temperature was lower temperature than the original roof surface as 18 °C (Nyuk Hien, Puay Yok, & Yu, 2007). In 2014, Singapore had the additional study both shrub albedo (SA) and evapotranspiration rate (ET) on the reduction of mean radiant temperature in the rooftop greenery measurement (Liang, Hien, Yok, & Kardinal, 2015).

In Hong Kong, the government had the best practices of modern green roofs which implemented in green and innovation buildings (Zhang, Xie, Zhang, & Zhang, 2012) and it has been gained widespread popularity since 2010 to 2014. The simulation program of the traditional Bowen ratio energy balance model (BREBM) and a recommend solar radiation shield effectiveness model (SEM) were used to investigate the thermodynamic transmission in green roofs (He & Jim, 2010). The study of 1400 green rooftops on high-rise housings indicated that the shortwave radiation was the main variable on energy balance of rooftop greening and the available doubling of water in the soil could bring the halving of heat storage (Tsang & Jim, 2011). The comparison of the contrasting photosynthesis-transpiration physiology of C3 and CAM herbs explained the differences of Heat-sink and indoor temperature effect (Jim, 2014c).

In Taiwan, firmly confidence in the implementation of green roofs brought up since 1978 by the Department of Economic Development. Lack of maintenance requirement of intensive green roofs resulted in freeze applications of roof garden. Since, the potential of energy efficiency, thermal comfort, life cycle cost and environmental benefits had been recognized in society. It became one of the most desirable to expand the green area (Kim, Hong, Jeong, Koo, & Jeong, 2016).



(a) Marina Barrage, Singapore (14,000 m^2)

(b) Coach Park Link Bridge at Sentosa, Skyrise greenery awards 2013

(c) NUS Education Resource Centre, Skyrise greenery awards 2013

(d) Jem, 12-storey office tower and offers 6 storeys, skyrise greenery awards 2015

(e) Park Royal on Pickering, skyrise greenery awards 2013

(f) Punggol Breeze, skyrise greenery awards 2013

Figure 1.1 Utilizations of modern green roofs in Singapore
Source: www.skyrisegreenery.com

This section illustrated the progress in the existing literatures of the performance on energy efficiency by green roofs in tropical climate that summarized in Table 1.2 In addition to study the theoretical performance of thermal, insulation effect and energy consumption of green roof, this research provides unique remarks that facilitate to understand the performance of energy efficiency of green roofs.

1.1.3 Situation of green roofs in Thailand

In Thailand, the increasing of the high intensity and solar energy input on the bare concrete and synthetic roofs especially in the summer, which the generated heat sink caused to the high temperature indoor and warm surrounding temperature in city. The lack of green space and the rising of heat temperature generated the problem of thermal comfort, energy consumption and UHI effect. One of solutions to reduce to the upstream of UHI in city is green roofs innovation. The ability of passive cooling on green roofs related to thermal benefits that necessary for the architectural design in tropical climate, Thailand.

Nevertheless, the analysis on thermal performance of greenery roofs in Thailand. It is not widely prevalent and the research and information of green roofs can be difficult to access. The mentioned of limitations on green roofs in Thailand are several disadvantages. Most restrictions were discussed by the researcher, project owner, architect and landscaper which are the initial cost and maintenance costs of green roofs. However, the opportunities to come up green roofs to widespread in Thailand locally are the trend of green design, the subsidy of government, the heat stroke in summer, the lack of green space and the UHI in massive city.

Thailand's neighboring countries were widely adopted green roofs technology and their carried out some quantitative data. However, the difference data in vegetation species, construction materials, location and microclimate are significantly limitation. These results are not directly related with the climate and environment of the city in Thailand. Thus, the research and measurement related to energy performance of the green roofs should be carried out in this location.

Table 1.2 Studies relate to green roof model outstanding in recent years.

Authors	Investigate target	Heat conductivity	Boundary
(Alexandri & Jones, 2007)	Substrate moisture and temperature of nodes	f (Substrate moisture)	The steady of temperature for internal (20 °C)
(Takebayashi & Moriyama, 2007)	Evaporation and substrate moisture	f(Substrate moisture), logarithmic	Monitor of indoor temperature
(Sailor, Hutchinson, & Bokovoy, 2008)	$T_{substrate–surface}$	Assume constant	The conduction transfer function (CTF)
(S. Ouldboukhitine, Jaffal, & Trabelsi, 2011)	$T_{substrate–surface}$	f(Substrate moisture), linear	Roof support temperature
(Tabares-Velasco, Zhao, Peterson, Srebric, & Berghage, 2012)	$T_{substrate–surface}$, heat flux, net radiation	The assumed constant	Bottom substrate temperature
(Djedjig, Ouldboukhitine, & Bozonnet, 2012)	$T_{substrate–surface}$	f(Substrate moisture), linear	Bottom substrate temperature
(P. Chen et al., 2015)	$T_{substrate–surface}$	f(Substrate moisture), linear	Boundary condition

Source: (P. Chen, Li, Lo, & Tung, 2015)

Table 1.3 Researches related to the study of thermal performance on green roofs in tropical climate.

Authors	Countries	Descriptions	Assumptions	Results in thermal performances
(Hien et al., 2003)	Singapore	Intensive	The study of the direct and indirect thermal affects on rooftop gardens in the tropical	The maximum temperature was decreased as 30°C, differenced as 4.2°C and the mean radiation temperatures (MRT) were 4.05-4.5°C, The maximum variation in afternoon was 109W/m^2
(Wong et al., 2003)	Singapore	Intensive	The study of reduce the heat on the building and study the cost-effective in cooling energy	The reduction of energy consumption around 1–15%. Saving in the peak space load of 17–79% and 17–79% in the space cooling load
(Nyuk Hien et al., 2007)	Singapore	Extensive	The study to analyze four of green roof systems to investigate the differences of thermal performance in tropical conditions	The reduced of heat flux by roof structure over 60% of heat gain.
(Liang et al., 2015)	Singapore	Semi-intensive	The study to quantify of rooftop and analysis of tmrt and study model to tmrt	t_{mrt}, t_a and t_s on rooftop was lower than above the concrete roof. The regression modeling of ET, SA and t_{mrt} were used 525 data points. The t_{mrt} prediction model with 150 data points was investigate.
(Feng, Meng, & Zhang, 2010)	China	Extensive	The study to energy balance and analysis energy outgoing and incoming pathway of extensive green roofs	The convection of plants–soil made up 0.9%. The total dissipated heat 58.4% was found in the evapotranspiration, 30.9% was found in the net long-wave radiative exchange and the net photosynthesis 9.5% but transferred into the room was only 1.2%.
(Tsang & Jim, 2011)	Hong Kong	High-rise rooftop	The study of theoretical of green roof thermal performance and used theoretical estimate to evaluate the efficiency of thermal performance in green roof and analysis of energy saving	During in summer the green roof prevented the solar energy at 43.9 TJ. The storage of higher heat up to 75% in the bare roof albedo 0.30. The convection coefficient on 12- 16 can increase the heat from 24% and 45% respectively.
(Jim & Tsang, 2011a)	Hong Kong	Intensive	Analysis the thermal performance in the intensive green roof	The degree of latent heat loss through green roof leading to cooling and the tree canopy layer can decrease the solar radiation.

Table 1.3 Researches related to the study of thermal performance on green roofs in tropical climate.

Authors	Country	Description	Assumptions	Result
(Jim & Peng, 2012a)	Hong Kong	Extensive	The study of substrate moisture effect to thermal regime in extensive green roof	In rainy days, substrate-moisture affect on temperatures is only, but during the cloudy days was effect to a little.
(Jim, 2014a)	Hong Kong	Extensive	The study effect of air-conditioning energy utilization by different building thermal insulation with green roofs	Indoor space, the heat flux was reduction. However, the thermal mass and thermal capacity develop to leading the thermal-insulation with the elevated and moisture penetration in the hot days.
(Jim, 2014b)	Hong Kong	Extensive	The study effect of building thermal-insulation by green roofs on indoor thermal performance and ambient temperature	To increase the cooling, the thicker substrate and denser of leaves must be set up on buildings leading to good BTI.
(Jim, 2014c)	Hong Kong	Extensive	The study effect of heat-sink and indoor warming by extensive green roof	During the rainy and summer cloudy days, *Arachis pintoi and Sedum mexicanum* with GHE bring more the heat flux for indoor space. In summer, the extensive green roofs cannot transfer the cooling to indoor environment.
(Kim et al., 2016)	South Korea	Intensive& extensive	The study of model to the optimal green systems by estimate the energy consumption and thermal comfort	The application of the green systems to enhance 0.18–2.18% of the thermal comfort and 0.02–11.00% was decrease by energy consumption. The economic and environmental benefit was reductions up to 12.62% and 18.36% of the optimal green systems.

Table 1.3 Researches related to the study of thermal performance on green roofs in tropical climate.

Authors	Country	Description	Assumptions	Result
(Liu, Shyu, Fang, Liu, & Cheng, 2012)	Taiwan	Extensive	The study of drought resistance and thermal effect measure for plants suitable to extensive green roof	Euphorbiaceae, Portulacaceae and families Crassulaceae are the plants grew well. The 35 cm of plants was high reductions of temperature and then 15, 10 cm respectively. The green leafed can the reduction of temperature more than purple/red leafed plants.
(P. Chen et al., 2015)	Taiwan	Extensive	The study of the practicability of model on thermal transfer by green roofs	In summer, the heat flux and temperature of plants roof was 4.90°C and 93.12 W/m^2 for the insulation effect.
(Takebayashi & Moriyama, 2007)	Japan	Extensive	Analysis of the surface thermal budget and high reflection roof to reduction of urban heat	The green surface, the heat flux is small due to of the large heat flux with evaporation, whereas the net radiation is large.

1.2 The classification and technology of green roofs

1.2.1 Green roofs types

Modern green roofs or green roofs types are typically divided into two main types both extensive and intensive though some researchers including the classification of semi-intensive (Y. Lin & Lin, 2011)(Yang, Yu, & Gong, 2008)(Vijayaraghavan, 2016)(Kokogiannakis & Darkwa, 2014)(Berardi et al., 2014). Figure 1.2 presented the different type of three green roofs.

Intensive green roofs are also known as living roofs or garden roofs. The distinctive attribute of intensive green roofs is plant biodiversity such as herbs, grasses, perennials, lawn, shrubs, bushes and trees. Intensive green roofs can accessible and recreational activities. It has the characteristic of depth soil, heavy weigh, high installation or initial costs, high diversity of plants and it had the high demand of maintenance requirements. Extensive green roofs are usually inaccessible. It has the lightest type of green roofs because of the relative with thin layer of soil, grow sedums and moss. The smaller plants on final layer are generally covered as vegetation, sedums, moss, herbs and grasses. It has the minimum requirement of maintenance and irrigation. Finally, Semi- intensive green roof is a combination with extensive and intensive green roofs and the extensive roofs must be represented as 25% or less of the total green area (Yang et al., 2008). Table 1.4 comparison characterizes of three main types of green roofs.

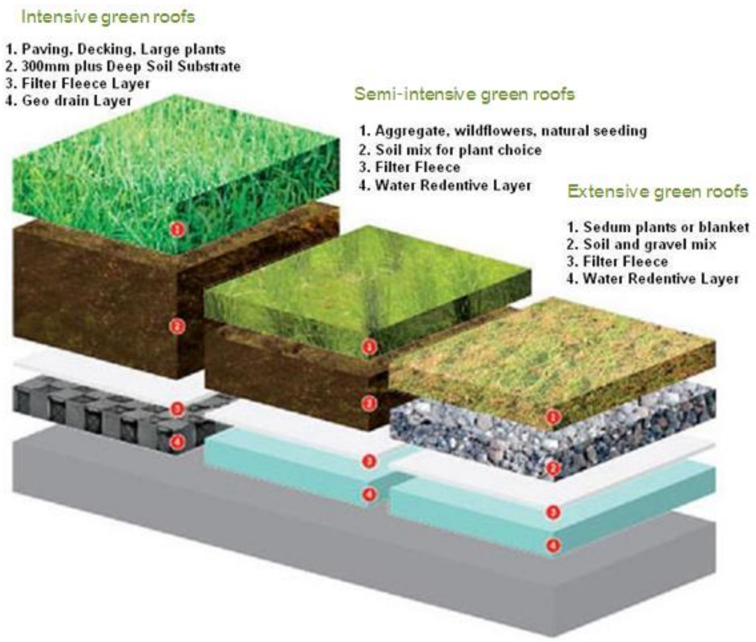


Figure 1.2 Three main types of green roofs
Source: http://www.superhomes.org.uk/resources/sedum-roof-covering/

Table 1.4 The following criteria can be divided to characterize the different types of green roofs

	Extensive green roofs	Semi-Intensive green roofs	Intensive green roofs
Accessibility	Often inaccessible	May be partly accessible	Usually accessible
Maintenance	Low	Periodically	High
Irrigation	No	Periodically	Regularly
Communities of plant	Moss-Sedum-Herbs and Grasses	Shrubs and Grass-Herbs	Perennials, Trees and Shrubs
Diversity of plant	Low	Greater	Greatest
The height of system build-up	60 - 200 mm	120 - 250 mm	Underground garages 150 - 400 mm
Weight	60 - 150 kg/m^2	120 - 200 kg/m^2	180 - 500 kg/m^2
Costs	Low	Middle	High
Use	The ecological to protection layer	The designed of green roof	Park like garden

Source: (Berardi et al., 2014)(International Green Roof Association, 2016) and modified from author

Characterize of green roofs depending on specifically context area in other countries which have differentiating factors. There are consisted of availability on climate condition, location, customer requirements, structural rooftop, materials, policy, plants and cost. Each type of green roofs is different characteristics depending on their applications and defining each country. It can be summarized into main three categories according to table 1.4.

1.2.2 Structure of typical green roofs components

In contrast to climatic conditions, local thermal efficiency regulations, environment and user expectations in each country offer different green roof components (Hui, 2011). Figure 1.3, presented green roof layers generally comprise of a root barrier, followed by protection layer, drainage element, filter fabric, growth substrate, and vegetation materials (Bianchini & Hewage, 2012a)(Rincón et al., 2014), other components and accessories below green roofs can be insulation layer, waterproofing membrane and roof deck or roof concrete. Table 1.5 described the performance of key elements of a green roof system.

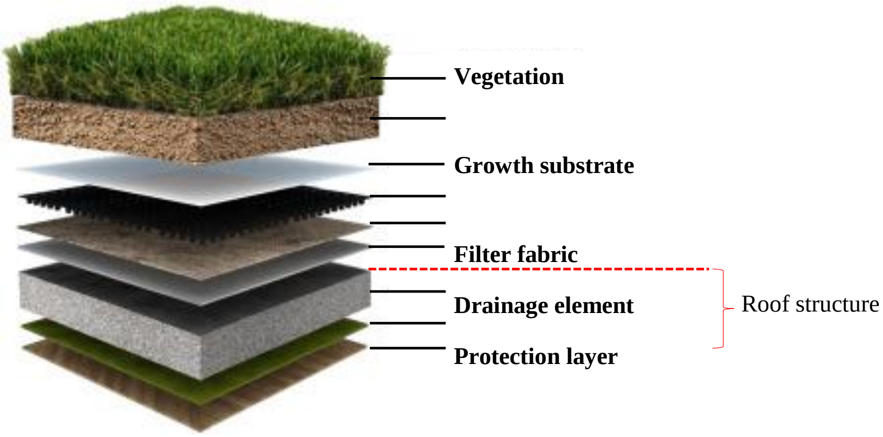


Figure 1.3 Schematics of green roofs components Source: (Vijayaraghavan, 2016)

Table 1.5 functions and performance characteristics of other layers on green roofs

Component layers	Functions (Vijayaraghavan, 2016)(Bianchini & Hewage, 2012b)	Characteristics (Hui, 2011)
Vegetation	The physical specific of plants affect on the environmental contribution as esthetic, environmental friendly, reduce effect heat from urban, improve air quality, recover the green space, increase the biodiversity, decrease storm water runoff and evapotranspiration processes. It provides an accessible space.	- Appearance of plant - The diversity species of plant and traditional species - Perennials - The pattern of water consumption - The tolerance of environmental - Free from weeds, diseases and pests
Growth substrate	This layer leading to performance thermal and water retention. Additionally, bring the space to plant roots to strengthen, to resist wind force and other the weather situation. The thickness of the growing medium associate to the plants and should be the weight balance with the performance.	- Weight (kg/m²) - Tolerance to wind, water and erosion - Appropriate water retention and supply nutrients
Filter fabric	A geotextile or mat maintain water to runoff control, keep the growing medium and delays the runoff water in the city's storm water sewage system to establish the performance of drainage layer and maintain permeability	- Effective of pore size (m²) - Weight (kg/m²) - Tensile strength (kN/m²) - Flow rate under hydraulic head of 10 cm (l/s/m²) - Penetration force (N)

Component layers	Functions (Vijayaraghavan, 2016)(Bianchini & Hewage, 2012b)	Characteristics (Hui, 2011)
Drainage/ storage element	A water retention capacity of drainage protects to a certain extent. It can drain the excess water and protects the root barrier from growing medium. Made of light, thin and flexible materials as polyethylene, polypropylene, polymer and gravel.	- Weight [dry] (kg/m²) - Water storage capacity (l/m²) - Filling volume (l/m²) - Flow rate (l/s/m²) - Compressive strength (kN/m²)
The protection of layer	A geotextile blanket is typically thickness between 2-12 mm, bring an additional analysis to retain water; prevent the waterproof membrane in the installation time.	- Tensile strength (kN/m²) - The water storage capacity (l/m²) - Thickness (mm) - Weight [dry] (kg/m²) -
Root barrier	The first layer above roofing or traditional materials which provided a waterproof membrane to the roof, It is essential to protect the building structure from plant roots and upper layers and protect water leakage problem. The membranes of root barriers are different materials both physical and chemical.	- Elongation to break (%) - Density (kg/m^3) - Tensile strength (N/mm²) -

1.2.3 Classification of technical aspects of built-in and modular green roofs

According to the versatile construction processes and techniques, green roof can be separate into two type as built-in green roofs and modular green roofs. A comparison of two systems explained in table 1.5 and modular green roof systems are commonly built in the tray or blanket (see in Figure 1.4). The modular system consisted of the drainage or irrigation systems, substrate or media and plants. It can be grown outside the roofs and interlock or set on the existing roof. The main components of modular roofs included all elements of green roofs module as drainage and coverage plant systems. Generally, the functions of modular systems are simplicity design, simple installation, time-saving construction, modification and adjustment after installation simply.

Table 1.6 The comparison of built-in and modular green roofs systems Source: (Hui, 2011)(Berardi et al., 2014)

Issue	Built-in green roofs	Modular green roofs
System	Installation as a series of layers	Prefabricated off-site and pre-grown in nursery
Period	Generally require a longer installation	The installation was require a shorter
plants	Higher complex and permanent	The modular design and sub-divided into standard interchangeable parts
Installation	On-site installation & growing	Made flexible or firm (metal or recycled plastic) trays
Components	Separate installation of green roof components	The essential components of the system already combined
Plants	Biodiversity of plant	Type of plants may be limited
Maintenance	Complexity of maintenance	Simple of maintenance
Cost	High	Low
Contractor	Use various subcontractors for design and installation	Use not many subcontractor
Weight	Generally high	Generally light

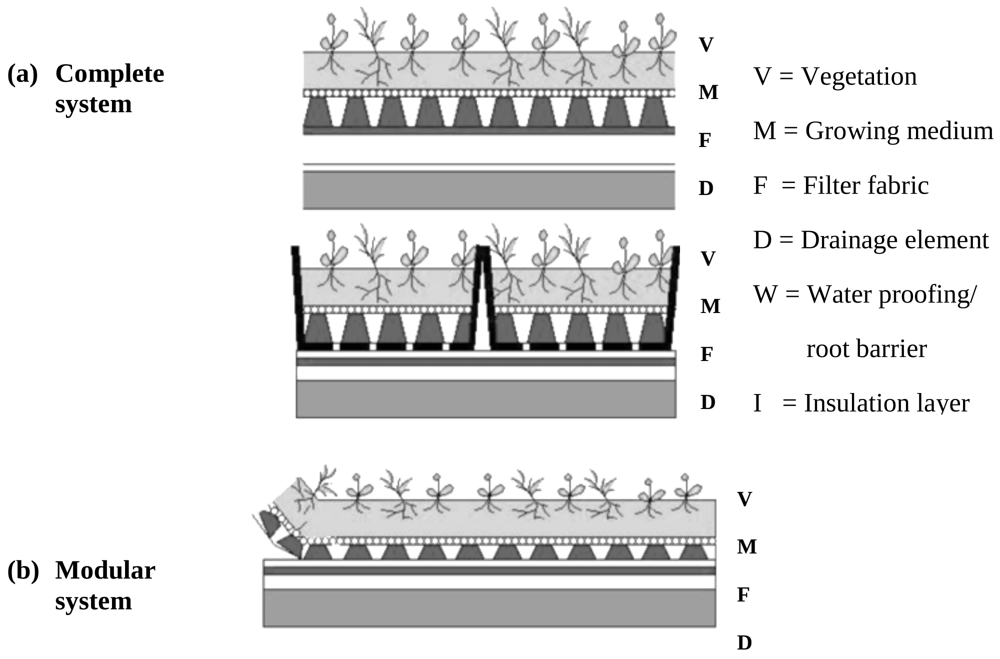


Figure 1.4 Types of extensive green-roofing (Oberndorfer et al., 2007)

1.3 The contribution of thermal transfer on green roofs

Several researches was analyzed the energy balance of green roofs in different regions. Vegetation and soil substrate help improving the energy balance in both sensible and latent heat flux. Sensible heat flux is a convection process and latent heat flux is on evaporative process. The combination of the conduction and the radiation in green roofs transfers heat into soil substrate and vegetation surfaces (Berardi et al., 2014).

An inertial mass in soil and foliage substrate reduces the dynamic of thermal transmittance. It results in high time lag and high thermal capacity. Foliage produces some heat energy for the photosynthetic process while the convection benefit of shading device from foliage prevents heat transfer exchange. Soil and foliage substrate provide cooling from evaporative and evapotranspiration process.

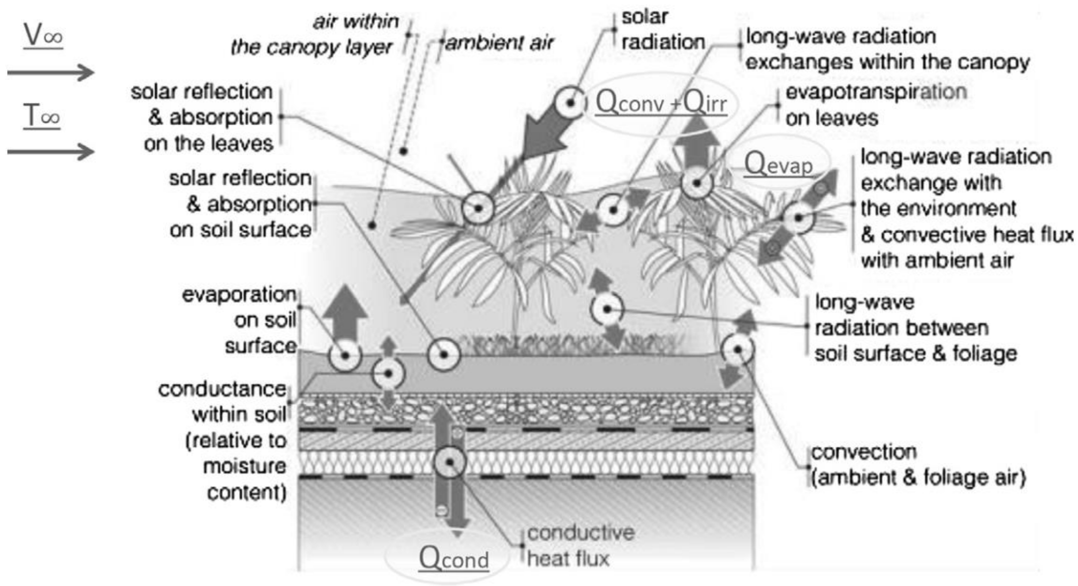


Figure 1.5 Contribution of heat transfer in green roofs (Berardi et al., 2014)

In essence, many researches occur in evaporation, dehydration and the heat transfer through green roof can be summarized that the growing of green roofs is effective in term of reducing heat transfer to buildings during summer time around 70-90% and 10-30% during winter time. The efficiency will be increased by 3% when growing both leaves and roots (Blank et al., 2013).

Yaghoobian and Srebric indicated that the influence on energy performance is different. Because it depends on plant coverage, climate condition, building type, as well as material and structure of green roofs. The simulations shown that the bare roof had the maximum surface temperature higher than green roof surface around 34% in summer. The daily exposure at the bare roof surface was 32%. It was higher than the surface of the green-coated surface (Yaghoobian & Srebric, 2015).

1.3.1 Building heat transfer characteristics

Solar radiation is direct radiation, radiant energy emitted and particularly electromagnetic energy. Half of the electromagnetic spectrum comes as short-wave radiation. Shortwave radiation is normally called as visible light or ultraviolet radiation, while long wave radiation refers to infrared radiation. Mostly, solar radiation is a visible light and some parts of ultraviolet part and infrared radiation part. Normally, shortwave radiation was considered as solar radiation. Diffuse radiation is also solar radiation and it scatters from direct radiation by cloud, dust, haze, ozone and particulates in the atmosphere. The amount of short-wave radiation from sunlight on ground surface also depends on global radiation. It includes both direct radiation and diffuse radiation. Extraterrestrial irradiation is the solar intense irradiation outside the earth's atmosphere and it is also called as solar constant.

Extraterrestrial radiation affects earth's atmosphere temperature. Part of the radiation can be reflected back in the atmosphere by fog and some radiations move into the earth's atmosphere. The rest of radiation distributes and absorbs by molecules in the air, water and dust, so that the surface temperature of the earth finally increase. Normally, solar radiation particularly transfers heat transmission into environment by convection and radiation. Partially, the heat can be transferred into the earth's surface by conduction. In addition, some heat transfers generate the evaporative water at the earth's surface during night time. In general, there are three types of external heat transfer into buildings, which are conduction, convection and radiation.

1.3.1.1 Conduction is the heat transfer from molecules into molecules. The amount of heat transferred through material depends on the thermal conductivity. Highly conductive materials have high thermal conductivity. In addition, thermal conductivity also depends on the density of the material and the difference of temperature and moisture between adjacent parts of material.

1.3.1.2 Convection is a heat transfer using air movement. Hot air has low density, lightweight and higher floating. Air in low temperature room can be rotated and replaced. The heat transfer will be carried out.

1.3.1.3 Radiation is an energy transmission or emission through air space, material medium and vacuum in the form of electromagnetic waves.

Heat radiation radiates into buildings in both direct and diffuse radiation. There are shortwave and long wave radiation from sunlight. It can radiate from other objects or buildings. When solar radiation reflects on opaque surface, it will be absorbed and reflected. Part of the absorption on heat radiation will cause higher temperature materials. Other parts will transfer to environment by radiation, convection and conduction. Actually, those processes depend on surface properties and material absorption.

Reflectivity is an optical property of material. It describes how much light can be reflected from the material in relation to the amount of light incident on the material. The reflection always occurs on each material surface, the light-diffusing (translucent) materials as well also depend on volume of the material.

Emissivity can be defined as the energy ratio. It can radiate from material's surface to that radiated from a blackbody (a perfect emitter) at the same temperature and wave-length and under the same viewing conditions. The emissivity of the material surface is effective in emitting energy as electromagnetic radiation or thermal radiation. Thermal radiation also includes visible and infrared radiation.

1.4 Environmental benefits of green roofs

The difference types of green roofs results in the difference of environmental benefits for example material substrate, soil depth, plant type and climate condition. Normally, the previous research extensively analysis the environmental benefits. Many researchers analysis the energy consumption reduction, the improving of urban heat island, the reduction of air pollution mitigation, the benefit of water management, the reduction of sound absorption and the ecological preservation. The demonstration of environmental benefits on green roofs from relevant research can be summarized as follows in Table 1.7

Table 1.7 Researches relate in the environmental benefits of green roofs.

Environmental benefits of green roofs	Source
Efficiency of energy consumption	
Decreasing cooling and heating loads	(Klein & Coffman, 2015) (Berardi et al., 2014)
Improved air temperature	(Peng & Jim, 2013)

Environmental benefits of green roofs	Source
Reduction of Urban heat island effect	
Decrease of the urban heat island effect	(Vanuytrecht et al., 2014)(Li & Norford, 2016)(Getter & Rowe, 2006)(C.-F. Chen, 2013)(Santamouris, 2014)(Vijayaraghavan, 2016)
Reduction of carbon footprints	(Berardi et al., 2014)(Häkkinen Tarja, 2012)
Mitigation of air pollution	
Improved urban air quality	(Mentens, Raes, & Hermy, 2006)(Vijayaraghavan, 2016)(Hiremath, Balachandra, Kumar, Bansode, & Murali, 2013)(Klein & Coffman, 2015)
Mitigation of air pollution	(Clark, Adriaens, & Talbot, 2008)(Clark et al., 2008)(Currie & Bass, 2008)(Gagliano, Detommaso, Nocera, & Evola, 2015)
Decrease of water management	
Stormwater management	(Gregoire & Clausen, 2011)(Zhang et al., 2012)
Enhanced water run-off quality	(Czemiel Berndtsson, 2010)
Improved use of rainwater	(Berardi et al., 2014)
Enhancement of urban hydrology	(C.-F. Chen, 2013)(General Services Administration, 2011)
Efficiency of sound absorption	
Sound insulation	(Vijayaraghavan, 2016)(Connelly & Hodgson, 2013)
Noise absorption	(B. S. Lin et al., 2013)
Improving of ecological preservation	
decrease of habitat	(Van Mechelen, Dutoit, & Hermy, 2015)

Environmental benefits of green roofs	Source
Biodiversity and landscape	(Van Mechelen et al., 2015)(Mechelen, Dutoit, & Hermy, 2015)

Green roofs are effectively in the difference reducing of indoor and outdoor air temperature (Chan & Chow, 2013) and the improving of the energy consumption in buildings both warm and cold climate (Gagliano et al., 2015). It also plays an important role in the insulation for building but the benefit of green roofs more than insulation materials (Rincón et al., 2014). In tropical climates, green roofs are evidently contribute both cooling ventilation and passive ventilation (B. S. Lin et al., 2013). It also decrease the high outdoor temperature and prevent the direct impact from solar radiation. The substrate of green roof layers provide both shading and cooling. It have potentially protect the influence of solar radiations from surrounding (S. E. Ouldboukhitine, Belarbi, & Sailor, 2014).

In extreme conditions, Klein and Coffman explained that the temperatures above concrete roof established higher readily than green roofs. Those plants are native plant species and its provide high potentially of evapotranspiration rates in community (Klein & Coffman, 2015).

A previous study in Hong Kong's tropical climate investigated the efficiency of intensive and extensive green roof benefits that influences on the thermal comfort in building and neighborhood in microclimate scale. In particular, the covering both green roofs reduced the footprint of resident and low rise building in neighborhood area. It can generated the cooling air temperature at the pedestrian in urban level. Intensive green roofs can reduced the ground surface temperature at 0.5–1.7 °C that higher than extensive green roofs (Peng & Jim, 2013).

Table 1.8 Comparison of energy consumption reduction in tropical climates (Berardi et al., 2014)

Weather atmosphere	Observations for reducing energy consumption
Warm climates	Protection of direct solar radiation Providing shading for building Reducing surface temperature variations and decrease indoor temperatures and temperature stability.

Weather atmosphere	Observations for reducing energy consumption
	Reducing the maximum of indoor air temperature Reducing the energy consumption of air condition
Tropical climates	Reduction the difference of daily temperature variations
Arid climates	Increasing the efficiency of reducing outdoor temperature and internal temperature Reducing the air conditioner energy load
Subtropical Climates	Effectively decrese the high ambient air temperature

The review of others benefits of green roofs has been described in Chapter III such as emission from the production process, improvement of air quality, reduction of CO_2 emission, approaches for habitat creation, mitigation of urban heat island effect in city, reduction of infrastructure improvement, reduction of flood risk, provision of recreational space and increase surface function and Aesthetics (see in chapter III Environmental benefits of air plant green roofs in hot and humid climate)

1.5 Variables of architectural design

1.5.1 **Climate**

Climate and site are the main variables that affect to the architectural design. Contexts of climate condition in each area result in the different architectural pattern. With that reason, the design guidelines should be analyzed and evaluated climate and site variables. Climate variables consist of solar radiation, air temperature, relation humidity, precipitation and air movement.

1.5.1.1 Solar radiation

Solar radiation is the main variable that affects buildings and locations directly. The reflection of solar radiation and solar geometry in location influences the surrounded environment.

- Solar radiation or insolation includes;
  - Direct radiation
  - Diffused radiation
  - Reflected radiation
- Solar Geometry, the solar trajectories analysis allows the designer to control sunlight into building. As a result, the designer should know angle, altitude and angle of the bearing. It can be calculated from the sun chart at latitude

in winter solstices (June 21) and summer solstices (December 21). It was calculated from equation 6.

$$\text{Winter Solstices}\varnothing = 90^{o} - (\text{Latitude} + 23^{o}27')$$

$$\text{Summer Solstices}\ \varnothing = 90^{o} - (\text{Latitude} - 23^{o}27') \quad (6)$$

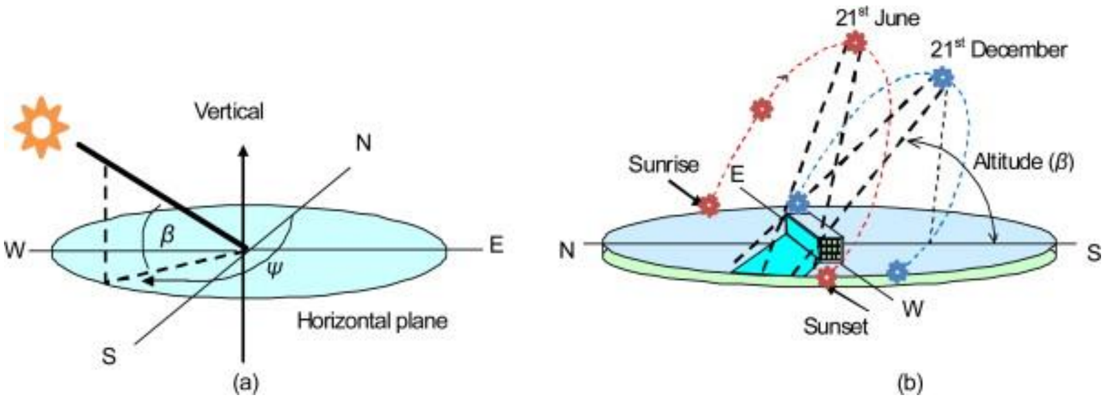


Figure 1.6 Solar altitude and azimuth (a) and solar trajectories on 21 June and 21 December (b).

Mean Radiant Temperature (MRT) can be measured by the average thermal radiation. It includes direct sunlight that influences the environment and temperature from heat radiation. It can be calculated from the surface temperature of each side of the building. It uses solid angle between the measured positions and the boundaries of each surface. The average surface temperature is the MRT. The operating temperature is the average of the room temperature and the average temperature of the surface. MRT is the value of surface temperature that affect the comfort and measurement results in terms of operating temperature. There are average room temperatures and surface temperature.

The measurement of MRT was conducted using globe thermometer. It is a round bronze ball and painted black with a small round hole. The thermometer is inserted in the center of the ball. This thermometer is read out as operative temperature or globe temperature. MRT affects thermal comfort more than air temperature as 40 %, if the air temperature rises by 1.4 ^{o}C and MRT decreased by 1 ^{o}C. The thermal sensation will remain the same. MRT value will depend on surface temperature and solid angle.

MRT can relate to human sensation and human perception. Hence, the MRT measurement is delicate and difficult to measure. MRT can measure and calculate from equation 7.

$$MRT = Tg + Kg * V^{0.5} * (Tg - Ka) \quad (7)$$

Tg = Globe Temperature

Ta = Air Dry Bulb Temperature

V = Air Velocity

Kg = Convection Coefficient of Globe as Follows:

1.5.1.2 Air Temperature

Temperature is a fundamental measure of human comfort. It is a primary design variable. It helps in dealing with effects of humidity, sun and wind. The effect of external air temperatures result in the comfort of user behavior. Generally, the thermal comfort is approximately 20-26.6 ^{o}C (Tanit Jindawanick, 2007). The range of thermal comfort may be different or can be conFigured such as ASHRAE. It determines a temperature range from 22.2 to 26.1^{o}C for thermal comfort.

If the temperature is below than the comfort level. The body will lose the heat from the body by convection and heat radiation. The design needs to know the basics of air temperature. It needs to analyze the term, which consist of annual curves, diurnal temperature swing, heating & cooling degree-days and bin data.

- Annual curves
    - Monthly mean temperature
    - Average daily maxima & minima
    - Record high & low temperature
- Diurnal Temperature Swing is the difference value between day-time and night-time temperatures. These showed monthly throughout the year.
- Heating & Cooling Degree-Days is a pointer to the period of ambient temperature outside comfort zone and the estimating of the heating and cooling load system.
    - Degree-Days are the sum of the differences between the outside air temperature and the design base temperature.
    - Degree-Hours is the sum of the difference in air temperature and the base temperature at the hour.
- Bin data is the number weather hours in every 5 ^{o}C

1.5.1.3 Humidity and Precipitation

Humidity is the amount of water vapor in the air. It can be measured in two types.

- Absolute humidity is the amount of water in the air. The unit is the weight of water in pounds per weight of air.
- Relative humidity (RH) is the percentage of air vapor when compared to the maximum amount of water vapor in the air. If the relative humidity is 100%, the air is saturated so that the steam cannot absorbed air vapor. If the weather is cool, it will be condensed into rain, snow or fog.

Relative humidity directly affects to human comfort. It is important in hot and humid condition. The low humidity makes dry condition and comfortable skin. On the other hand, high humidity makes the body feels hot. As a result, the heat loss process of evaporation can be difficult. If high humidity cause sweat on skin, it will be difficult to evaporate. In addition, moisture also contributes to the growth of mold and lemongrass. The relative humidity in human comfort is in the range of 20-80%.

1.5.1.4 Air Movement

Wind is an important variable in the climate. Wind is the air that move due to the difference air pressure between two areas. It moves from high to low air pressure. Temperature is a major factor that contributes to low air pressure, based on convection theory. At temperatures over 27 ^{o}C, the hot air mass will expand, light weight and floating up resulting to low pressure. The air in the adjacent area will move into the area that provide air infiltrates to the building. It generates cold feeling.

In hot and humid climates, winds help reducing air humidity. In hot dry weather, wind help in water evaporating process, cool air and increase humidity. Wind data for decision analysis includes wind direction, wind speed and wind frequency.

1.5.2 **Site**

Micro climate and location directly relates to lay-out plan and buildings. The geography and vegetation around the building directly impact human comfort and natural comfort zone in building. Plants and vegetation help transferring heat energy from solar radiation into evapotranspiration (ET) and gas. The evapotranspiration of plant provide the cooling of ambient air temperature.

The density of foliage results in the lower of indoor air temperatures than typical air temperatures. The density of leaves provides shading for building. In addition, the tree also adjusts the direction of wind movement. Leaves are the wind buffer in the open area. Moreover, tree also helps filtering dust and sound absorption. The color of flowers and leaves can refresh people’s feeling and mood.

1.5.3 **Vegetation**

The utilization of plants is an environmental element, visual elements and structure elements. Plant material directly affects to humans and environment such as the quality of the air, water quality, groundwater permeability, precipitation, climate change, weather and season. Plants influence the aesthetics to create a perspective, approach, linkage and environmental consistency. The composition of the vegetation structure determines the extent of the area, building, function and space.

The main objective of the vegetation utilizing is climate control uses to create a comfortable environment for residential and environmental surrounding. In another word, it creates a comfort zone as well as emotional and spiritual environment. Plants help creating harmony between architecture and environment. It improves cooling to the building and the surrounding environment. The outstanding of plants is a nature symbol that present emotional, symbolic and aesthetic uses.

1.6 Crassulacean Acid Metabolism (CAM) plants of air plant green roofs

The criterion of plant selection on air plant green roof had to deal with main characteristic of each species, which has ability to tolerate with tropical climatic conditions. Crassulacean acid metabolism or CAM plant has special function in adapting itself to high temperature, arid climate conditions and drought tolerance by Crassulacean acid metabolism (CAM) photosynthesis. The photosynthetic mechanism of this plant consist of two carbon sequestrations, which is similar to C_4 plants and different time of the day. CAM plants have potential in fixing CO_2 during the night-time for the photosynthetic mechanism (Rowe, Kolp, Greer, & Getter, 2014). The fix carbon dioxide (CO_2) process of CAM plant was found in Crassulaceae family. The open stomata during night time can uptake CO_2, which will lead to the reduction of the dehydration process. The photosynthesis process (Starry, Lea-Cox, Kim, & van Iersel, 2014) of CAM plants can be concluded that;

- The reaction of malic acid on carbon fixation by Phosphoenolpyruvate carboxylase (PEP carboxylase) and bacteria catalyzes bicarbonate (HCO_3^-)
- The short duration for opening stomata and absorption of CO_2 during the dawning
- The malic acid into pyruvate and CO_2 with assimilation while the Calvin cycle with closed stomata in daytime.
- The stomata opening at nightfall when malic acid has been depleted

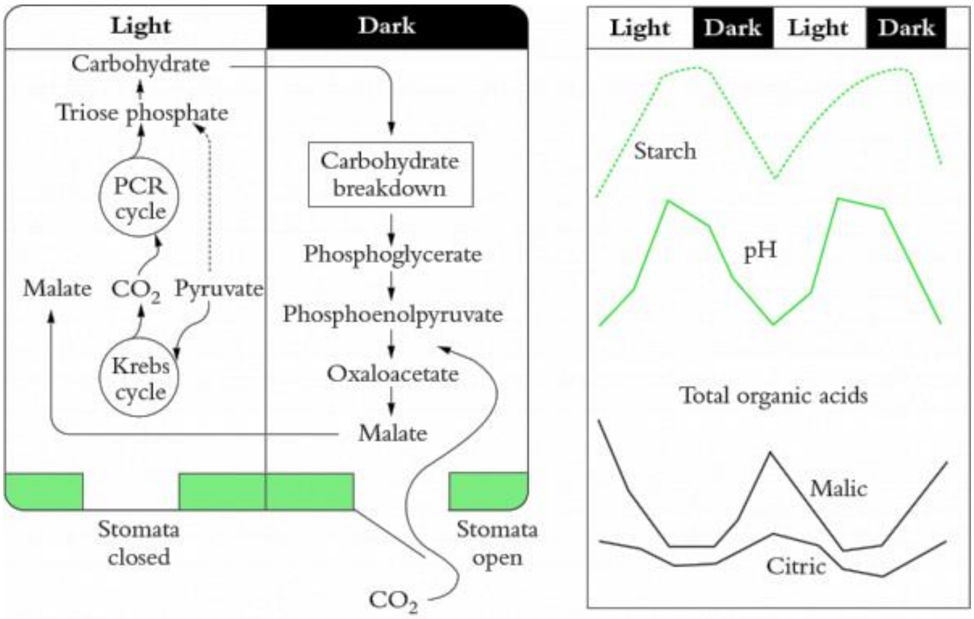


Figure 1.7 Photosynthesis of CAM plants in daytime and nighttime

Source: Singlespeed Climbing & CAM Photosynthesis, 2009

The main experimental plants are in Bromeliaceae family. Both of them are CAM plants species, the Epiphyte *Tillandsia usneoides* L. (Spanish Moss) and Tillandsia recurvifolia Hooker (Tillandsia Cotton Candy).

1.6.1 The Epiphyte Tillandsia usneoides L. (Spanish Moss)

Commonly, *Tillandsia usneoides* are also called Spanish Moss, whose family name is Bromeliaceae and xerophytic family. It is colloquially found on the branches of sparsely foliated and tree. The Spanish Moss characteristics consist of small stems, longitudinal line, rootless, soilless and air plant. The trichome leaves have silver-gray scales covering. Trichome leaves can absorb humidity, water and nutrients especially calcium from rain, air and dust in the atmosphere. Moreover, Spanish Moss can accumulate heavy metals including formaldehyde, mercury, benzene and toluene. Those metals bring benefits to decrease pollution and clean up the air in communities as well as urban areas (Martin & Siedow, 1981)(Fang, Xiaosong, Junjie, & Xiuwei, 2011).

Spanish Moss was originally found in the south-eastern of United States, Central Argentina and conspicuously widespread in Central and South America. It can be grown by hanging on a branch or structure up to 6 meters. The seeds and fragments can propagate and carry by wind, bird, insect and stick of a branch. The consideration of leaf density was carried out by calculating the weight of plant in a unit area per square meter (g/m_2) instead leaf area index (LAI) because of rootless features (Fang et al., 2011).

Figure 1.8 Tillandsia usneoides air plant green roofs (Sloping on roof structure)

1.6.2 *Tillandsia recurvifolia Hooker* "Tillandsia Cotton Candy"

Tillandsia recurvifolia Hooker (Tillandsia Cotton Candy) is a hybrid cultivar among the Bromeliad family and Tillandsioideae sub-family in the Tillandsia genus. It is hybrid parentage and colloquially that can be called as “Tillandsia hybrid” between stricta and recurvifolia hybrid. It is typically known as “air plant” which can be grown above tree and rock in flow ventilation and high sunlight. The heavily silver trichomes on plant can reflect solar radiation. It can grow vegetatively in temperature approximately 10-32 ^{o}C. It can adapt itself in tolerate temperatures as low as 5 ^{o}C and it requires high level of humidity.

Figure 1.9 Tillandsia recurvifolia Hooker "Tillandsia Cotton Candy"air plant green roofs (Sloping on roof structure)

The leaves of Cotton Candy are relatively small and frequently overlap. Its leaves are medium hardness. It has greenish and silvery grey leaves because of trichome covering, which determines the water absorbability level, moisture and nutrients from air and rainfall. Moreover, trichome helps reflecting solar radiation from sunlight. The booming flowers of Cotton Candy are rose-pink. Its root system can hang on rocks, branches and trees. The plant requires low – medium water. If it gets too much water, it will be the symptoms of rot leaf. The sun exposure of leaf requirement is bright filtered light indoors and outdoors.

Tillandsia Cotton Candy is a drought-resistant plant. The watering should be provided in less quantities in the evening because the open stomata will close during the day time as to reduce the evaporation rate. The stomata will open during nighttime for photosynthetic mechanism and fix carbon dioxide (CO_2) process. The advantages of Tillandsia Cotton Candy is that it is a drought tolerant plant, comes with an affordable price and needs low maintenance.

1.7 The analysis of economics, laws, and polices analysis

1.7.1 Economic Analysis

The feasibility analysis of the green roof economics is based on the calculation of life cycle cost of building.The selection of green roof systems consider plant types and waterproofing materials. In economics of green roof considerate the performance of life cycle material such as waterproofing life cycle of 10-20 years could be extending the duration to 50 years (Nagase & Dunnett, 2010).

Many researches was discussed the economics limitation of green roofs such as the economics of green roofs is the higher cost (Theodosiou, 2009) and mentioning obstacles such as the lack of rainfall in the southern European cities leading to the low of performance in green roof (Ascione, 2013). On the other hand, the assessment of life cycle cost of green roof in Singapore was found that green roofs could be saving 14.6% which is less than conventional roofs (Sailor, 2011). For countries in Northern Europe, the abundance of amount rainfall results to the high performance of green roof (Ascione, 2013). The advantages and limitations of green roofs can be summarized in table 1.9

Table 1.9 Economic Benefits and Barriers of Green Roofs

Economic Benefits	Economic Barriers
- Reduce energy consumption - Increase thermal insulation in retrofitting - Reduce maintenance costs of roof due to lengthening life - Reduce costs of water rain off and urban infrastructure - Improve market and price of the buildings - Increase usable surface of the building	- High construction cost - High maintenance cost, especially with intensive green roofs or when irrigation is needed Complexity of construction - Risks of failure - Expensive integration in existing buildings if adjustments to the structure are needed

Source: State-of-The-Art Analysis of The Environmental Benefits of Green Roofs (Umberto Berardi, 2014)

The problems and limitations of green roofs are caused by flooding which is caused by insufficient slopes. Lack of the drain tube and the drainage layer leading to the planting material. The problems to strong wind might be caused to lightweight of planting material. The select of plants that are not suitable to the environment. The reducing the limitations or problems of green roofs will increase the widespread in function of green roofs.

1.7.2 The laws and regulations related to green roof

Nowadays, Thailand has no law or direct policy on green roofs. There are only regulations related to the design of buildings to energy conservation. The enforcement has been to determine the type of building size, standards, and procedures for the design of energy conservation buildings in 2009. In 2013, Bangkok has set a sustainable green space in space with at least 50% of its free space green. Green spaces are characteristic of green building obviously from external context is important. Green space issues for large buildings or extra-large buildings. Thailand are required through the new urban planning in 2013 by the guidelines of expert committee's for considering report of environmental impact assessment (EIA). There are clear regulation to calculate the population in the building by determine the green area of 1 square meter per population in that area and at least 50% of the area is permanently green space and another area of water permeability. Therefore, green roofs is guidelines to use green space.

1.7.3 The policies related to green roofs in foreign countries

Policies around the world was focus on energy consumption. There is a campaign to promote sustainable architecture using green roofs (Carter, 2008). These policies generally consist of promoting of the financial incentives, tax deductions and bonus.

For Thailand, there is not clear of the policy related to green roofs. There are only policies and promoted from the other of organizations. However, the creating consciousness and options to design leading to energy-saving and reduction effect of environmental. In particular, the reducing the temperature that effect to energy consumption is an important to consideration. The relevant parties should be aware of the impact on the environment and energy saving.

Table 1.10 The examples of promote the policy of green roofs in foreign countries

Germany	Munich: The enforcement of landscaping for flat roofs to surfaces with areas> 100 m^2
	Esslingen: Support 50% of the cost on green roofs.
	Darmstadt: Support financial to green roofs.
Denmark	Copenhagen: All new of the roof constructions with a roof level below 30 ° must be landscaped with a supporting structure.
Canada	Toronto: The development of the new space has determine the area of 200 square meters. It is necessary to have a green roof covering of 20%- 60% of the roof area.
	Vancouver, BC: All new of the commercial and industrial buildings with an area of more than 5000 square meters was to require a green roof. And the operators are exempt from license fees.
	Austin, TX: Green roof density bonus to area of 8 square feet / 1 square foot of green roof.
	Chicago, IL:Support 50% of the cost or $ 100,000 to the development of green roof construction by the covering 50% or more of space on flat roofs.
	Baltimora, MA: Storm water management represents to 10% of the cost for new storm water management techniques (up to $ 10,000).
	Milwaukee, WI: The motivation in municipal areas to increase the green roof area by supporting cost $ 5 / sq. Ft.

	Minneapolis, MN: The Storm water fees of 50% for buildings that enhance of storm water management through green roofs.
	Nashville, TN: Promote of installation on green roof by reducing the drainage fee for every square foot of green roof (reduce $ 10)
	New York City, NY: Provides 1 year of tax credit with $ 100,000 (or $ 4.5 per square foot) for green roofs with at least 50% of the roof area.
United States	Philadelphia, PA: Support of credit to business taxes as 25% of all costs incurred in building green roof as $ 100,000
	Portland, OR: Support the FAR bonus, the city was provides a bonus area for each building type with an extra bonus of 3 square feet / green roof space that may be created without additional permits. And a payback of up to $ 5 per square foot for utility systems to make green roofs possible.
	Seattle, WA: Support of bonus in the area of 3 square feet / green roof.
	Washington, DC: The establishment fund of green roof with a discount of $ 5 per square foot / green roof.

Source: State-of-The-Art Analysis of The Environmental Benefits of Green Roofs (Umberto Berardi, 2014)

CHAPTER II

MATERIAS AND METHODS

2.1 Background and rational

Global warming and climate change become the international problem that need to be concerned. Architectures play an important role toward environmental problems in both direct and indirect way. Those problems include energy consumption among buildings through its lifetime. That leads to greenhouse effect phenomena by 33% of the total greenhouse gas emission worldwide. (Zhou et al., 2014) Energy consumption in construction sector as well as building maintenance also result in 40% of total energy consumption in the world. The reduction of energy can be done by applying passive design as a design approach that recognized both short term and long term environmental impacts. This strategy is important as to tackle global warming. (Ghaffarianhoseini et al., 2013).

Roof building is a part of building envelope, which receives energy from sunlight directly. The energy conservation Act 2009 Thailand regulates roof thermal transfer value (RTTV) as to prevent the influence of solar radiation, to reduce the heat transfer through roof, to reduce solar radiation and to reduce reflecting solar radiation to the atmosphere. The reducing of heat transfer rate results in thermal comfort to the indoor and outdoor environment.

Green roof is a sustainable building strategy. It can be called as green architecture, clean architecture and clean technology. This technology can share its part in reducing global warming in both direct and indirect type. (Coutts, Daly, Beringer, & Tapper, 2013) Green roof can be applied as a design guidelines, which consider to be the way to reduce an environment impact. The increasing green area in a building such as moss, plant, vegetable and tree will reduce heat storage during the daytime and will decrease heat reflection during nighttime. This phenomenon was called Urban Heat Island Effect. (Chen, 2013). Green roofs can be divided into two major categories according to the usage. Intensive green roof weighs more than 300 kg/m^2 and extensive green roof weighs extra than 60-150 kg/m^2 (Berardi, GhaffarianHoseini, & GhaffarianHoseini, 2014).

Green roofs is a natural cooling technique that creates thermal comfort for user. Commonly, the typical properties of plant and leaf are sun shade, solar radiation and solar absorption. The leaves reflectance as 10-20% of the total of solar radiation and solar absorption values as 40-80% of total values. If leaves are applied to the building heat insulation, it will reduce the amount of solar radiation and decrease the surface temperature on roof surface and building envelopment surface. The efficiency of heat transfer to the building would be decreased accordingly.

Green roofs are an effective method in easing indoor and outdoor temperature. In addition, it can reduce the load of power energy in both warm and cold weather.

Green roof yielded an outstanding experimentation result showing that they help decreasing air temperature and reducing energy consumption of the air conditioning. Green roofs can help decreasing urban heat island effected the phenomenon in city. Plant can help reducing air pollution mitigation and providing better air quality. The substrates of green roof can be sound insulation and absorption. Furthermore, green roofs also provide ecological integrity and biodiversity of species and plants.

However, the disadvantage and limitation of green roofs is that it is not economy. Intensive and extensive green roofs need firm structure support. The structure of green roofs weight higher than traditional roofs. In addition, green roofs require more maintenance in cutting, fertilizing and weeding especially drainage system that requires inspection and supervision continuously. Weather in tropical with high precipitation makes it necessary to have sloping roof but intensive and extensive green roofs have less slope roofs, it results to slow drainage. Hence, covered plant on bare roof may affect moisture. The humidity of the plant may result in high humidity that enter the building. The selected plant species should consider from various factors. It needs to be easy to maintenance and tolerates to local climate. This study aims at eliminating the limitations of green roofs which is an important knowledge to encourage more green roofs in Thailand.

This research was conducted using both Tillandsia usneoides L. “Spanish moss” and Tillandsia recurvifolia Hooker "Tillandsia Cotton Candy". Those plants in the study were air plants, with that reason, it does not require soil. Those plants are Bromeliaceae family and Tillandsia genus. The main characteristics of the two air plants are that they are drought tolerant plants, easy maintenance, lightweight and growing slowly. The leaves of Spanish moss and Tillandsia have trichome covered. The characteristic of Trichome is light white feathers covered the whole leaf that it can absorb moisture and nutrients in the air. The photosynthesis of plants is Crassulacean Acid Metabolism (CAM)

This research aims at investigating the efficiency of the reducing heat transfer through air-plant green roofs in hot and humid climates. The air plants in the experiment were Tillandsia usneoides L. (Spanish moss) and Tillandsia recurvifolia Hooker (Tillandsia Cotton Candy). This experiment were constructed in three laboratories as to compare the properties in reducing heat transfer to buildings and to collect surface temperature document. Air plant green roofs is a design guidelines toward sustainable architecture that consistent with climate change effectively in the current situation. Air plant green roofs is an important knowledge for green building in tropical climate. This knowledge can be applied in comfortably and efficiently save energy to the building.

2.2 Key word

Air-plant Green Roof, Tillandsia usneoides L., *Tillandsia recurvifolia Hooker* "Tillandsia Cotton Candy", Green Roofs

2.3 Objective

2.3.1 To investigate the efficiency of air plant green roofs that reduce air temperature in residential buildings, which situated in hot and humid climates.

2.3.2 To compare the economic between green roofs by air plants and roofs that are effective in reducing heat transfer among buildings, a case study of two types of air plants, Tillandsia usneoides L. (Spanish moss) and Tillandsia recurvifolia Hooker (Tillandsia Cotton Candy).

2.3.3 To provide green roof design guidelines by air plants for residential buildings in a humid climate for the efficiency of energy savings.

2.4 Scope of research

2.4.1 Study and do the experiment on the performance of air plant green roofs for residential buildings with sloping roofs of 30^o

2.4.2 Study on the reduction of heat transfer value of air plant green roofs through roof thermal transfer value (RTTV) and comparison with conventional roof (without air plant green roofs)

2.4.3 Study on the two types of air plants Tillandsia usneoides L. (Spanish moss) and Tillandsia recurvifolia Hooker (Tillandsia Cotton Candy).

2.4.4 Study on the fiber cement roofing materials

2.4.5 Study on mocked up temperature in close systems (Non-air-conditioned buildings) contain with the constructing of 3 laboratories.

2.4.6 Study and experiment in tropical climate, Hat Yai District, Songkhla Province during April to June. Located at latitude 6^0 55N, longitude 100^0 26E and 34 m above the sea level.

2.5 Variables in this research

2.5.1 Independent variables

- Type of air plants including Tillandsia usneoides L. (Spanish moss) and Tillandsia recurvifolia Hooker (Tillandsia Cotton Candy)
- Air gap between air plant green roofs and traditional roof or fiber cement of the air plant (air gap of 10 cm., 20 cm., 30 cm. and 40 cm)
- The density air plants green roofs (500 g/sq.m., 1,000 g/sq.m. and 1,500 g/sq.m.)

2.5.2 Dependent variables

- Roof thermal transfer value and surface temperature (^oC) and surface air temperature
    - The surface temperature of green roof (^oC)
    - The ambient air temperature (^oC)

- During the experiments, all data was collected the environmental conditions including ambient air temperature and relative humidity.

2.5.3 Extraneous variables

Extraneous variables and control variables in this study was the external environment during the experiment may be affect the variability on the efficiency of heat transfer in green roofs such as rainfall, humidity, temperature, speed of airflow, wind direction and location of the study.

Table 2.1 The morphology of Spanish moss and Tillandsia Cotton Candy

Common name	Spanish Moss	Tillandsia Cotton Candy
Scientific name	*Tillansia usenoides* L.	*Tillandsia recurvifolia Hooker* "Tillandsia Cotton Candy"
Family name	Bromeliaceae	Bromeliaceae

2.6 Materials and Methods

2.6.1 The criteria of the selection vegetation

Principle on plants selections should be tolerance in tropical climate and economic feasibility. The plant selection criteria are following in this principle.

- Air plants and low-weight due to the intensive green roof which is used the high of soil substrate that effects on weight the influence of structure.
- Tolerance on weather condition, high humidity and solar radiations
- Fairy on operation and maintenance
- Long life cycle of plant
- The plant are leaf all year
- The easy to find in the market
- The plant which is low cost

The selection of plant based on 7 criterias which is evaluated by study the data of air plant and observed from the plant was cultivated which is the grow up. Two species of air plant can be selected were Spanish moss and Tillandsia Cotton Candy.

Spanish moss and Tillandsia Cotton Candy are the CAM family which is in the daytime, the stomata in the leaves remain shut during to reduce the CO_2. When the concentration of CO_2 within the cell was increased the activity of the enzyme Oxygenase is reduced leading to lower the rate of photorespiration process. The reduced evapotranspiration plant which is the CAM family has efficiency and higher than C3 and C4 plants (Andrzej et al., 2009).

2.6.2 Study area

The study area was conducted in humid tropical climate Songkla situated at the southern of Thailand at latitude 6^0 55N and longitude 100^0 26E. The climate is dominated by the locoted troptcal monsoon which consists of summer and rainy season. The summer is February - July and the highest of temperature in April. The population of 158,218 is accommodated by the density of 12,676.05/km^2 which is with merely 20.50 km^2 of land.

Table 2.2 The document of climate condition of Hat Yai (1981–2010)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average high °C	31.0	32.7	34.2	34.6	33.8	33.5	33.2	33.1	32.5	31.8	30.4	29.7
Average low °C	22.0	22.1	22.9	23.7	24.0	23.8	23.5	23.5	23.4	23.3	23.2	22.6
Average rainy days	8.2	3.6	7.2	12.4	14.3	13.6	14.0	15.2	18.5	21.1	21.4	18.4
Average RH (%)	80	77	76	78	81	80	79	79	82	85	87	85
Mean daily sunshine hours	5.9	5.9	6.0	4.8	3.7	3.7	3.7	3.7	3.6	3.6	3.5	3.5

Source: https://en.wikipedia.org/wiki/Hat_Yai

2.6.3 Period of the study

The research on air-plant green roof for residential buildings was conducted in 3 periods:

- The study of the feasibility on economics perspective of green roofs which compared the life cycle cost of air plant green roofs which discussed and focused on internal and external costs of air plant green roofs. This period was conducted 3 mouths in Thailand and 3 mouths in university of Vienna (see in paper II and chapter III).
- The research studied an analysis of key adopting green roof factors (SWOT) in Germany (Berlin, Neubrandenburg and Hamburg), Austria (Vienna, Graz and Linz) and the cities in temperate climate. This Period was operated approximately 6 months from June until November, 2016 which it is described in paper I.
- The performance of air-plant green roof in tropical climate by the experiment. It was operated in 6 months from April-September. Due to the summer and rainny season has a constant of the climate compared to the other seasons and shown clearly the efficiency of green roofs by air plants (see in chapter IV: the performance of air-plant green roofs on thermal parameters and chapter V: the efficiency on air gab of air-plant roofs on the parameters of thermal surface)

2.6.4 Study Flow

Preparation of equipment process are following;

- Temperature Datalogger Temperature-Humidity Datalogger USB (DT-171)
- Thermocouple Type K
- Moisture Meter (DT-125H)

Figure 2.1 Equipment for study

source: http://eastern-energy.nanasupplier.com

Table 2.3 Equipment lists for the experiment

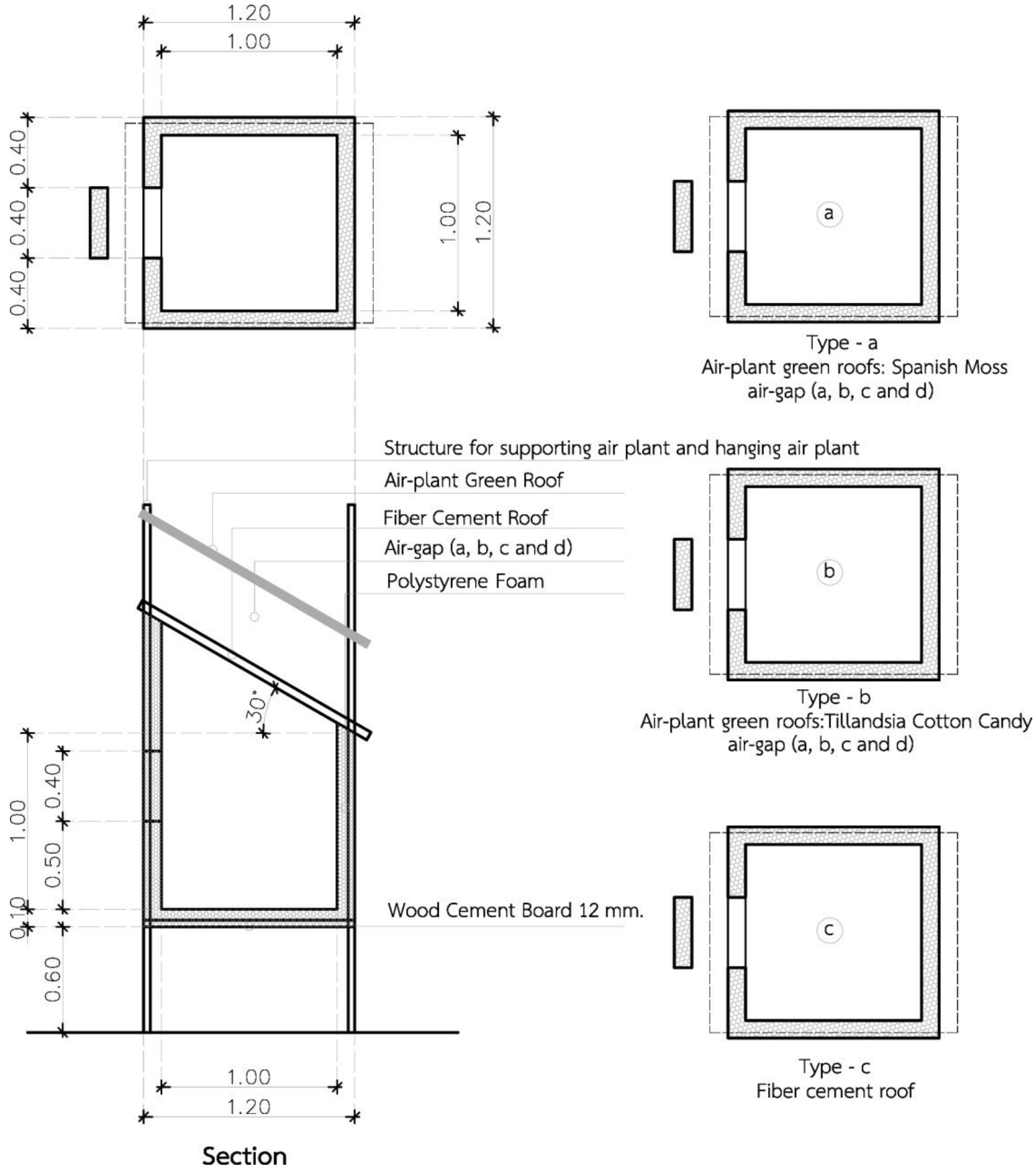
Variable	Equipment	Measurement range	Accuracy	Measure point
Temperature	CEM DT-171	-40 °C-70 °C	±0.5 °C	T1,T2,T3,T4, T5 and T6
Relative humidity, RH	CEM DT-125H	0.1- 24%	±0.05%	
Dew point(°C)	CEM DT-171	-40 °C-70 °C	25 °C (40-100%RH)	

Figure 2.2 The preparation of equipment process

2.6.5 Mockup for Temperature Testing

There are three mocked up room that were set at the experimental site. It was 1.20m (L) x 1.20m (W) x1.20m (H) used polystyrene foam (Density 1.25 lb/ft³, thickness 4 inch). The roof was fiber cement and the floor was wood cement board, which is density of 12 mm. The mocked up was closed 5 sides, as to prevent heat from outdoor. And on top of the roof double fiber cement tile and the installation of green roofs two pattern. The mockup room can adjust the air gap, which is independent variable. Experimental design of the simulation room as a closed system to reduce complication. The three control variables are the same. The walls are insulated to protect the outside influences of the laboratory, such as temperature, humidity, wind and solar radiation. The three mocked up room rooms are as followed:

- Mockup room 1(a) Green roof (Spanish Moss)
- Mockup room 2(b) Green roof (Tillandsia Cotton Candy)
- Mockup room 3(c) Fiber cement roof without green roof (control room)



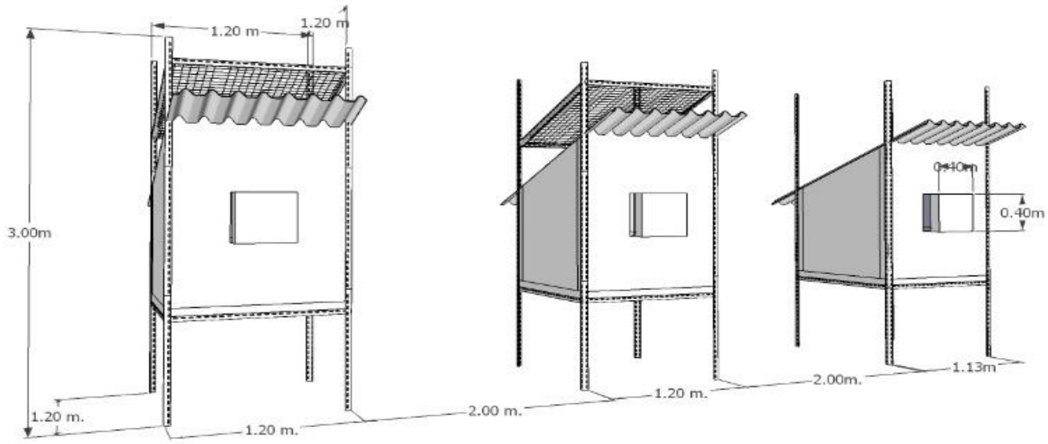


Figure 2.3 Mockup room 1(a) Green roof with Spanish Moss, Mockup room 2(b) Green roof with Tillandsia Cotton Candy and Mockup room 3(c) Fiber cement roof without green roof.

1(a) 2(b) 3(c)

Figure 2.4 Mockup room 1(a), Mockup room 2(b) and Mockup room 3(c)

(a)

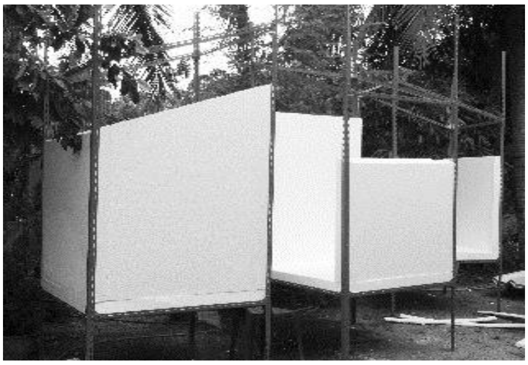
(b)

Figure 2.5 (a) and (b) Location and environment at Songkhla Inland Fisheries Research and Development Center

(a)

(b)

Figure 2.6 (a) and (b) the opening of system channel for collecting the document from data locker at surface temperature and indoor temperature



(a) (b)

Figure 2.7 (a) and (b) The construction of mockup rooms at Songkhla Inland Fisheries Research and Development Center, Thailand

(a) (b) (c)

Figure 2.8 the sizing and type of mockup room with 1.20m (L) x 1.20m (W) x1.20m (H)

2.6.6 The surface temperature for the document collecting

To study the difference of temperature in 3 mocked up rooms, some measured surface and lower temperature of green roofs was conducted by setting high and low of head position from green roof pitch 5 cm. It can be install of both green roofs at an angle of 30 degrees by facing west to be influenced by solar radiation. The location of the experiment is open space. The data collection was controlled variables and the data inside the mockup room such as humidity and ambient temperature.

Table 2.4 The position of the surface temperature for setting of temperature/K-type thermocouple data logger

	Type 1(a) Green roof (Spanish Moss)	Type 2(b) Green roof (Tillandsia Cotton Candy)	Type 3(c) Fiber cement roof
T1	The surface temperature of green roof	The surface temperature of green roof	The surface temperature of roof
T2	The lower surface temperature of green roof	The lower surface temperature of green roof	The lower surface temperature of roof
T3	The temperature in the air gap between the green roof and roof sheet	The temperature in the air gap between the green roof and roof sheet	Ambient temperature
T4	The lower surface temperature of green roof	The surface temperature of green roof	-
T5	The lower surface temperature of green roof	The lower surface temperature of green roof	-
T6	Ambient temperature	Ambient temperature	-

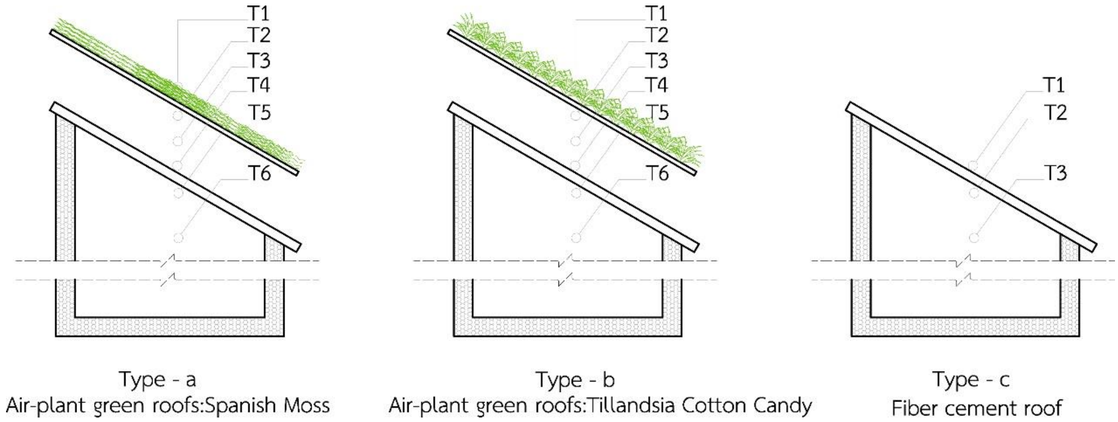


Figure 2.9 The position of the surface temperature measurement in mockup room which is temperature/K-type thermocouple data logger

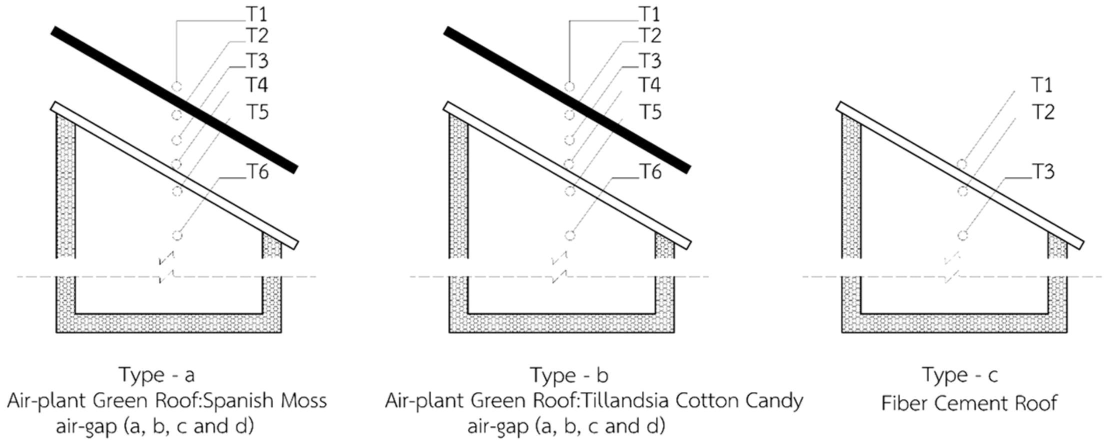


Figure 2.10 The position of the surface temperature measurement in mockup room which is temperature/K-type thermocouple data logger.

2.6.7 The experimental procedure and the data collection.

The experiment on thermal performance on green roof was divided in two experiments.

- Experiment I: to study the performance of temperature decreased on the density of air plants.
- Experiment II: to study the performance of temperature decreased on air gap of air plant.

2.6.8 Data analysis

- The field measurements was conducted on August, October and November which is collected the data from 6.00AM-6.00PM.
- The surface temperature is a major indicator and can investigate the thermal performance. The surface temperatures were measuring on rooftop which is presented in T1 by different types of green roof. (Figure 2.10)

- Air temperatures were measuring at point T6 for both Spanish Moss and Tillandsia Cotton Candy but in fiber cement roof is presented in T3. Mostly, in the day time the surface temperature was higher than the ambient temperatures.

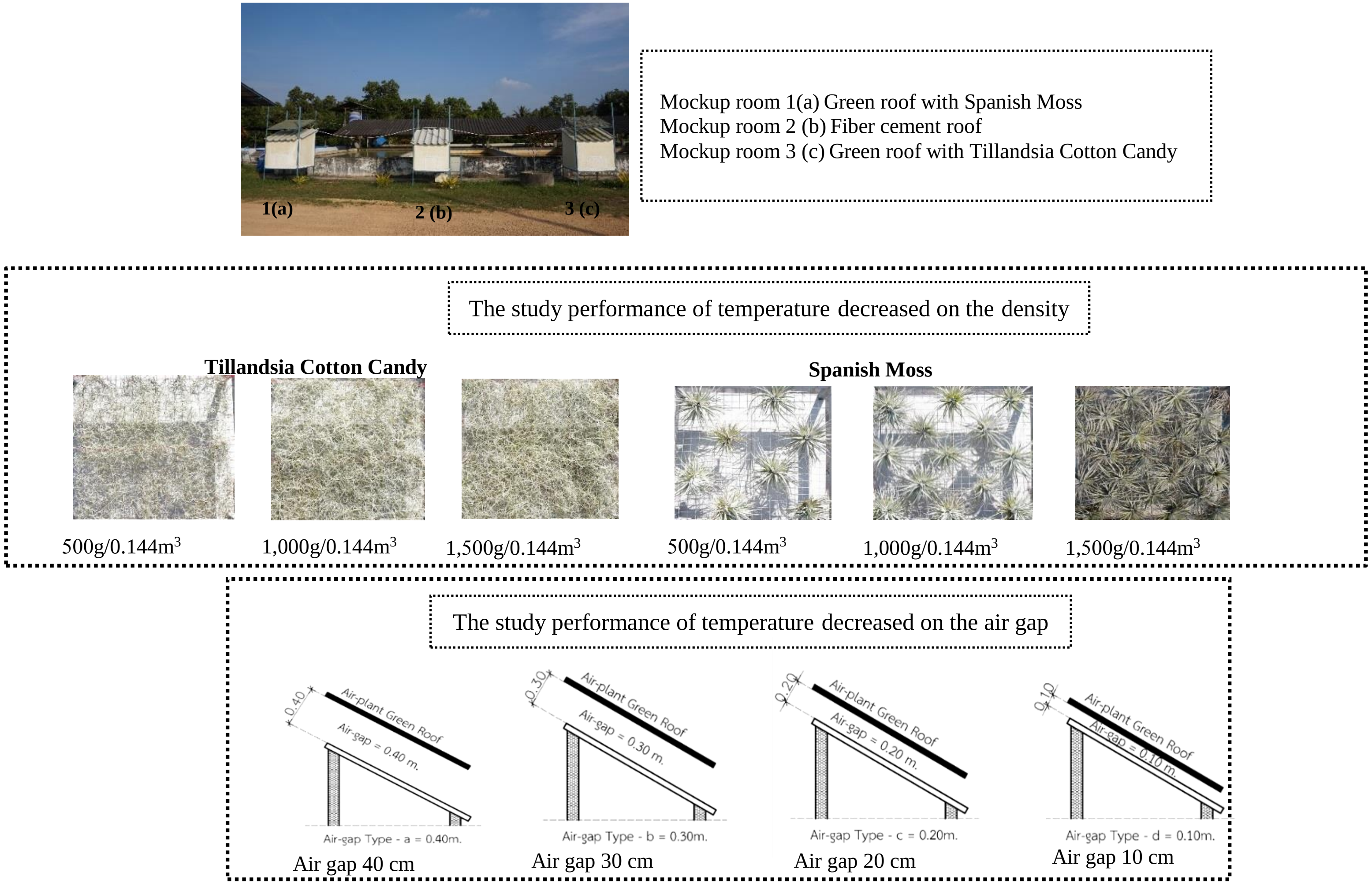


Figure 2.11 The set up and methodology

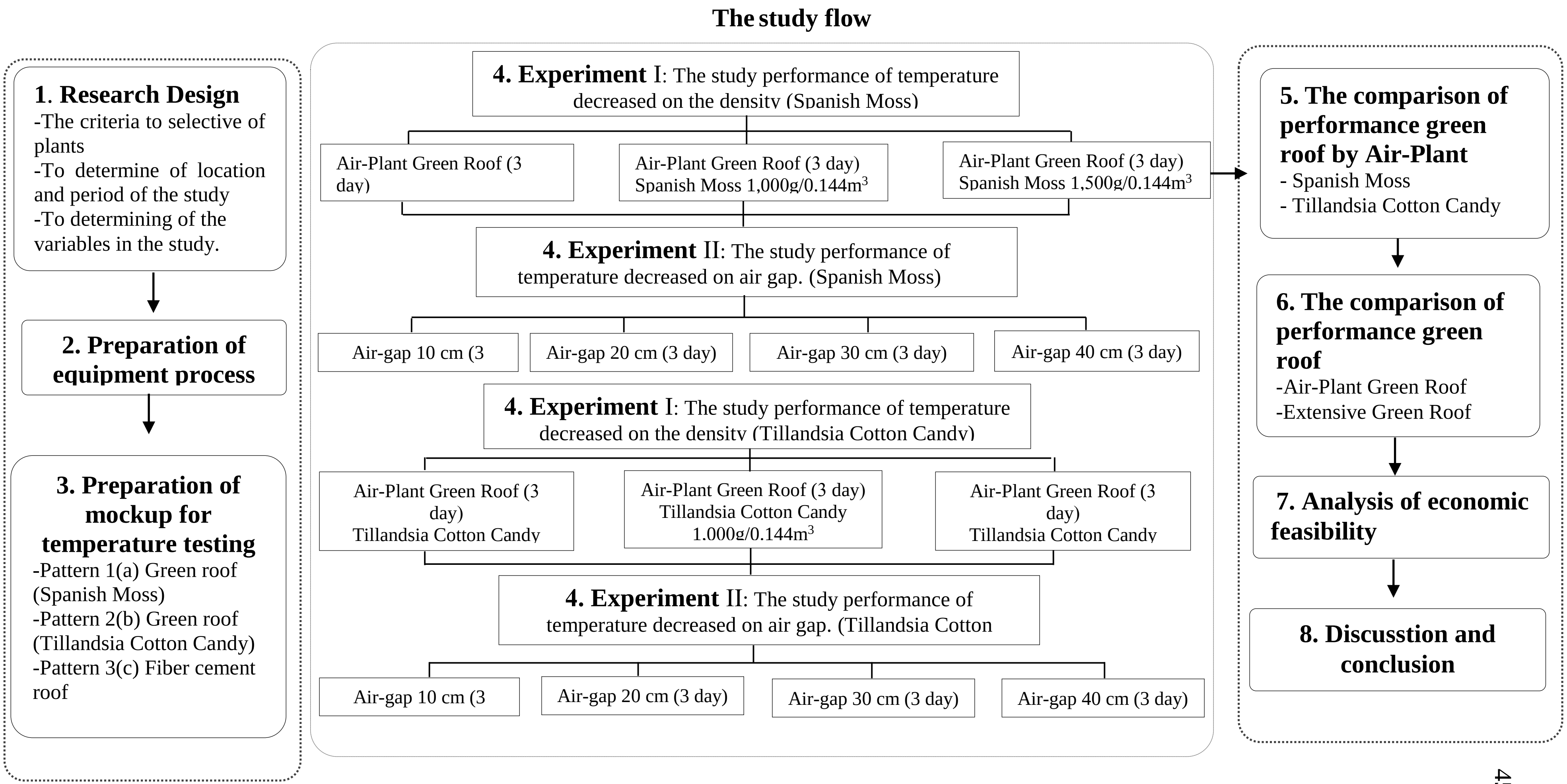


Figure 2.12 Framework of the experiment to the performance of green roof by air plants for residential buildings in hot and humid climates.

CHAPTER III

ENVIRONMENTAL BENEFITS OF AIR PLANT GREEN ROOF IN HOT AND HUMID CLIMATE

According to the study, green roofs also benefit their surrounded environment. It has been accepted as a sustainable built environment for both microclimate and macroclimate. The analysis of environmental benefits extensively considered from the emission in the production process, air quality improvement, carbon reduction, habitat creation and mitigation of urban heat island effect, reduction of flood risk, infrastructure improvement, recreational space and increase surface function for human well-being. This paper had studied the environmental benefits of intensive green roofs, extensive green roofs and air plant green roofs. The review from secondary data showed the data of environmental benefits from intensive green roofs and extensive green roofs. The environmental benefits of air plant green roofs had been measured under the similar environmental circumstance in hot and humid climate in Thailand. The Crassulacian Acid Metabolism (CAM) or xerophyte and epiphyte plants were selected and used in the air plant green roof. It was found out that those plants required less maintenance. However, two common species of CAM plants in this paper are air plants, which are Spanish moss and Tillandsia Cotton candy. With that reason, the classifications of green roofs have been represented by different environmental benefits. Therefore, the consideration of environmental benefits of green roofs is indispensability and supports the decision making for the utilization of green roofs.

The increasing number of population growth and the expansion of urbanization are continually going higher. The developments are based on the demand of human needs and satisfactions. We have learned that the development of infrastructure and agriculture may demolish our natural resources. For example, the rapid development of dwelling in Malaysian, ranked as the thirtieth of world's greenhouse gas emissions, the community had contributed energy consumption and 40% of carbon emission had defected natural ecosystems in country in the last decades.

In the meantime, the developments of construction sector and the utilization of non-renewable materials in buildings, infrastructures and public utilities result in environmental problems(C.-J. Kim et al., 2015). The increasing temperature in cities areas is believed to be the cause of urban heat island (UHI) phenomenon (Kiesel, Orehounig, Shoshtari, & Mahdavi, 2012)(Santamouris, 2014). The material of buildings, pavements and constructions (cement and asphalt) in the city reflects and absorbs heat from solar radiation (Takebayashi & Moriyama, 2007). In general, footprint of buildings in the area has similar size to the building rooftop. So, if rooftops materials reflect and absorb solar radiation, it will be the main barrier of the heat transfer to the building. The roof areas, therefore, have environmental benefits and can save up the energy in buildings. The utilizations of green roofs in cities can also help environmental issues in the current situation (Chen, 2013)(Peng & Jim, 2013)(J. Kim, Hong, Jeong, Koo, & Jeong, 2016).

The graph above shows the change of maximum temperatures for 6 months in Hatyai, Songkhla, Thailand from 2011 to 2015. According to the study, temperature in Hatyai changes dramatically over five years. In April 2015, the temperature went up to 35.29°C, which is higher than April 2011. At that time, the temperature used to be around 3.11°C. (See figureure 3.1). Hatyai generally receives most of average maximum summer temperatures in April, which is 31.4°C.

Green roofs on commercial buildings are widely used in order to support the cooling requirement that increase the efficiency of insulation in buildings and reduction of the overall thermal transfer value(Chan & Chow, 2013). Green roofs also use the technology for improving environmental quality (Lin, Yu, Su, & Lin, 2013)(Clark, Adriaens, & Talbot, 2008)(Van Mechelen, Dutoit, & Hermy, 2014) and climate change in cities (Williams, Rayner, & Raynor, 2010), urban ecosystem(Bianchini & Hewage, 2012a)(He & Jim, 2010), green infrastructure (Clark et al., 2008) and built environment(Benvenuti, 2014).

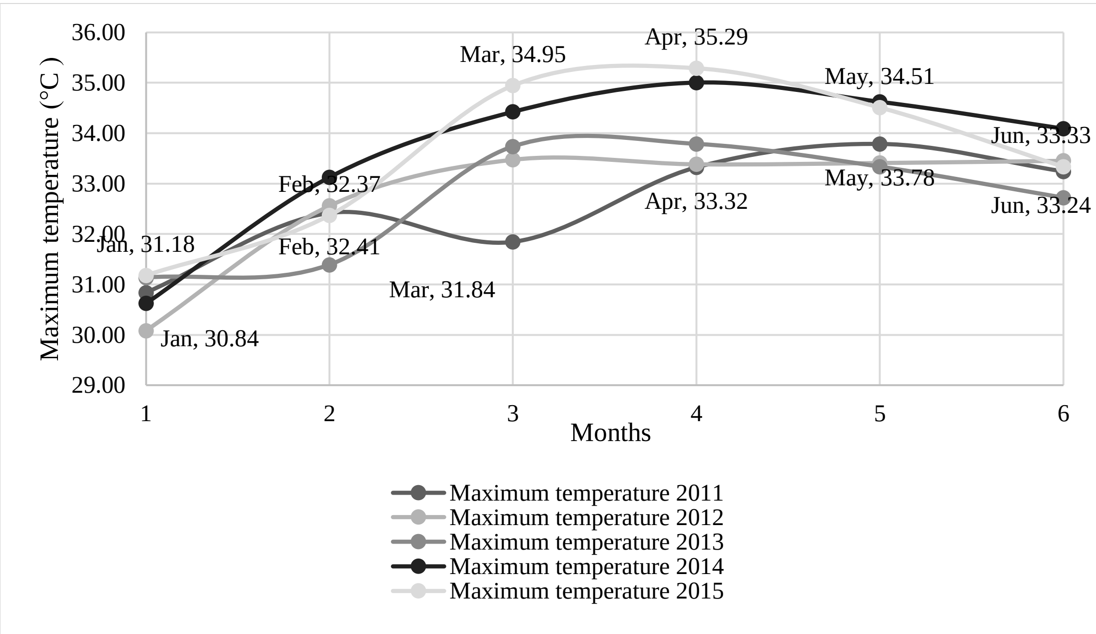


Figure 3.1 Comparision of maximum temperature in January, 2011 until June, 2015 at Hatyai, Songkhla, Thailand

The growing number of the expansion of green roofs came from environmental benefits, environmental awareness and ecological advantages (Nawaz, McDonald, & Postoyko, 2015)(Berardi, GhaffarianHoseini, & GhaffarianHoseini, 2014). Green roofs is one mitigation way for urban heat island effects(Jim & Peng, 2012). The evapotranspiration reduces heat (Poë, Stovin, & Berretta, 2015)(Marasco, Culligan, & McGillis, 2015) and mass transfers (Ouldboukhitine, Spolek, & Belarbi,

2014) due to transpiration of plants, soil and water irrigation. The characteristics of passive technique by green roofs provide the influence parameters of heat transfer and evapotranspiration are leaf area index, fractional coverage, refection coefficient and stomatal resistance (Liang, Hien, Yok, & Kardinal, 2015)(Berardi et al., 2014)(Saadatian et al., 2013).

The barriers of green roofs through lifecycle cost analysis have been discussed in various studies before(Vijayaraghavan, 2016) for example the intensive of maintenance requirement(Coutts, Daly, Beringer, & Tapper, 2013), irrigation system(Van Mechelen, Dutoit, & Hermy, 2015), construction cost (Carter & Keeler, 2008), waterproofing layer, substrate material, structure support and vegetation failure risks. Air plant green roofs have been developed and designed as to decrease several barriers of green roof in hot and humid climate.

This paper aims at studying, comparing and identifying multidisciplinary insights of the environmental benefits in air plant green roofs, both Tillandsia usneoides L. “Spanish moss” and Tillandsia recurvifolia Hooker “Cotton candy”. Furthermore, the objective of this study is trying to make a clear understanding and recognizing their potentials of environmental benefits of air plant green roofs.

3.1 An overview on Air Plant Green roofs

Sustainable development and environmental friendly are the major concepts of air plant green roofs. Air plants in the Crassulacean Acid Metabolism (CAM) have the outstanding characteristics of epiphyte rootless and xerophyte. Tillandsia usneoides L. “Spanish moss” and Tillandsia recurvifolia Hooker “Cotton candy” was chosen for the study in this paper (see figureure 3.2) . The selection criterias of air plant were considered from the qualifications of low plant weight, low construction, high weather resistance, low or zero maintenance, affordable price and convenient purchasing.

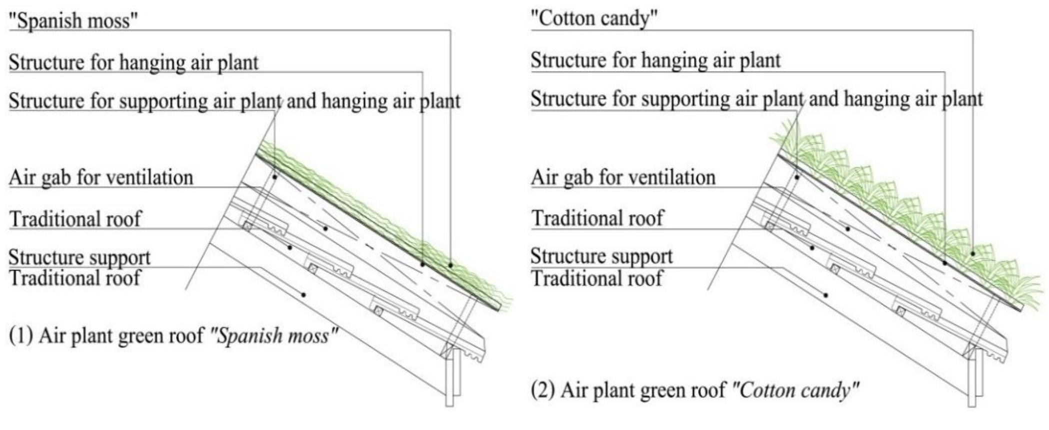


Figure 3.2 Structure of Air plant green roofs both “Cotton candy” and “Spanish moss”

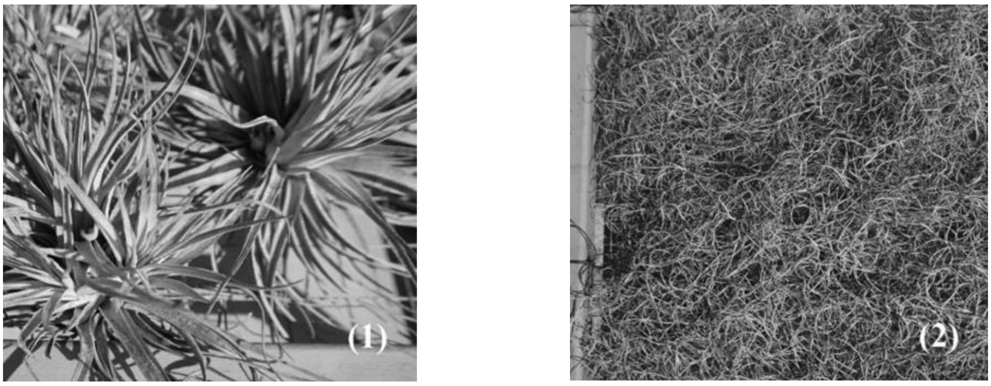


Figure 3.3 Tillandsia recurvifolia Hooker "Cotton candy" (1) and Tillandsia useoides L. "Spanish moss" (2)

The main characteristics of air plant green roofs are the thickness of growing media, which needs to be less than 10 cm. The construction technique has to be simple and easy for the installation and maintenance in both sloped roofs and traditional roofs. The weight of structures and plant should be lower than 5–10 kg/m^2. The roof is inaccessible area because of the sloped roof plant. The diversities and types of plants are quite limit because of the feature of lightweight structures, for example Spanish moss, Cotton candy and other air plants. The drainage and irrigation system are not necessary because it can be utilized with the infrastructure of the original roof. The structure of air plant green roofs includes vegetation layer (Spanish moss or Cotton candy), lightweight structure (welded wire mesh and hanging structure) and air gab between air plant and traditional roof. Air plant green roofs can be compatible with the developed techniques of modular system (see figureure 3.3). Leaf area index (LAI) of air plant depends on plant species. In this term, Spanish moss is colloquially called as air plant and grows up on hanging structures, wire or tree branch. It costs low maintenance cost because the foliage growth rate is very slow, there is no aerial roots and the length is approximately 6 m. Spanish moss requires very little water and can absorb nutrients from the ambient air and rainfall. It is in the bromeliad family and Tillandsia genus.

The main characteristic of air plant green roofs is the double roof skin, which can reduce an extreme of solar radiation and ambient air temperature. The air gab between air plant and material roof is a space for convection before entering into building. The shading of air plant can also extend the durability of roof materials.

3.2 Environmental benefits of Air Plant Green Roofs

The installations of air plant green roofs can mitigate environmental problems and build environment in communities(Zuo & Zhao, 2014). In this study, the analysis of environmental benefits consists of several principle components (See figureure 3.4). The method of this study consists of primary and secondary data. The primary data was conducted from both intensive and extensive green roofs. It can be collected from air plant green roofs of Spanish moss and Cotton candy. The environment can obtain these benefits consequently.

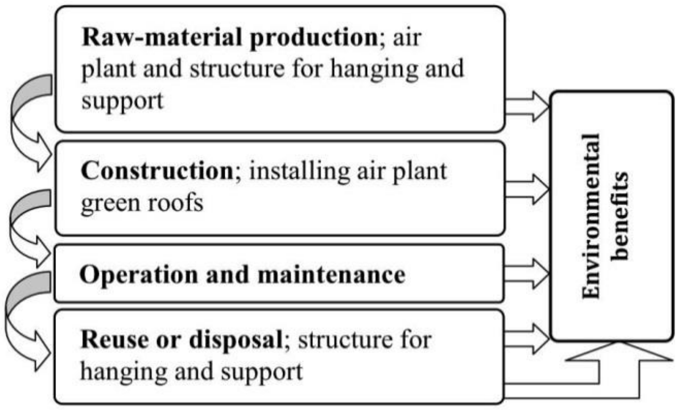


Figure 3.4 Process flow analysis on environmental benefits of air plant green roof.

Moreover, it considers from resource usage and pollution reduction through the process of raw-material production, construction, operation or maintenance and reuse or disposal (See in figurers 3.5)

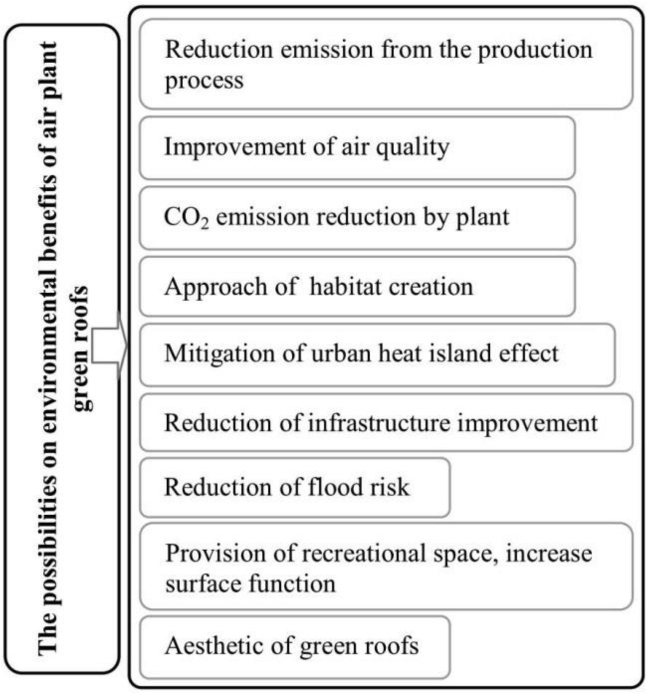


Figure 3.5 Principle components analysis on environmental benefits of air plant green roofs

Table 3.1 Data of environmental value of air plant green roofs (Cotton candy and Spanish moss) from primary data

Benefits	**Value (\$/m²)** **Cotton Candy**	**Spanish Moss**	**Type**
Emission from production process	0.0587 One time	0.0587 One time	Cost
Improvement in air quality	4.43-11.08 Annual	1.53-3.83 Annual	Benefit
CO_2 emission by plant	0.55-0.65 Annual	1.60-1.88 Annual	Benefit
Approach of habitat creation	0-10.19 Annual	0-10.19 Annual	Benefit
Mitigation of urban heat island effect	4.72-6.61 Annual	4.72-6.61 Annual	Benefit
Infrastructure improvement	7.80-25.80 One time	7.80-25.80 One time	Benefit
Reduction of flood risk	0.70-2.41 Annual	0.70-2.41 Annual	Benefit
Provision of recreational space	-	-	Benefit
Aesthetic of green roofs	8.86-13.29 Annual	2.30-3.83 Annual	Benefit

Source: (Bianchini & Hewage, 2012b)(Martin & Siedow, 1981)

3.2.1 Emission from the production process of air plant green roofs can be considered from the emitted toxic from raw-material (plant and structure), manufacturing, usage and disposal into environment. The goal of production process on green roofs is zero toxic emission. However, Bianchini and Hewage estimated the air pollution cost from different factors depending on material substrate that the total of air pollution cost for intensive green roofs is about 5.90-14.06 \$/m^2 and extensive green roofs is (polymers layer) between 14.06-22.20 \$/m^2(Bianchini & Hewage, 2012b). In this study, both types of air plant green roofs use mild steel or low carbon steel as to cover the structure, which can be reused for construction. Therefore, the related process of carbon emission depends on the source of steel and the carbon intensity of electricity generation(Birat, Vizioz, Pressigny, Schneider, & Jeanneau, 1999).

The scenario of intermediate steel industry in Thailand showed that it can reduce the emission of GHGs. It was changed due to the ecological and economic new generation arc furnace (ECOARC) during 2011-2030 (Kerdporn, Wangjiraniran, & Suriyawong, 2013). The demanded amount of covering steel structure is about 4.19

kg/m^2. Lars Mathiesen illustrated the CO_2 emissions of Asia in 1995 as 0.7 per ton of crude steel(Koo, Park, Hong, & Park, 2014) while the Kyoto protocol considered the carbon tax at 20 $/ton of CO_2 emission (Ki-moon, 2008). Therefore, the CO_2 emission cost of air plant green roofs is fluctuated around 0.0587 $/m^2.

3.2.2 Improvement of air quality, the polluted substances on green roofs are NO_2, SO_2, CO, PM_{10} and O_3(Currie & Bass, 2008). The improvements of air quality relate to the physical and mental health outcomes of the human in urban dwelling directly(Bonnefoy, 2007). Yang et al. had quantified the removal level of air pollution on green roofs in Chicago for one year that it contains of 52% of O_3, 27% of NO_2, 14% of PM_{10} and 7% of SO_2 (from 1,675 kg in 19.8ha)(Wu, Yang, Chew, Hou, & Li, 2014). Bianchini and Hewage made an estimation on the air quality improvements of green roofs by considerating the quantity of nitrate, dust and particulate in the air. This research also calculated the air quality benefits of green roofs, the result stayed between 0.025 $/m^2 and 0.03 $/m^2 (Bianchini & Hewage, 2012b). Spanish moss and Cotton candy air plant improve air quality with photosynthesizes and air filtrations from the use of carbon dioxide, toxicant, heavy metal and dust as its nutrient (Srivastava, 2012). Moreover, the toxicants in the air and water can be removed from metabolism process. The environmental benefits of air quality on air plant green roofs was estimated and considered from the amount of toxicant, nitrates, heavy metal and dust. The benefit of initial cost of air quality was about 2% to 5%. Therefore in term of production cost, benefit of" Cotton candy" is around 4.43-11.08 $/m^2 and " Spanish moss is between1.53-3.83 $/m^2.

3.2.3 The reduction of CO_2 emission by plant had different potential according to the types of the plants. According to the Kyoto protocol in 2008, it accounted for the CO_2 emission manual and also stated that Carbon tax reduction was 20 $/ton(Ki-moon, 2008). Bianchini and Hewage illustrated the intensive and extensive green roofs, which could deduct the carbon reduction tax as 1.4E-4 $/m^2 to 1.7E-4 $/m^2 (Bianchini & Hewage, 2012b). Martin and Siedow described that the CO_2 reduction by Spanish moss in daytime is approximately 25%. They also indicated a wide range of temperature, irradiance and water content. The high rate of CO_2 affected the increasing humidity rate relatively especially at night time. Consequently, 1 m^2 of Spanish moss green roofs areas can reduce the CO_2 rate about 0.0072 kg and 0.0085 kg(Martin & Siedow, 1981). Therefore, the carbon reduction benefit of both air plant green roofs can be estimated as 1.60-1.88 $/m^2 for Spanish moss and 0.55-0.65 $/m^2 for Cotton candy.

3.3.4 Approaches for habitat creation on green roofs have particularly outstanding benefits for biodiversity, restoration ecosystem and reduction of habitat loss (Blank et al., 2013) (Porsche & Köhler, 2003). Portland city has invested approximately 275,000 $/acre as to increase natural habitats. At present, community areas have to face with various problems i.e. traffic, building construction and human-made environment. Furthermore, green roof can protect species and create natural habitats for small animals such as bird, butterfly, insect and bee(Carter & Keeler, 2008). Bianchini and Hewage made an estimation about the increasing number of habitat creation. They said that it will approximately benefit 30% of intensive green roofs at 0-20.4 $/m^2 and 15% of extensive green roofs between 0-10.2 $/m^2 (Bianchini & Hewage, 2012b). The habitat creation benefit of air plant green roofs assumed to be 15% for both Cotton candy and Spanish moss. Therefore, in term of habitat creation on air plant green roofs, its benefit can go from 0-10.19 $/m^2.

3.3.5 Mitigation of urban heat island effect in city, the growth of urbanizations, building and infrastructure lead to the increasing of urban heat island effect(Lin et al., 2013)(Ouldboukhitine, Belarbi, & Sailor, 2014). Normally, City center has higher air temperature than the surface temperature in rural or suburban(Coutts et al., 2013). The albedo from construction surface such as building, concrete and asphalt has typically ranged between 0.1 to 0.2(Kiesel et al., 2012), which is lower than green roofs (the albedo of green roofs range from 0.7 to 0.85)(Rosenzweig, Gaffin, & Parshall, 2006). One of mitigation strategies of urban heat island effect is the utilization of green roofs(Zinzi & Agnoli, 2012). Trees and plant roofs can reduce temperature. It surely can lead to the reduction of the energy demanding on heating and cooling systems(Carter & Keeler, 2008). Bianchini and Hewage considered the mitigation benefit of urban heat island effect on green roofs at 8.3E-3 $/m^2 and 1.2E-3 $/m^2 (Bianchini & Hewage, 2012b). In this case, the estimation of UHI phenomenon in these air plant green roofs is at 10-14% of the energy consumption in residential buildings(Zinzi & Agnoli, 2012). Moreover, the estimation of the benefit value is between 4.72 $/m^2 and 6.61 $/m^2.

3.3.6 Reduction of infrastructure improvement from green roofs is a social benefit on the storm water management in the city, which can decrease infrastructure both operation and maintenance in municipality(Getter, Rowe, Robertson, Cregg, & Andresen, 2009). Green roofs can reduce pressure from the storm water in drainage system in city area during the peak flow period. In addition, it can decrease the amount of rainwater runoff in city and neighborhood(Köhler & Poll, 2010). The infrastructure costs for storm water management in Portland city valued at 30 $/m^2 per year. The benefit of storm water volume reduction from green roofs can be estimated between 25% and 86%(Bianchini & Hewage, 2012b). In this study, both air plant green roofs are considered the annual benefit for saving the infrastructure costs in city from 7.80-25.80 $/m^2.

3.3.7 Reduction of flood risk on green spaces can reduce the damage to life, property and economic in cities and countries. Obviously, the growth of urbanization results in the decreasing of green surface such as tree, park and forest. It was widely known that the green space can support the storm water runoff in urban areas.

Furthermore, World Bank considered the loss in the worst flood disaster in Thailand, 2011 to be up to ฿1,356 billion ($40,419 million) The city of Portland also discussed about the adsorption capacity of water runoff from green roofs at 26-86% of rainwater. Bianchini and Hewage calculated the green roofs benefit of flooding reduction from 7.1E-4 $/m^2$ to 2.4E-3 $/m^2$(Bianchini & Hewage, 2012b). Therefore, Cotton candy and Spanish moss could save in term of money to reduce flood risk between 0.70-2.41 $/m^2$.

3.3.8 Provision of recreational space and increase surface function of green roofs or living roofs are the potential of intensive green roofs(Saadatian et al., 2013). It can support the reduction of green space and increase the quality of life in city. The value of recreational spaces on intensive green roofs can resemble with public parks(Garrison, Horowitz, & Lunghino, 2012). From the study, the intensive green roofs in the City of Toronto can improve green area in city approximately at 20 $/m^2$(Sousa, 2002). On the other hand, air plant green roofs and extensive green roofs cannot provide the provision of recreational space for the approaching of human activities. In this case, occupants in urban area and surrounding buildings could receive the comfortable of sight visual perception from the slope of green roofs. It provides human wellbeing related to the visual comfort and associated view which are spiritual values(Feng, Zheng, Wang, Yu, & Su, 2015).

3.3.9 Aesthetics of green roofs came from the enhancing between the built environment of facade building and the green city. One of the major principles of architectural design is aesthetic aspects. On the other hand, aesthetic value are hard to defy or make an estimation since its value comes from personal appreciation or decision. Commission for Architecture and the Built Environment (CABE) in England realized the importance of aesthetic value. Projects on creating built environment such as architecture, urban design and public space are introduced. Parks and green spaces are the alternative to provide amenities and enhancing people's quality of life. The identification of the aesthetic value depends on the willing to pay. The aesthetic value of building that is adjacent to the park in city can increase the rising of property value around 6%. The building that has the perspective of green space will increase the price up to 8% of property value. Respectively, the property that located close to green space and has directly green perspective, can increase the value of building from 7.3-11.3%. Bianchini and Hewage assumed the probabilistic of aesthetics benefit for intensive green roofs from 5-8% of initial construction cost and the addition value between 8.3- 43.2 $/m^2$. For extensive green roofs, it is estimated from 2-5% of property value and the increased of property value could be from 2.6-8.3 $/m^2$ (Bianchini & Hewage, 2012b).

The evaluation of aesthetic value on air plant green roofs has different assumption because the physical descriptions of plants are different. Distinctively, Cotton candy plants have silver white leaves and largely bloom pink flowers once time per year, the diameter of Cotton candy is about 13-15 cm. The flowers of Spanish moss are very tiny and inconspicuous bloom. The flowers of air plants profit to aesthetic value therefore it can increase the value of property. In this study, the aesthetics value of Cotton candy considered the value higher than Spanish moss. The aesthetics benefit of Cotton candy estimated between 4-6% of initial's cost of air plant. Therefore, the addition value of cotton candy estimated from 8.86-13.29 $\$/m^2$. Consecutively, Spanish moss estimated from 3-5% of property value or from 2.30-3.83 $\$/m^2$.

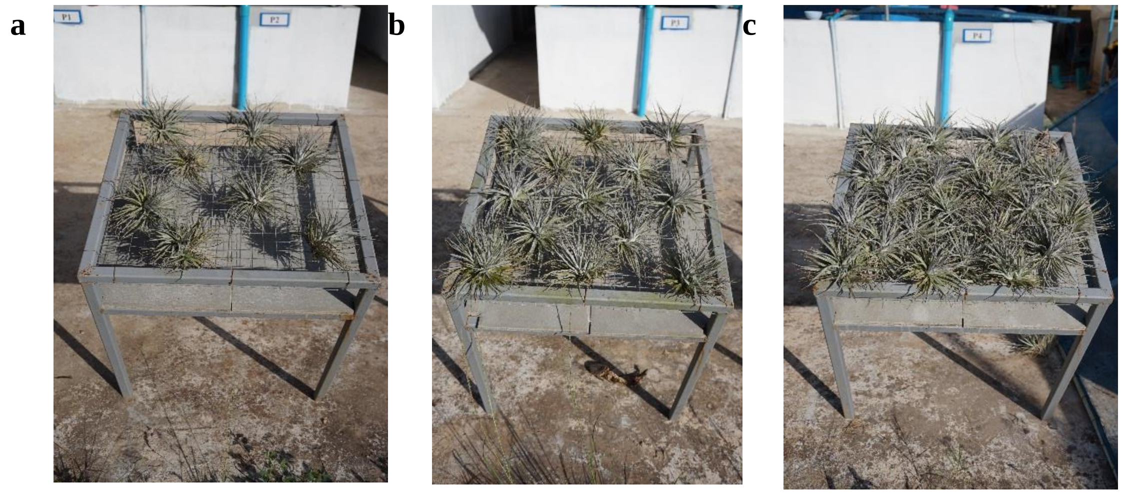
CHAPTER IV

Performance of Density on Air-Plant Green Roofs in Thermal parameters

Previous researches studied on the leaf volume for evapotranspiration and shading benefits (Refahi & Talkhabi, 2015). The functions on leaf effect on energy saving and the reduction of heat surface. The covering of plantation provides shading and cooling which is passive application. Normally, the density of plantation was expressed to the leaf area index (LAI).

4.1 The density of air plant

The comparison on the air plant density efficiency was investigated on surface temperature within three difference densities both Spanish Moss and Tillandsia Cotton Candy such as the density of 500 g/0.144m^3, 1000 g/0.144m^3 and 1,500 g/0.144m^3.

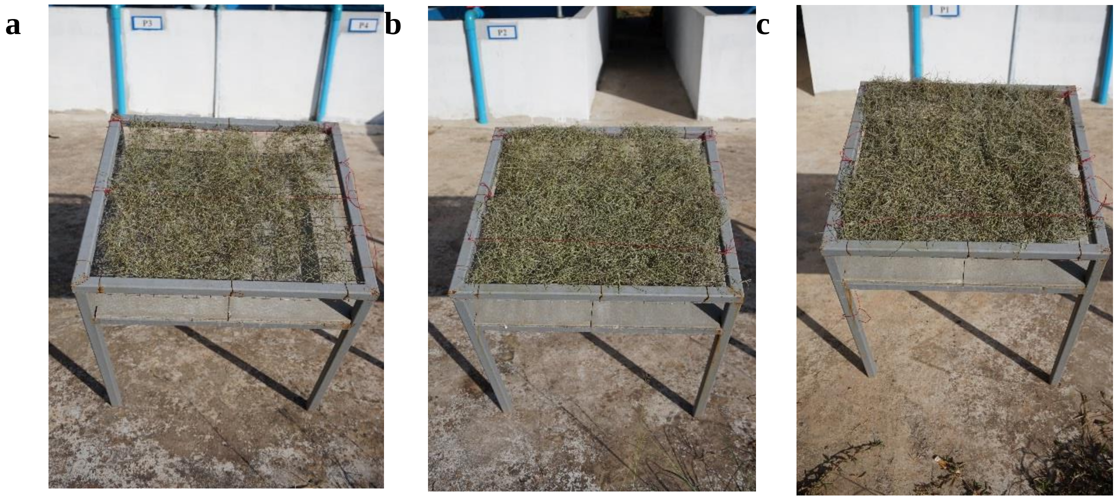


Spanish Moss 500 g/0.144m^3	Spanish Moss 1000 g/0.144m^3	Spanish Moss 1,500 g/0.144m$^{3/}$

Figure 4.1 The density pattern of the Tillandsia Cotton Candy (a) 500 g/0.144m^3, (b) 1000 g/0.144m^3 and (c) 1,500 g/0.144m^3

Table 4.1 The compared density of the air plant green roofs

Type of air plant	Pattern 1	Pattern 2	Pattern 3
Spanish Moss	500 g/0.144m^3	1000 g/0.144m^3	1,500 g/0.144m^3
Tillandsia Cotton Candy	500 g/0.144m^3	1000 g/0.144m^3	1,500 g/0.144m^3



Tillandsia Cotton Candy 500 g/0.144m^3	Tillandsia Cotton Candy 1000 g/0.144m^3	Tillandsia Cotton Candy 1,500 g/0.144m^3

Figure 4.2 The density pattern of the Tillandsia Cotton Candy (a) 500 g/0.144m^3, (b) 1000 g/0.144m^3 and (c) 1,500 g/0.144m^3

The leaf area index (LAI), which is the most important parameter, from the studied Refahi and Talkhabi (2015) were found that when the higher values of LAI factor leading to the decrease in energy consumption. Teemusk and Mander (2009) were found that the doubling the canopy LAI (from 3-6) achieve 50% of reduction in roof heat flux and the studied from Sailor (2011) was found that when LAI increases affect to the heating decrease therefore, the energy savings to cooling increase. Zeng et al (2017) were studied in the heating-dominated cities was found the interactive relationship between foliage height and LAI. In the cooling-dominated cities was found the cooling energy consumption leading to decrease while increasing LAI and foliage height. Therefore, LAI is the most significant factor that affects to the energy consumption.

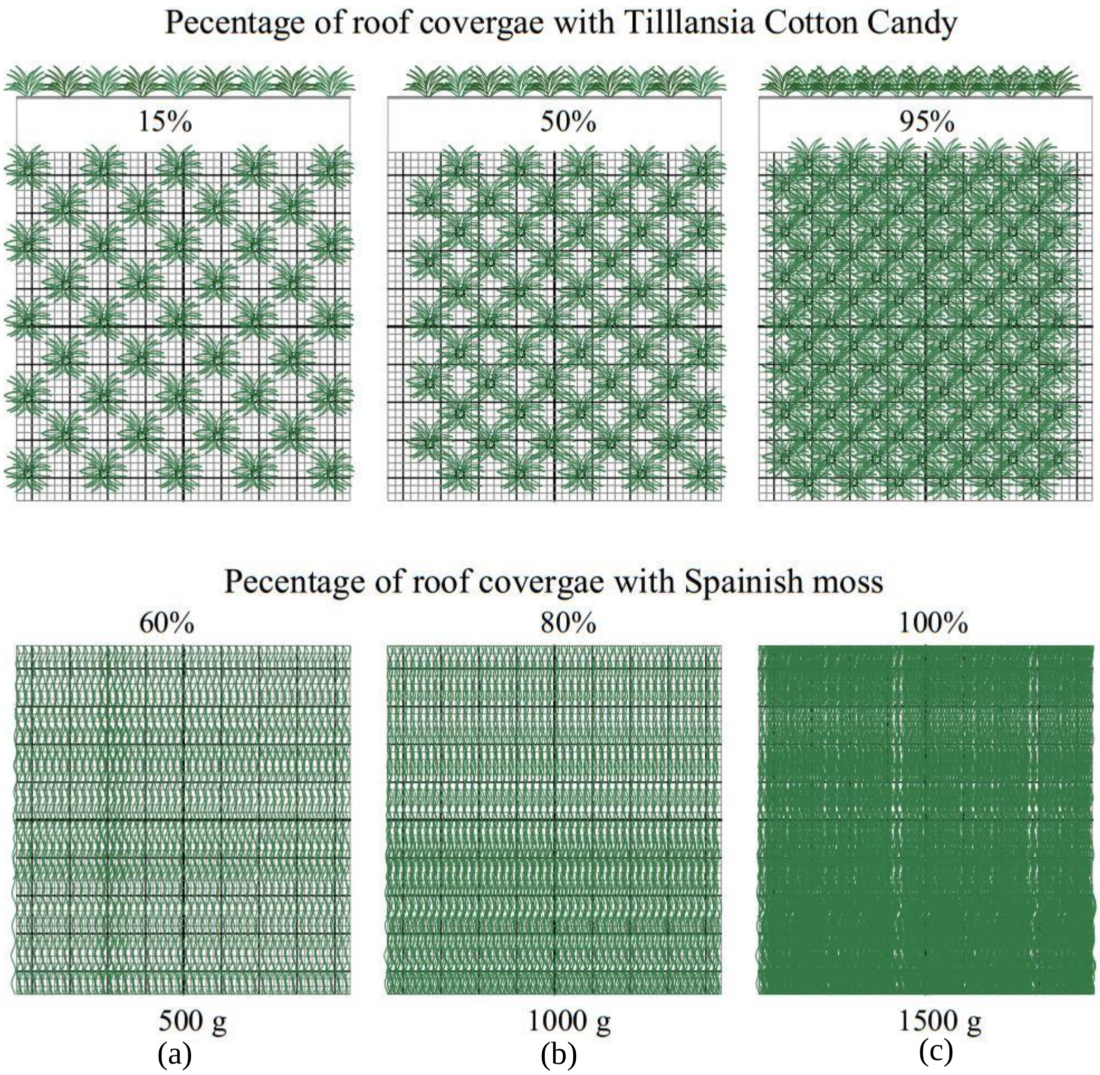


Figure 4.3 The density pattern of the Tillandsia Cotton Candy and Spainish moss (a) 500 g/0.144m^3, (b) 1000 g/0.144m^3 and (c) 1,500 g/0.144m^3

4.2 Thermal performance of air plant green roofs

The thermal performance of air plant green roofs is normally explained by two approaches either mathematical model or experimental quantification. This topic shows the mathematical model which is energy plus software for building simulation which accommodates the green roof model named Fast All Season Soil Strength (FASST) developed by Frankenstein and Koenig for the US Army Corps of Engineers.

The radiation is balanced by the sensible heat and latent heat as in Figure 4.1.

Radiation = (Sensible Heat) + (Latent Heat)

Radiation F_t = Sky $_{\text{Short Wave + Long Wave - Reflection}}$

Sensible Heat H_f = Heat$_{\text{Convection}}$ (Evaporation$_{\text{plant}}$)

Latent Heat L_f = $l_f \, LAI \, \rho_{af} \, C^f_{hn} \, W_{af} \, r_s \, (q_{af} - q_{f,sat})$

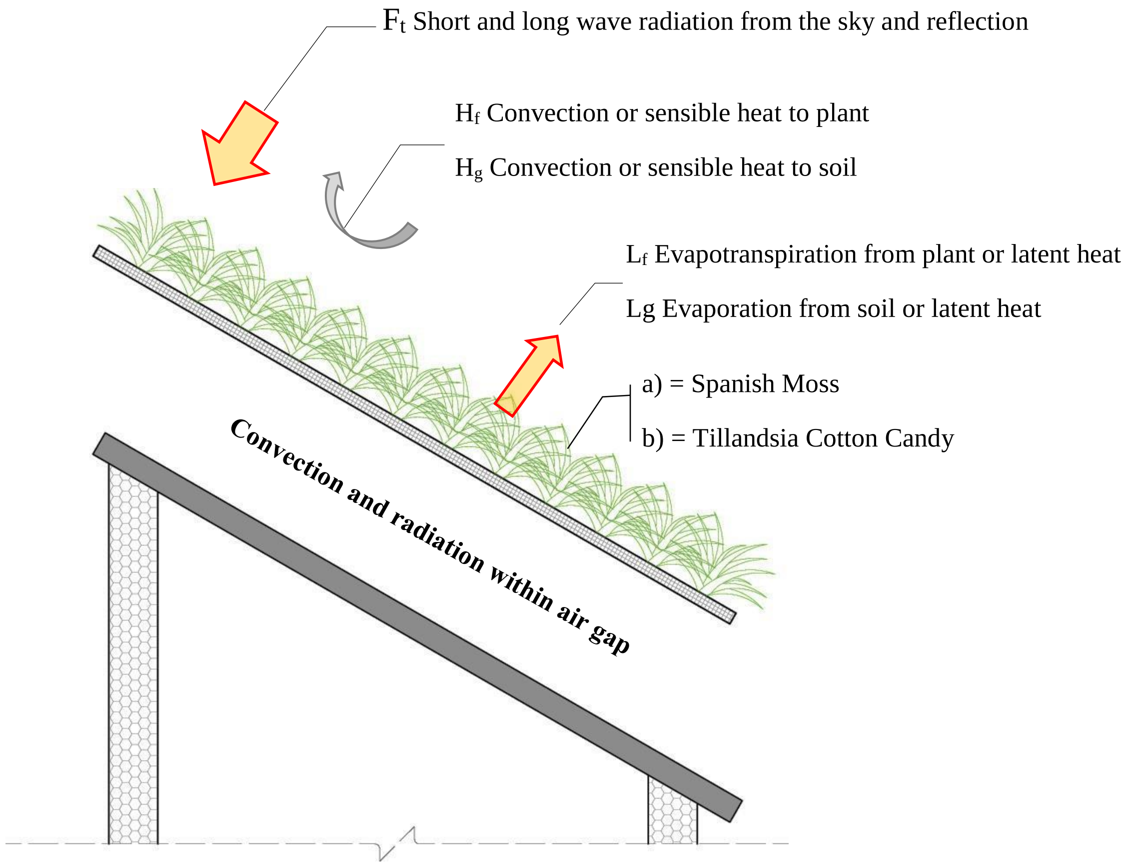


Figure 4.4 Heat balance of air plant green roofs

4.3 Experimental Validation of Air Plant Green Roofs (20 cm away from the external surface of the traditional roof)

4.3.1 Node 1: Surface temperature at the edge of Spanish Moss roof (density 500 g/0.144m^3)

During day-time, the comparison of the average surface temperature between Spanish Moss roof (density 500 g/0.144m^3) and controlled roof on November 4, 2014 are different. The average of different temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Spanish Moss ($T5_{\text{Spanish Moss}}$) as 3.58°C. T_{dif} between T_{amb} and surface temperature under the controlled roof

(T_2) as 2.70°C. The average of T_{amb} during the daytime was 36.67±7.44°C and the relative humidity (RH) was 55.42±16.15%.

In the night time, however, the average of T_{dif} between T_{amb} and $T_{5\ Spanish\ Moss}$ was 3.43°C and $T_{dif\ control}$ was 3.86°C. T_{amb} during the night time was 27.76 ±1.87°C and RH was 83.93±±5.18%. The average temperature of $T_{5\ Spanish\ Moss}$ was 33.10 ±8.25°C all day and T_{amb} on November 4, 2014 was 36.67 ±7.44°C.

4.3.2 Node 2: Surface temperature at the edge of Spanish Moss roof (density 1,000 g/0.144m^3)

During the day-time, the comparison of the average surface temperature between Spanish Moss roof (density of 1000 g/0.144m^3) and controlled roof on October 11, 2014 are different. The average of T_{dif} between T_{amb} and $T5_{Spanish\ Moss}$ was 6.96 °C and decreased in range 2.1-14.1°C. T_{dif} between T_{amb} and T_2 was 2.30°C which was lower than $T5_{\ Spanish\ Moss}$. The average of T_{amb} during the daytime was 38.92 ±8.51°C and RH was 53.60 ±19.46%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Spanish\ Moss}$ was 2.82°C. It was decreased in range1.8-5.7°C and $T_{dif\ control}$ was 3.20°C. T_{amb} during the night time was 27.72 ±1.29°C and RH was 82.02±7.09%. The average of $T_{5\ Spanish\ Moss}$ was 28.42±5.74°C all day.

4.3.3 Node 3: Surface temperature at the edge of Spanish Moss roof (density 1,500 g/0.144m^3)

During the day-time, the comparison of the average temperature on surface Spanish Moss roof (density of 1,500 g/0.144m^3) and control roof on August 21, 2014 are different. The average T_{dif} between T_{amb} and $T5_{\ Spanish\ Moss}$ was 8.1°C and decreased in the range 0.6-15.2°C. T_{dif} between T_{amb} and T_2 was 4.42°C, which was lower than $T5_{\ Spanish\ Moss}$. The average of T_{amb} during the daytime was 35.94±5.42°C and RH was55.93±17.15 %.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Spanish\ Moss}$ was 2.90°C. It decreased in the range of 1.3-4.9°C and $T_{dif\ control}$ was 3.72°C. T_{amb} during the night time was 26.98±1.92°C and RH was 79.64±8.67%. The average of $T_{5\ Spanish\ Moss}$ was 31.44±6.04°C all day.

4.3.4 Node 4: Surface temperature at the edge of Cotton Candy roof (density of 500 g/0.144m^3)

During the day-time, the comparison of the average surface temperature between Cotton Candy roof (density of 500g/0.144m^3) and control roof on November 4, 2014 has difference which the average of T_{dif} between T_{amb} and $T5_{\ Cotton\ Candy}$ was

3.33°C and decreased in range -3.70-11.20°C. T_{dif} between T_{amb} and T_2 was 2.70°C. It was lower than $T5_{Cotton\ Candy}$. The average of T_{amb} during the daytime was 36.67±7.44°C and RH was 55.42±16.15 %.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Cotton\ Candy}$ was 3.42°C. It decreased in the range of 2.60-5.20°C and $T_{dif\ control}$ was 3.86°C. T_{amb} during the night time was 27.76±1.8°C and RH was 82.02. ±7.09%. The average of $T_{5\ Cotton\ Candy}$ was 28.82±7.45 °C all day.

4.3.5 Node 5: Surface temperature at the edge of Cotton Candy roof (density of 1,000 g/0.144m^3)

During the day-time, the comparison of the average surface temperature between Cotton Candy roof (density of 1,000 g/0.144m^3) and control roof on October 11, 2014 seem to be different. The average of T_{dif} between T_{amb} and $T5_{Cotton\ Candy}$ was 5.01°C and decreased in range 0.80-12.6°C. T_{dif} between T_{amb} and T_2 was 2.30°C which was lower than $T5_{Cotton\ Candy}$. The average of T_{amb} during the daytime was 38.92±8.51°C and RH was 53.60±19.46 %.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Cotton\ Candy}$ was 2.99°C. It decreased in range of 2.00-4.90°C and $T_{dif\ control}$ was 3.20°C. T_{amb} during the night time was 27.72±1.29°C and RH was 83.93. ±5.18%. The average of $T_{5\ Cotton\ Candy}$ was 29.31±7.43°C all day.

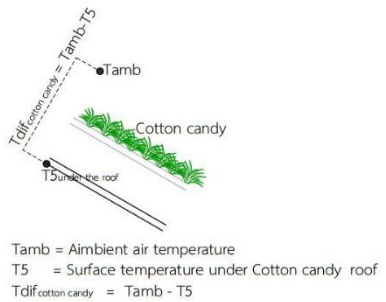
4.3.6 Node 6: Surface temperature at the edge of Cotton Candy roof (density of 1,500 g/0.144m^3)

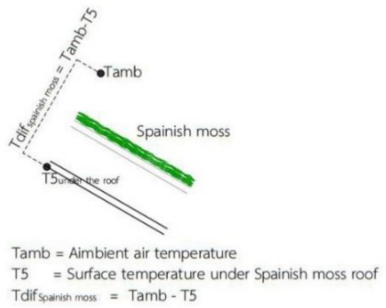
During the day-time, the comparison of the average surface temperature between Cotton Candy roof (density of 1,500g/0.144m^3) and control roof on August 21, 2014 are different. The average of T_{dif} between T_{amb} and $T5_{Cotton\ Candy}$ was 6.87°C. It decreased in the range of 0.70-14.50 °C. T_{dif} between T_{amb} and T_2 was 4.42°C which lower than $T5_{Cotton\ Candy}$. The average of T_{amb} during the daytime was 35.94±5.42°C and RH was 55.93±17.15 %.

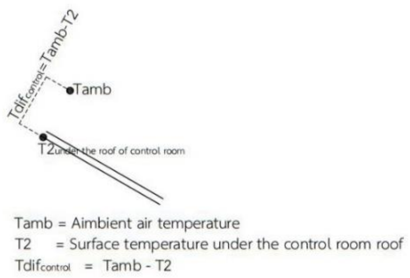
During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Cotton\ Candy}$ was 4.20°C. It decreased in the range of 1.30-11.20°C and $T_{dif\ control}$ was 4.92°C. T_{amb} during the night time was 28.14±3.60°C and RH was 79.80±13.13%. The average of $T_{5\ Cotton\ Candy}$ all day was 26.50±3.48°C.

Table 4.2 Comparison of the difference temperature (T_{dif}) of Spanish Moss and Cotton Candy (Weight per Volume (g/0.144m^3)

Date	g/ 0.144 m^3	**Spanish Moss** (**Average temperature**) Weight per Volume (g/0.144m^3)															
		Temperature(°C) Day-time								**Temperature(°C) Night-time**							
		$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)
4/11/2014	500	3.58 ±3.03	3.86 ±1.91	36.67 ±7.44		55.42 ±16.15		26.65 ±1.65	33.10 ±8.25	**3.43 ±0.38**	3.86 ±0.34	27.76 ±1.87		82.02 ±7.09		24.32 ±0.35	24.32 ±1.56
11/10/2014	1,000	6.96 ±2.99	4.48 ±2.29	38.92 ±8.51	0.00	53.60 ±19.46	0.50	26.40 ±1.82	31.97 ±6.37	2.82 ±0.61	3.20 ±0.55	27.72 ±1.29	0.00	83.93 ±5.18	0.00	24.70 ±0.24	24.91 ±0.78
21/8/2014	1,500	**8.1 ±3.8**	4.42 ±2.92	35.94 ±5.42		55.93 ±17.15		25.00 ±1.23	27.87 ±2.41	2.90 ±0.81	3.72 ±0.77	26.98 ±1.92		79.64 ±8.67		23.06 ±0.27	24.08 ±1.17
		6.21 ±2.35								3.05 ±0.33							
Date	g/ 0.144 m^3	**Cotton Candy** (**Average temperature**) Weight per Volume (g/0.144m^3)															
		Temperature(°C) Day-time								**Temperature(°C) Night-time**							
		$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)
4/11/2014	500	4.33 ±2.27	3.86 ±1.91	36.67 ±7.44		55.42 ±16.15		26.65 ±1.65	33.34 ±8.27	3.42 ±0.35	3.86 ±0.34	27.76 ±1.87		82.02 ±7.09		24.32 ±0.35	24.34 ±1.60
11/10/2014	1,000	5.01 ±2.60	4.48 ±2.29	38.92 ±8.51	0.00	53.60 ±19.46	0.50	26.40 ±1.82	33.92 ±8.23	2.99 ±0.50	3.20 ±0.55	27.72 ±1.29	0.00	83.93 ±5.18	0.00	24.70 ±0.24	24.73 ±0.93
21/8/2014	1,500	**6.87 ±3.42**	4.42 ±2.92	35.94 ±5.42		55.93 ±17.15		25.00 ±1.23	29.06 ±3.12	**4.20 ±2.62**	3.72 ±0.77	28.14 ±3.60		79.80 ±13.13		24.01 ±0.56	23.95 ±1.23
		5.40 ±1.31								3.54 ±0.61							







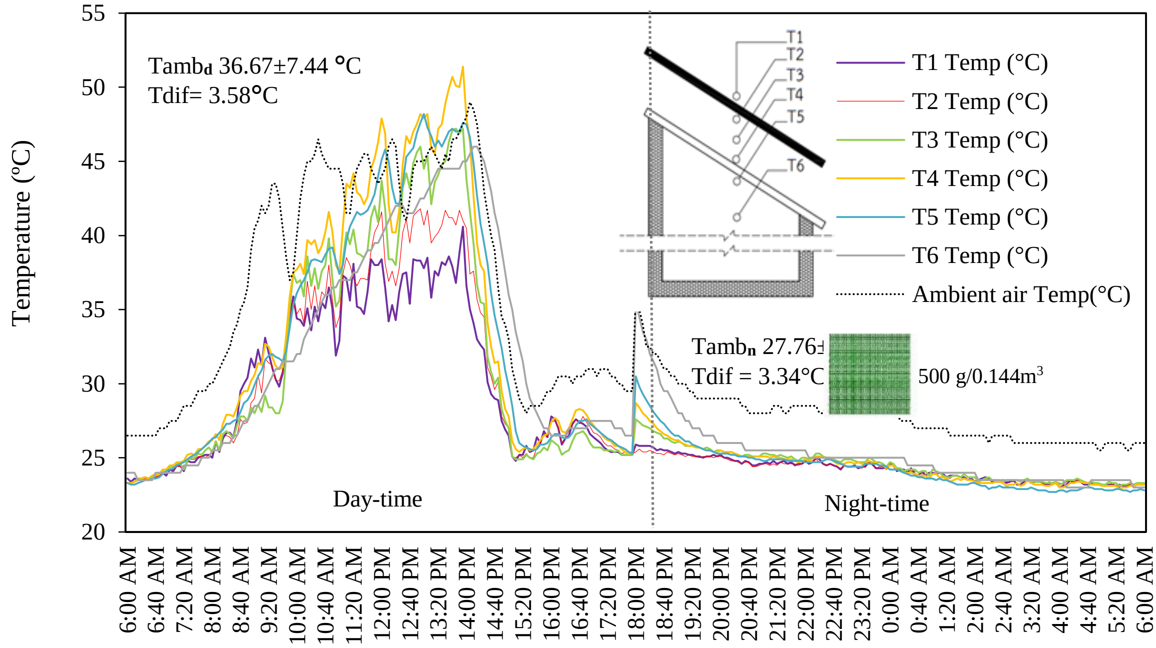


Figure 4.5 The temperature variation of Spanish Moss green roof on density 500g/0.144m^3

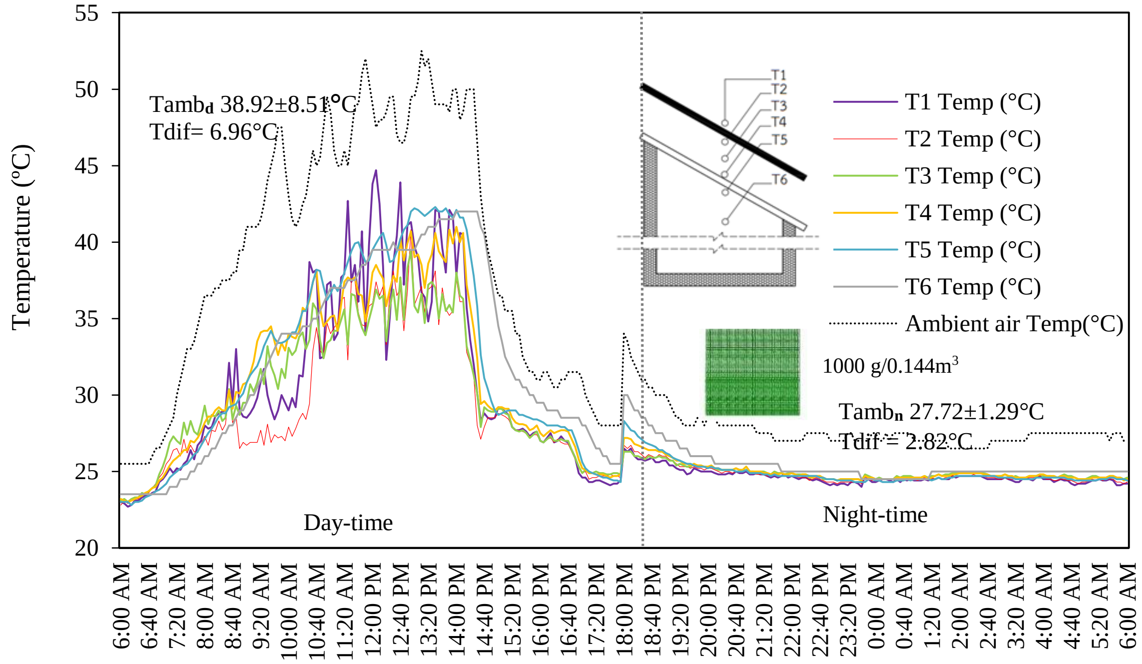


Figure 4.6 The temperature variation of Spanish Moss green roof on density 1,000g/0.144m^3

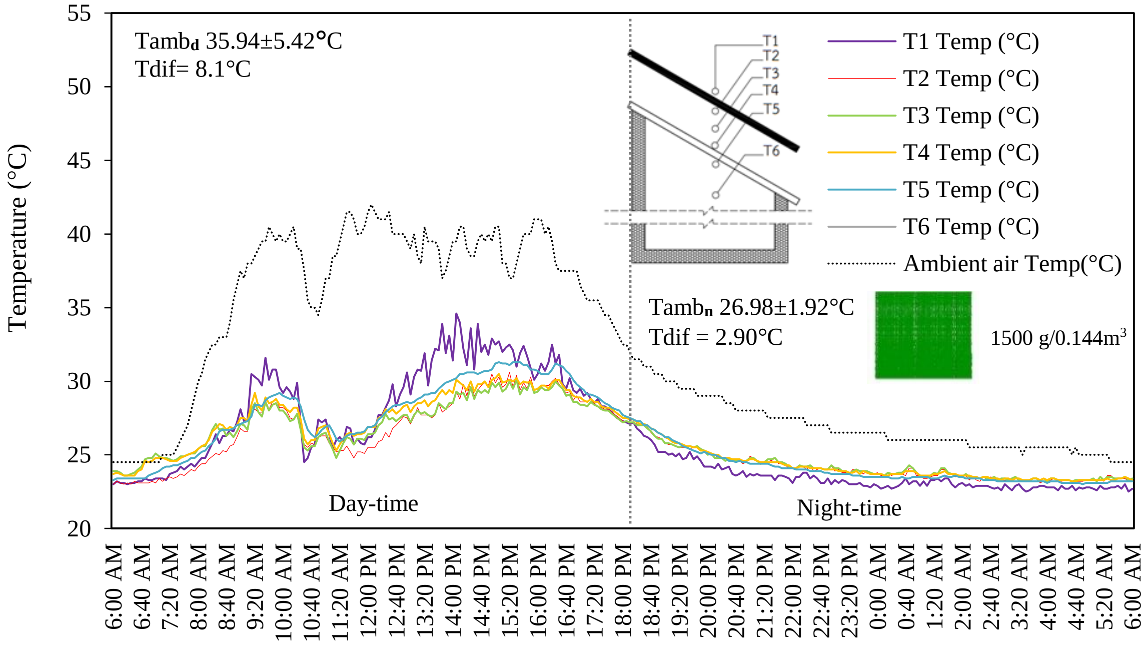


Figure 4.7 The temperature variation of Spanish Moss green roof on density 1,500g/0.144m^3

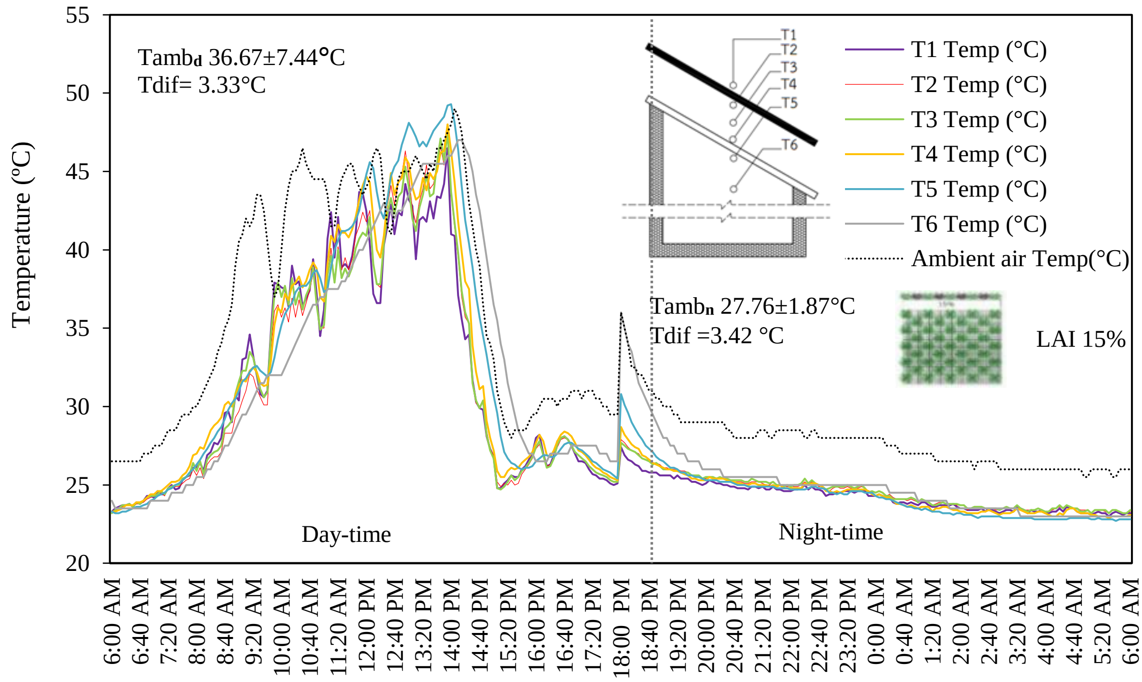


Figure 4.8 The temperature variation of Cotton Candy green roof on density 1,500g/0.144m^3

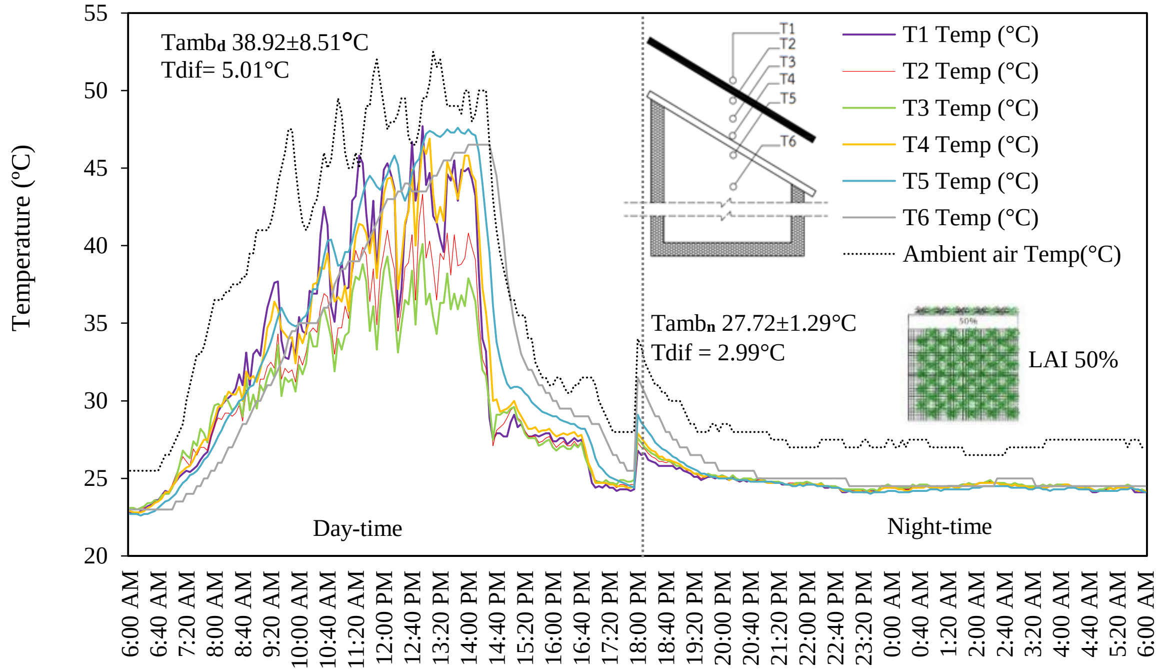


Figure 4.9 The temperature variation of Cotton Candy green roof on density 1,500g/0.144m^3

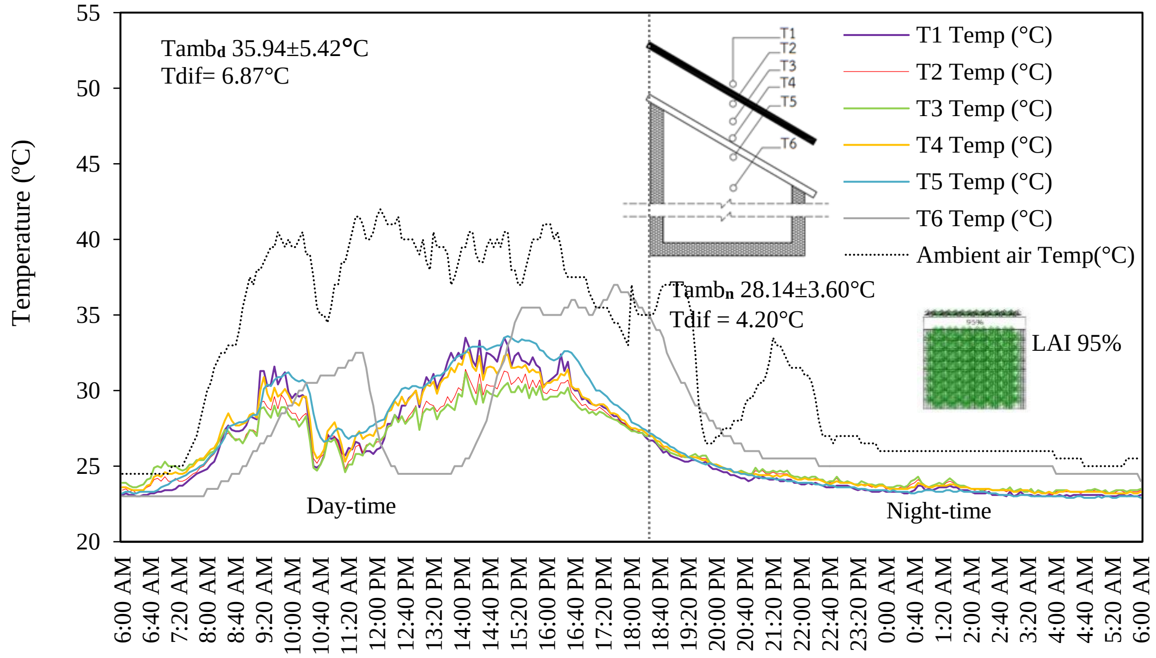


Figure 4.10 The temperature variation of Cotton Candy green roof on density 1,500g/0.144m^3

4.4 Conclusion

In general, major advantages of green roofs are passive cooling. Numbers of previous researches has been studied in order to improve basic understanding toward this topic. However, the different species of plant and leaf area index (density of plant) result in the difference thermal performance efficiency. As to evaluated and compared the efficiency of air plant green roofs, this research has adopted the experimental approach by comparing two types of air plant green roofs (Spanish Moss roof and Cotton Candy roof) on three weight per volume at density of 500 g/0.144m^3, 1,000 g/0.144m^3 and 1,500 g/0.144 m^3). The main conclusions of this research can be summarized as follows:

4.4.1 Comparison between measured surface temperature of Spanish Moss roofs with density of 500 g/0.144m^3, 1,000 g/0.144m^3 and 1,500 g/0.144m^3

The experimental results of Spanish Moss roofs had inversion difference between daytime and nighttime. During the daytime, the average of difference temperature ($\overline{T}$dif) on Spanish Moss roof with density of 1,500 g/0.144m^3 decreased. The temperature was higher than that 1,000 and 500 density respectively. $\overline{T}$dif of Spanish Moss roof at density of 1,500 g/0.144m^3 and 1,000 g/0.144m^3 had similar value. During the night time, $\overline{T}$dif on Spanish Moss roof with density of 500 g/0.144m^3 had decreased the temperature higher than that 1,000 and 1,500 density respectively. $\overline{T}$dif of Spanish Moss roof at density of 1,500 g/0.144m^3 and 1,000 g/0.144m^3 had similar value.

During the daytime, the high density of Spanish Moss roof is suitable for thermal reduction from ambient air temperature. On the other hand, thin layer of Spanish Moss roof seems to be appropriate with thermal reduction during nighttime. Leaf area index of Spanish Moss resulted in heat transfer to ambient air temperature.

4.4.2 Comparison of measured surface temperature of Cotton Candy roofs with density of 500 g/0.144m^3, 1,000 g/0.144m^3 and 1,500 g/0.144m^3

The results from this experiment of the leaf surface temperature of Cotton Candy roofs also shows similarly with during daytime and nighttime. The measurement of surface temperature presented that Cotton Candy roof with density of 1,500 g/0.144m^3 had decreased the temperature higher than that 1,000 and 500 density respectively. During the night time, measured temperatures of Cotton Candy roofs at density of 1,500 g/0.144m^3 decreased the surface temperature higher than the density 500 and 1,000 g/0.144m^3 respectively.

4.4.3 Comparison across crops between Spanish Moss and Cotton Candy roofs

The characteristics of air plant green roof also affect the ventilation of thermal reduction. During in daytime, the density of leaf area index is an insulation, which reduce heat transfer before entering the building. During the daytime, it was found out that the temperature of Spanish Moss roofs as density of 1,500 g/0.144m^3 decreased the temperature higher than that Cotton Candy. Spanish Moss roof at density of 1,500 g/0.144m^3 reduced the ambient air temperature as 8.1°C and Cotton Candy roof at density of 1,500 g/0.144m^3 decreased the ambient air temperature as 6.87°C.

During the night time was found that Cotton Candy roofs as density of 1,500 g/0.144m^3 was decreased the temperature higher than that Spanish Moss. Cotton Candy roof as density of 1,500 g/0.144m^3 was reduced the ambient air temperature as 4.20°C and Spanish Moss roof as density of 500 g/0.144m^3 was decreased the ambient air temperature as 3.43°C.

It is not clear that for the ventilation and mass transfer within the air plant green roof there is a small correlation between Spanish Moss and Cotton Candy measurements. However, Cotton Candy has the outstanding characteristic. Air gap between Cotton Candy leaves improved the cooling ventilation inside building especially during the night time.

CHAPTER V

Performance of Air Gab on Air-Plant Green Roofs on Thermal parameters

Air gab between green roofs and traditional roof affect to flow air ventilation. The heat transfer of the air depends on the temperature difference, the distance of the air gap and the materials of green roofs. The efficiency of the heat exchanger depends on several factors, such as the hotter air of the air space, cooler outside air and cool air channels. The air gap will result in the better heat transfer performance of the roof and better heat dissipation.

5.1 The air gap of air plant green roofs

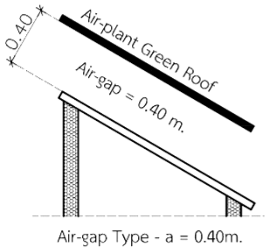
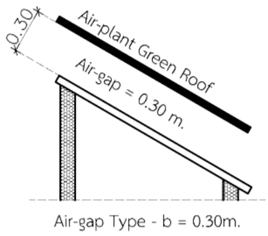
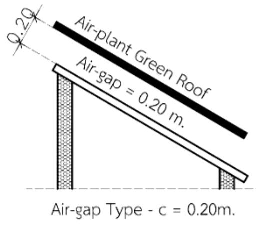
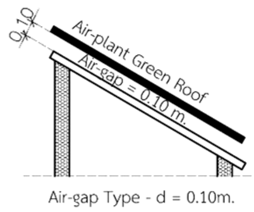
The comparison of the air gab efficiency on air plant was conducted on surface temperature within the four difference types of air gab both Spanish Moss and Tillandsia Cotton Candy.

- Type 1: Air gap with green roofs 40 cm (density of 500 g/0.144m^3, 1000 g/0.144m^3 and 1,500 g/0.144m^3)
- Type 2: Air gap with green roofs 30 cm (density of 500 g/0.144m^3, 1000 g/0.144m^3 and 1,500 g/0.144m^3)
- Type 3: Air gap with green roofs 20 cm (density of 500 g/0.144m^3, 1000 g/0.144m^3 and 1,500 g/0.144m^3)
- Type 4: Air gap with green roofs 10 cm (density of 500 g/0.144m^3, 1000 g/0.144m^3 and 1,500 g/0.144m^3)

(a) (b)

Figure 5.1 (a) and (b) the experiment on the performance of air gab for collecting data

Table 5.1 the detail section on air plant green roofs with the difference air gab 4 types

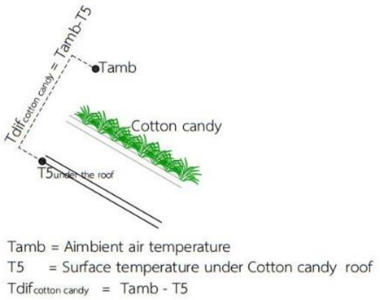
Type 1(a)	Type 2(b)	Type 3(c)	Type 4(d)
			
Air gap 40 cm	Air gap 30 cm	Air gap 20 cm	Air gap 10 cm

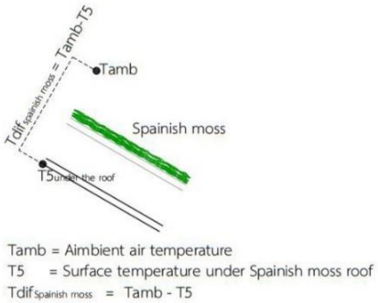
(a) (b) (c)

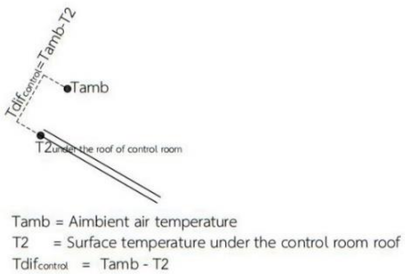
Figure 5.2 (a), (b) and (c) the experiment on the air gab performance

Table 5.2 Comparison of the different temperature (T_{dif}) on Air gab 10, 20, 30 and 40 cm of Spanish Moss and Cotton Candy roof (Weight per Volume (500g/0.144m^3)

Date	Air gap (cm)	Spanish Moss of weight per volume (500g/0.144m^3 (Average temperature)															
		Temperature(°C) Day-time								Temperature(°C) Night-time							
		$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)
4/11/2014	10	**3.58** ±3.03	3.86 ±1.91	36.67 ±7.44		55.42 ±16.15		26.65 ±1.65	33.10 ±8.25	3.00 ±0.36	3.33 ±0.38	27.04 ±0.69		84.78 ±4.35		24.28 ±0.30	24.04 ±0.41
9/11/2014	20	2.98 ±1.53	2.35 ±1.13	36.33 ±6.68	0.00	59.01 ±20.09	0.00	25.96 ±1.22	34.31 ±7.48	**3.43** ±0.38	3.86 ±0.34	27.76 ±1.87	0.00	82.02 ±7.09	0.00	24.32 ±0.35	24.32 ±1.56
15/11/2014	30	2.12 ±1.57	1.88 ±1.25	30.31 ±2.99		77.22 ±10.31		25.68 ±0.78	28.19 ±3.05	3.15 ±0.42	3.77 ±0.33	26.16 ±1.54		86.87 ±5.07		23.75 ±0.61	23.01 1.18
18//11.2014	40	2.38 ±0.76	1.73 ±0.78	28.60 ±1.92		82.50 ±6.11		25.25 ±0.73	26.22 ±1.75	2.28 ±0.29	2.40 ±0.33	25.46 ±0.62		90.74 ±0.81		23.81 ±0.56	23.18 ±0.54
		2.77 ±0.65								2.97 ±0.49							
Date	Air gap (cm)	Cotton Candy of weight per volume (500g/0.144m^3 (Average temperature)															
		Temperature(°C) Day-time								Temperature(°C) Day-time							
		$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)
4/11/2014	10	**4.33** ±2.27	3.86 ±1.91	36.67 ±7.44		55.42 ±16.15		26.65 ±1.65	33.34 ±8.27	3.00 ±0.35	3.33 ±0.38	27.04 ±0.69		84.78 ±4.35		24.28 ±0.30	24.05 ±0.43
9/11/2014	20	2.89 ±1.33	2.35 ±1.13	36.33 ±6.68	0.00	59.01 ±20.09	0.00	25.96 ±1.22	34.53 ±7.69	**3.42** ±0.35	3.86 ±0.34	27.76 ±1.87	0.00	82.02 ±7.09	0.00	24.32 ±0.35	24.34 ±1.60
15/11/2014	30	2.11 ±1.14	1.88 ±1.25	30.31 ±2.99		77.22 ±10.31		25.68 ±0.78	28.41 ±3.06	3.20 ±0.34	3.77 ±0.33	26.16 ±1.54		86.87 ±5.07		23.75 ±0.61	22.96 ±1.29
18//11.2014	40	2.19 ±0.60	1.73 ±0.78	28.60 ±1.92		82.50 ±6.11		25.25 ±0.73	26.41 ±1.89	2.21 ±0.31	2.40 ±0.33	25.46 ±0.62		90.74 ±0.81		23.81 ±0.56	23.25 ±0.55
		2.88 ±1.03								2.96 ±0.53							







5.2 Experimental Validation of Air Plant Green Roofs (20 cm away from the external surface of the traditional roof)

5.2.1 Node 1: Surface temperature at the edge of Spanish Moss roof (density 500 g/0.144m^3)

- Spanish Moss roof with a 10 cm wide air gap

During the daytime, the comparison of the average surface temperature between Spanish Moss roof (density 500 g/0.144m^3) and controlled roof on November 4, 2014 was different. The average of difference temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Spanish Moss ($T5_{Spanish\ Moss}$) was as 3.58°C. It decreased in the range of -4.30-11.70°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 2.70°C, which was lower than $T5_{Spanish\ Moss}$. The average of T_{amb} during the daytime was 36.67±7.44°C and the relative humidity (RH) was 55.42±16.15%.

During the night-time, the average of T_{dif} between T_{amb} and $T_{5\ Spanish\ Moss}$ was 3.00°C. It decreased in the range of 2-3.70°C and $T_{dif\ control}$ was 3.33°C. T_{amb} during the night time was 27.04 ±0.69°C and RH was 84.78±4.35%.

The average of $T_{5\ Spanish\ Moss}$ was 28.55±7.38 °C all day. T_{amb} on November 4, 2014 was 31.84 ±7.14°C.

- Spanish Moss roof with a 20 cm wide air gap

During the day-time, the comparison of the average surface temperature between Spanish Moss roof (density 500 g/0.144m^3) and control roof on November 9, 2014 was different. The average of the different temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Spanish Moss ($T5_{Spanish\ Moss}$) was as 2.01°C. It decreased in the range of -2.3-6.6°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 0.38°C, which was lower than $T5_{Spanish\ Moss}$. The average of T_{amb} during the daytime was 36.33±6.68°C and the relative humidity (RH) was 59.01±20.09%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Spanish\ Moss}$ was 3.43°C. It decreased in the range of 2.6-5.5°C. $T_{dif\ control}$ was 3.86°C. T_{amb} during the night time was 27.76 ±1.87°C and RH was 82.02±7.09%.

The average of $T_{5\ Spanish\ Moss}$ was 29.30±7.35 °C all day and T_{amb} on November 9, 2014 was 32.03±°6.51C.

- Spanish Moss roof with a 30 cm wide air gap

During the day-time, the comparison of the average of surface temperature between Spanish Moss roof (density 500 g/0.144m^3) and control roof on November 15, 2014 was different. The average different temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the Spanish Moss roof ($T5_{Spanish\ Moss}$) was as 2.12°C. It decreased in the range of -4.3-5.1°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 1.27°C, which was lower than $T5_{Spanish\ Moss}$. The average of T_{amb} during the day-time was 30.31±2.99°C and the relative humidity (RH) was 77.22±10.31%.

During the night-time, the average of T_{dif} between T_{amb} and $T_{5\ Spanish\ Moss}$ was 3.15°C. It decreased in the range of 2.3-4.4°C and $T_{dif\ control}$ was 3.77°C. T_{amb} during the night time was 27.16 ±1.54°C and RH was 86.87±5.07%.

The average of $T_{5\ Spanish\ Moss}$ all day was 25.59±3.47 °C and T_{amb} on November 15, 2014 was 28.23±3.15°C.

- Spanish Moss roof with a 40 cm wide air gap

During the day-time, the comparison of the average surface temperature between Spanish Moss roof (density 500 g/0.144m^3) and control roof on November 18, 2014 was different. The average difference temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Spanish Moss ($T5_{Spanish\ Moss}$) was as 2.38°C. It decreased in the range of 0.3-4.4°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 1.73°C, which was lower than $T5_{Spanish\ Moss}$. The average of T_{amb} during the daytime was 28.60±1.92°C and the relative humidity (RH) was 82.50±6.11%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Spanish\ Moss}$ was 2.28°C. It decreased in the range of 0.3-4.4°C. $T_{dif\ control}$ was 2.40°C. T_{amb} during the night time was 25.466 ±0.62°C and RH was 90.74±0.81%.

The average of $T_{5\ Spanish\ Moss}$ was 24.69±1.99°C all day and T_{amb} on November 18, 2014 was 27.02±2.12°C.

5.2.2 Node 2: boundary surface temperature of Cotton Candy roof (density 500 g/0.144m^3)

- Cotton Candy roof with a 10 cm wide air gap

During the day-time, the comparison of the average surface temperature between Cotton Candy roof (density 500 g/0.144m^3) and control roof on November 4, 2014 was different. The average of different temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Cotton Candy ($T5_{Cotton\ Candy}$) was as 3.33°C. It decreased in the range of - 3.70-11.20 °C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 2.70°C, which was lower than $T5_{Cotton\ Candy}$. The average T_{amb} during the day-time was 36.67±7.44°C and the relative humidity (RH) was 55.42±16.15%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Cotton\ Candy}$ was 3°C. It decreased in the range of 2.00-3.70°C. $T_{dif\ control}$ was 3.33°C. T_{amb} during the night time was 27.04 ±0.69°C and RH was 84.78±4.35%.

The average of $T_{5\ Cotton\ Candy}$ was 28.68±7.46°C all day and T_{amb} on November 4, 2014 was 31.84±7.14°C.

- Cotton Candy roof with a 20 cm wide air gap

During the day-time, the comparison of the average surface temperature between Cotton Candy roof (density 500 g/0.144m^3) and control roof on November 9, 2014 was different. The average different temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Cotton Candy ($T5_{Cotton\ Candy}$) was as 1.79°C. It decreased in the range of -3.60-6.40°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 0.38°C, which was lower than $T5_{Cotton\ Candy}$. The average of T_{amb} during the daytime was 36.33±6.68°C and the relative humidity (RH) was 59.01±20.09%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Cotton\ Candy}$ was 3.42°C. It decreased in the range of 2.60-5.20°C and $T_{dif\ control}$ was 3.86 °C. T_{amb} during the night time was 27.76 ±1.87°C and RH was 82.02±7.09%.

The average of $T_{5\ Cotton\ Candy}$ was 29.42±7.53°C all day and T_{amb} on November 9, 2014 was 32.03±6.51°C.

- Cotton Candy roof with a 30 cm wide air gap

During the day-time, the comparison of the average surface temperature between Cotton Candy roof (density 500 g/0.144m^3) and control roof on November 15, 2014 was different. The average of different temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Cotton Candy ($T5_{Cotton\ Candy}$) was as 1.90°C. It decreased in the range of -3.70-4.90°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 1.27°C, which was lower than $T5_{Cotton\ Candy}$. The average of T_{amb} during the daytime was 30.31±2.99°C and the relative humidity (RH) was 77.22±10.31%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Cotton\ Candy}$ was 3.20°C. It decreased in the range of 2.40-4.10°C and $T_{dif\ control}$ was 3.77 °C. T_{amb} during the night time was 26.16 ±1.54°C and RH was 86.87±5.07%.

The average of $T_{5\ Cotton\ Candy}$ was 22.96±1.29°C all day and T_{amb} on November 15, 2014 was 28.23±3.15°C.

- Cotton Candy roof with a 40 cm wide air gap

During the day-time, the comparison of the average surface temperature between Cotton Candy roof (density 500 g/0.144m^3) and control roof on November 18, 2014 was different. The average different temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Cotton Candy ($T5_{Cotton\ Candy}$) was as 2.19°C. It decreased in the range of 0.80-3.70°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 1.73°C, which was lower than $T5_{Cotton\ Candy}$. The average of T_{amb} during the daytime was 28.60±1.92°C and the relative humidity (RH) was 82.50±6.11%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Cotton\ Candy}$ was 2.21°C. It decreased in the range of 1.40-2.90°C. $T_{dif\ control}$ was 2.40°C. T_{amb} during the night time was 25.46 ±0.62°C and RH was 90.74±0.81%.

The average of $T_{5\ Cotton\ Candy}$ was 24.82±2.11°C all day and T_{amb} on November 18, 2014 was 27.02±2.12°C.

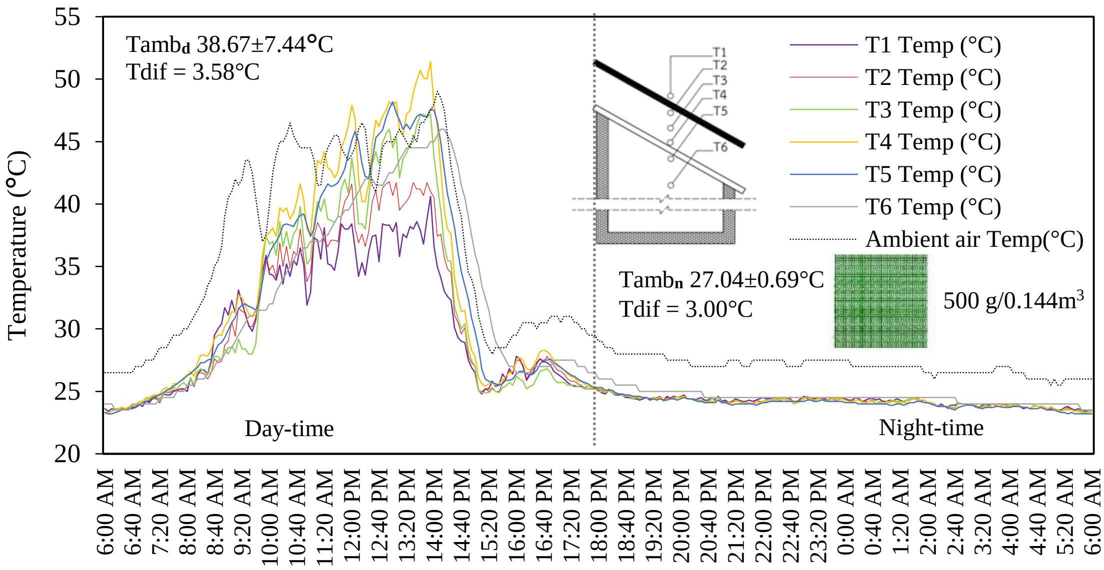


Figure 5.3 The temperature variation of Spanish Moss green roof on density 500g/0.144m^3 at air gap 10 cm

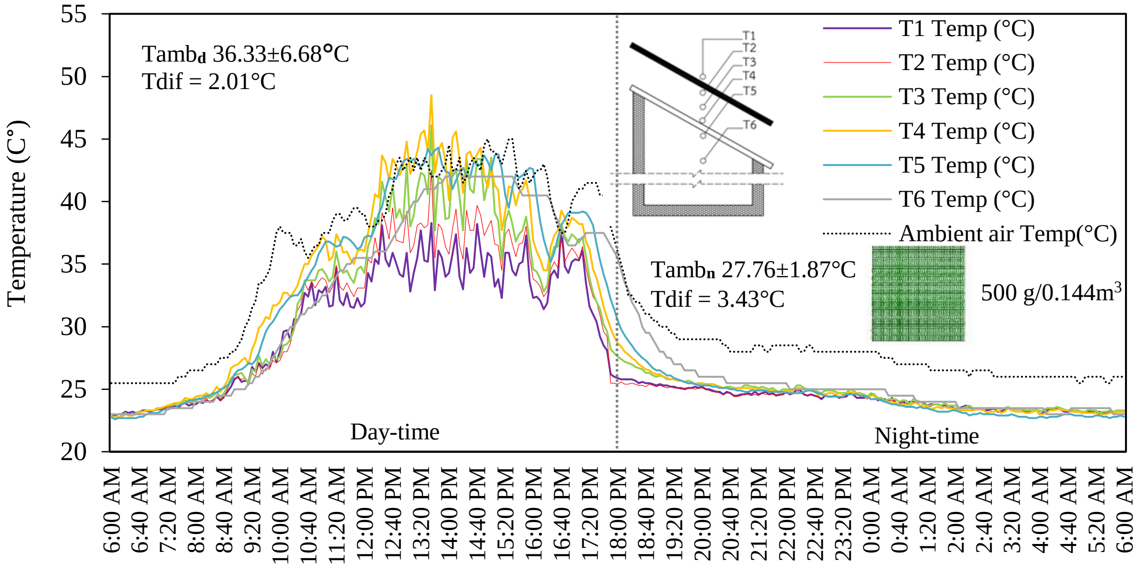


Figure 5.4 The temperature variation of Spanish Moss green roof on density 500g/0.144m^3 at air gap 20 cm.

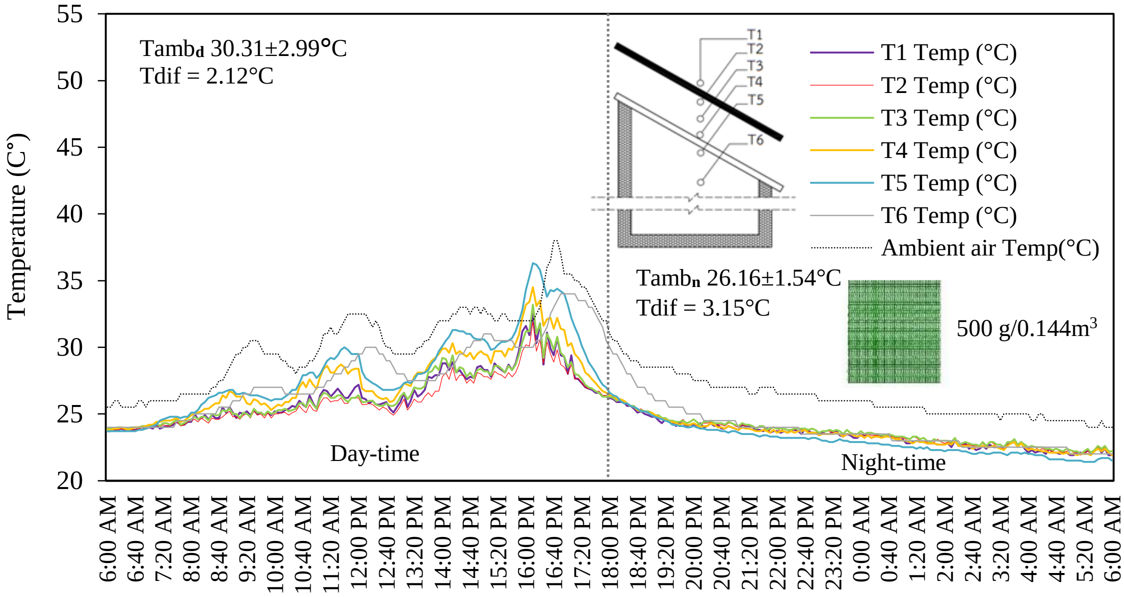


Figure 5.5 The temperature variation of Spanish Moss green roof on density 500g/0.144m^3 at air gap 30 cm

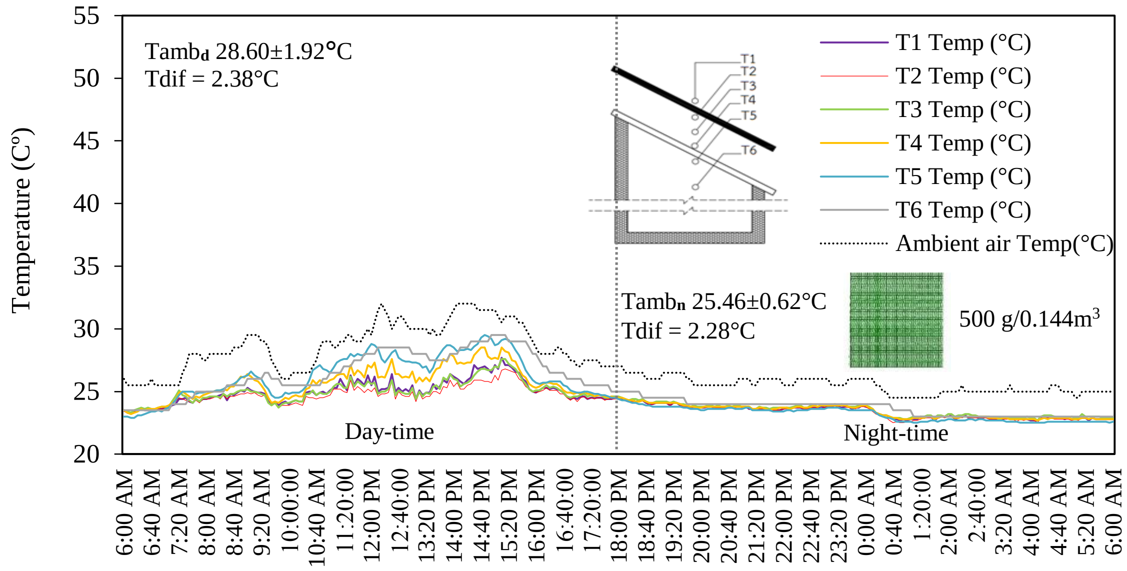


Figure 5.6 The temperature variation of Spanish Moss green roof on density 500g/0.144m^3 at air gap 40 cm

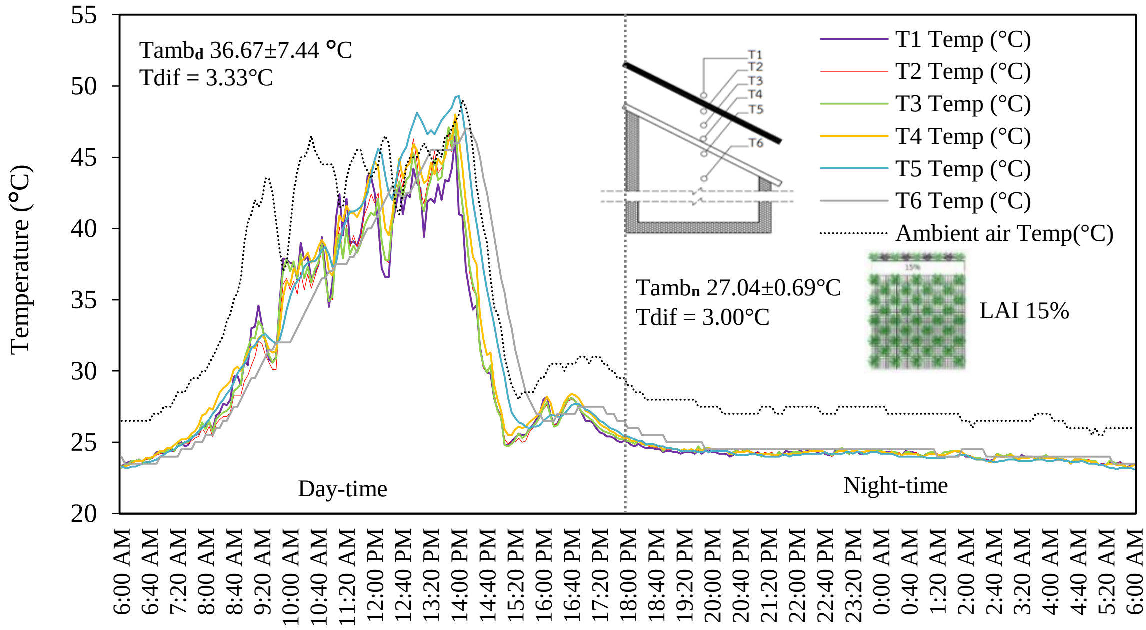


Figure 5.7 The temperature variation of Cotton Candy green roof on density 500g/0.144m^3 at air gap 10 cm

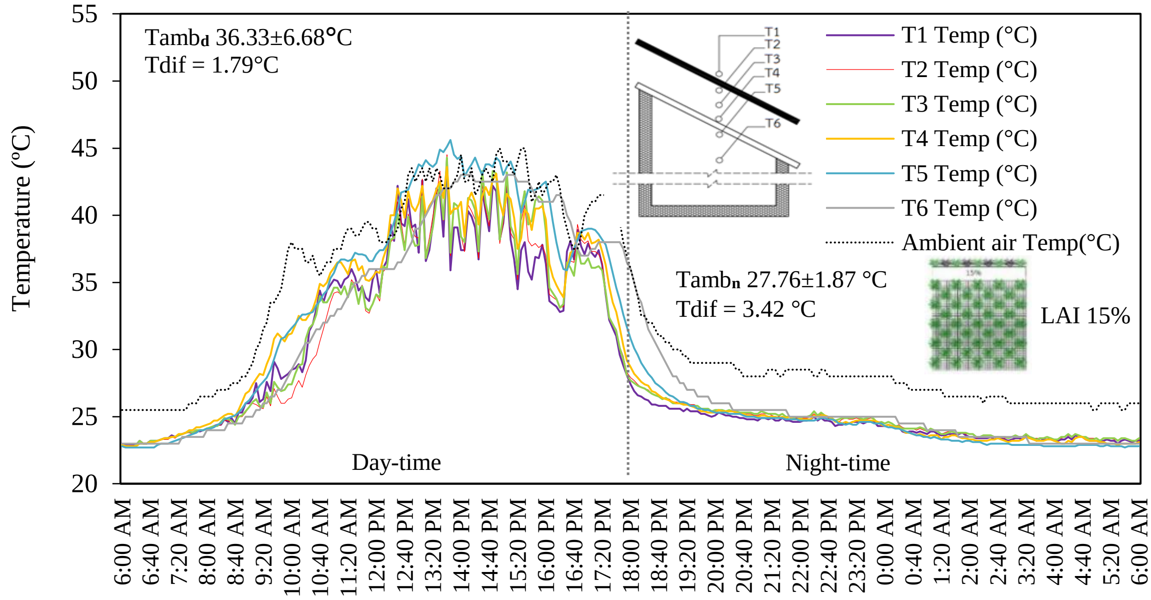


Figure 5.8 The temperature variation of Cotton Candy green roof on density 500g/0.144m^3 at air gap 20 cm

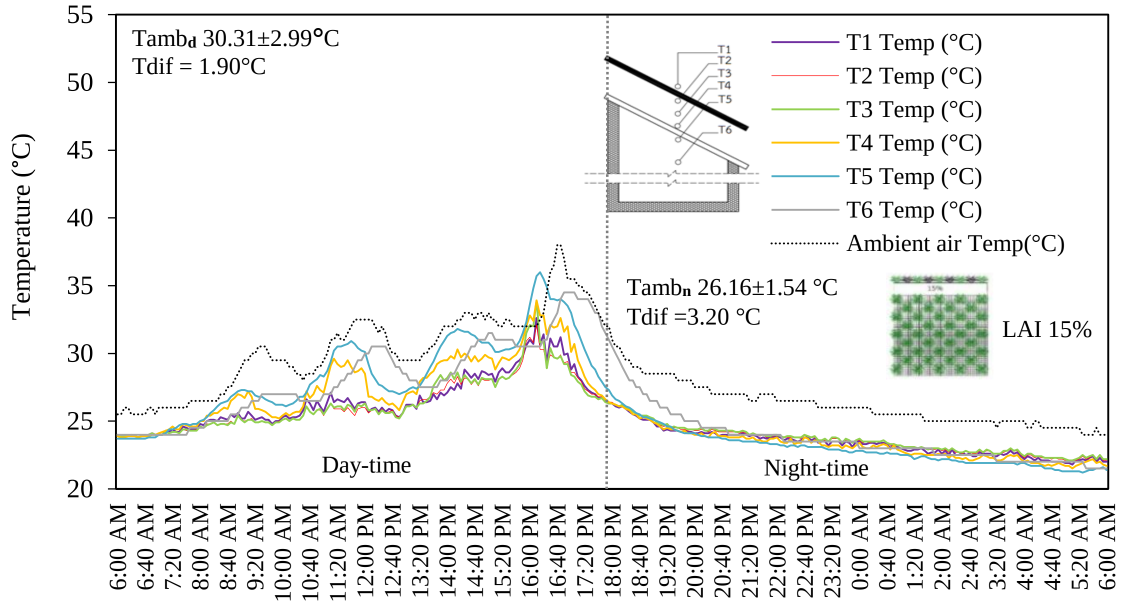


Figure 5.9 The temperature variation of Cotton Candy green roof on density 500g/0.144m^3 at air gap 30 cm

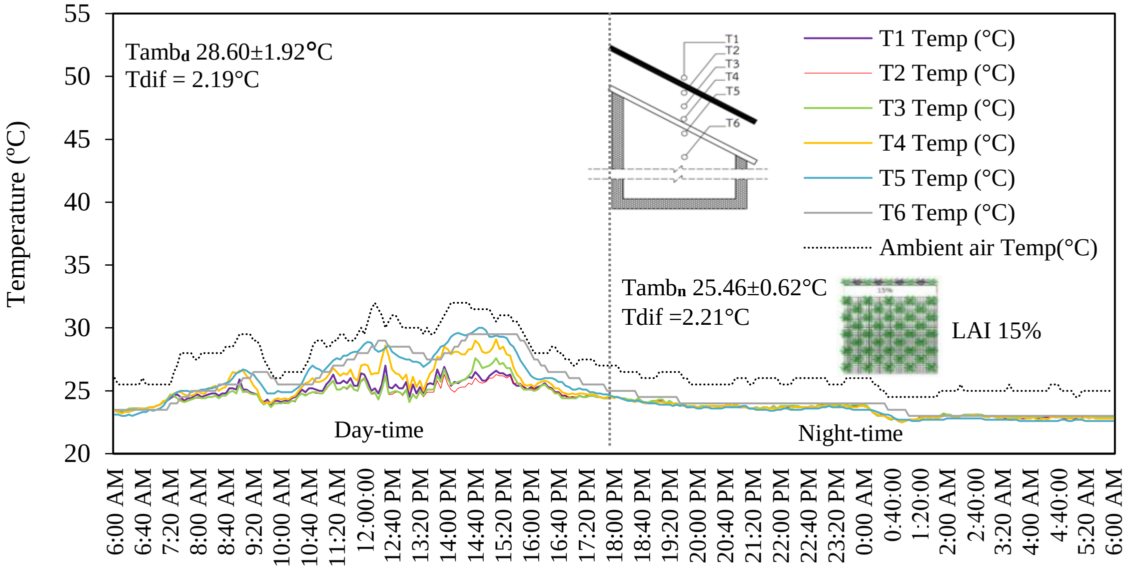
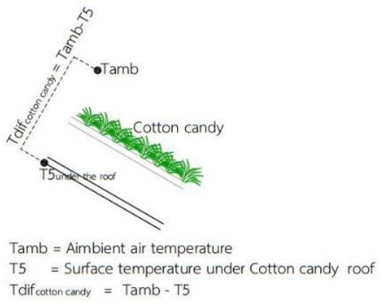
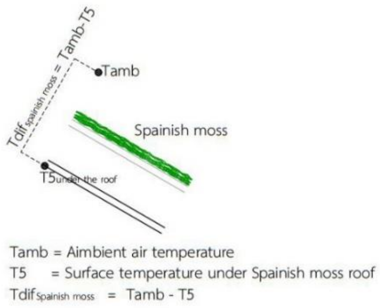


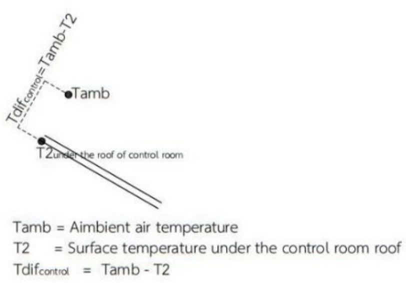
Figure 5.10 The temperature variation of Cotton Candy green roof on density 500g/0.144m^3 at air gap 40 cm

Table 5.3 The comparison of the different temperature (T_{dif}) on Air gab 10, 20, 30 and 40 cm of Spanish Moss and Cotton Candy roof (Weight per Volume (1,000g/0.144m^3)

Date	Air gap (cm)	**Spanish Moss of weight per volume (1,000g/0.144m^3 (Average temperature)**															
		Temperature(°C) Day-time								**Temperature(°C) Night-time**							
		$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)
11/10/2014	10	6.33 ±3.88	3.34 ±2.48	36.40 ±8.65		59.88 ±19.58		26.07 ±2.19	30.06 ±6.06	**2.82** ±0.61	3.20 ±0.55	27.72 ±1.29		83.93 ±5.18		24.70 ±0.24	24.91 ±0.78
25/10/2014	20	6.14 ±2.68	3.42 ±1.86	38.17 ±7.53	0.02	55.14 ±19.99	0.01	26.33 ±1.59	32.03 ±5.89	2.56 ±0.31	3.26 ±0.52	26.39 ±0.45	0.00	89.11 ±0.81	0.00	24.41 ±0.34	23.83 ±0.50
28/10/2014	30	**6.96**	2.30	38.92 ±8.51		53.60 ±19.46		26.40 ±1.82	31.97 ±6.37	2.70	3.47	26.41 ±0.61		85.76 ±2.30		23.85 ±0.24	23.45 ±0.52
31/10/2014	40	6.84	4.47	39.06 ±6.57		53.01 ±15.97		26.89 ±1.56	32.22 ±4.32	2.78	3.60	27.36 ±1.06		84.18 ±4.64		24.42 ±0.20	24.58 ±0.92
Date	Air gap (cm)	**Cotton Candy of weight per volume (1,000g/0.144m^3 (Average temperature)**															
		Temperature(°C) Day-time								**Temperature(°C) Day-time**							
		$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)
11/10/2014	10	3.77 ±2.55	3.34 ±2.48	36.40 ±8.65		59.88 ±19.58		26.07 ±2.19	31.99 ±7.24	2.99 ±0.50	3.20 ±0.55	27.72 ±1.29		83.93 ±5.18		24.70 ±0.24	24.73 ±0.93
25/10/2014	20	3.72 ±2.26	3.42 ±1.86	38.17 ±7.53	0.02	55.14 ±19.99	0.01	26.33 ±1.59	34.45 ±7.68	2.72	3.26 ±0.52	26.39 ±0.45	0.00	89.11 ±0.81	0.00	24.41 ±0.34	23.66 ±0.59
28/10/2014	30	5.01	2.30	38.92 ±8.51		53.60 ±19.46		26.40 ±1.82	33.92 ±8.23	2.96	3.47	26.41 ±0.61		85.76 ±2.30		23.85 ±0.24	23.45 ±0.52
31/10/2014	40	**5.93**	4.47	39.06 ±6.57		53.01 ±15.97		26.89 ±1.56	33.13 ±5.12	**3.05**	3.60	27.36 ±1.06		84.18 ±4.64		24.42 ±0.20	24.31 ±0.96







5.3 Node 1: Boundary surface temperature of Spanish Moss roof (density 1,000 g/0.144m^3)

- Spanish Moss roof with a 10 cm wide air gap

During the day-time, the comparison of the average surface temperature between Spanish Moss roof (density 1,000 g/0.144m^3) and control roof on October 11, 2014 was different. The average of different temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Spanish Moss ($T5_{Spanish\ Moss}$) was as 6.33°C and decreased in the range of 1.20-16.10°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 2.6°C, which was lower than $T5_{Spanish\ Moss}$. The average of T_{amb} during the daytime was 36.40±8.65°C and the relative humidity (RH) was 59.88±19.58%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Spanish\ Moss}$ was 2.82°C. It decreased in the range of 1.8-5.7°C and $T_{dif\ control}$ was 3.20°C. T_{amb} during the night time was 27.72 ±1.29°C and RH was 83.93±5.18%.

The average of $T_{5\ Spanish\ Moss}$ was 27.47±5.02°C all day and T_{amb} on October 11, 2014 was 32.04±7.54°C.

- Spanish Moss roof with a 20 cm wide air gap

During the day-time, the comparison of the average surface temperature between Spanish Moss roof (density 1,000 g/0.144m^3) and control roof on October 25, 2014 was different. The average different temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Spanish Moss ($T5_{Spanish\ Moss}$) was as 6.14°C and decreased in the range of 1.9-11.4°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 0.69°C, which was lower than $T5_{Spanish\ Moss}$. The average of T_{amb} during the daytime was 38.17±7.53°C and the relative humidity (RH) was 55.14±19.99%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Spanish\ Moss}$ was 2.56°C. It decreased in the range of 1.8-3.1°C and $T_{dif\ control}$ was 3.26°C. T_{amb} during the night time was 26.39 ±0.45°C and RH was 89.11±0.81%.

The average of $T_{5\ Spanish\ Moss}$ was 27.92±5.85°C all day and T_{amb} on October 25, 2014 was 32.26±7.94 °C.

- Spanish Moss roof with a 30 cm wide air gap

During the day-time, the comparison of the average surface temperature between Spanish Moss roof (density 1,000 g/0.144m^3) and control roof on October 28, 2014 was different. The average different temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Spanish Moss ($T5_{Spanish}$

$_{Moss}$) was as 6.96°C and it decreased in the range of 2.1-14.1°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 2.30°C, which was lower than T5 $_{Spanish\ Moss}$. The average of T_{amb} during the daytime was 38.92±8.51°C and the relative humidity (RH) was 53.60±19.46%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Spanish\ Moss}$ was 2.70°C. It decreased in the range of 1.7-3.7°C and $T_{dif\ control}$ was C. T_{amb} during the night time was 26.41 ±0.61°C and RH was 85.76±2.30%.

The average of $T_{5\ Spanish\ Moss}$ was 27.82±6.12°C all day and T_{amb} on October 28, 2014 was 32.64±8.69°C.

- Spanish Moss roof with a 40 cm wide air gap

During the day-time, the comparison of the average surface temperature between Spanish Moss roof (density 1,000 g/0.144m^3) and control roof on October 31, 2014 was different. The average difference temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Spanish Moss (T5 $_{Spanish\ Moss}$) was as 6.84°C and it decreased in the range of 1.6-16°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 4.47°C, which was lower than T5 $_{Spanish\ Moss}$. The average of T_{amb} during the daytime was 39.06±6.57°C and the relative humidity (RH) was 53.01±15.97%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Spanish\ Moss}$ was 2.78°C. It decreased in the range of 2-3.3°C and $T_{dif\ control}$ was 3.60°C. T_{amb} during the night time was 27.36 ±1.06°C and RH was 84.18±4.64%.

The average of $T_{5\ Spanish\ Moss}$ was 28.39±4.93°C all day and T_{amb} on October 31, 2014 was 33.19±7.51°C.

5.4 Node 2: Boundary surface temperature of Cotton Candy roof (density 1,000 g/0.144m^3)

- Cotton Candy roof with a 10 cm wide air gap

During the day-time, the comparison of the average surface temperature between Cotton Candy roof (density 1,000 g/0.144m^3) and control roof on October 11, 2014 was different. The average difference temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Cotton Candy (T5 $_{Cotton\ Candy}$) was as 4.40°C and it decreased in the range of -1-14 °C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 2.6°C, which was lower than T5 $_{Cotton\ Candy}$. The average of T_{amb} during the daytime was 36.40±8.65°C and the relative humidity (RH) was 59.88±19.58%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Cotton\ Candy}$ was 2.99°C. It decreased in the range of 2-4.90°C and $T_{dif\ control}$ was 3.20°C. T_{amb} during the night time was 27.72 ±1.29°C and RH was 83.93±5.18%.

The average of $T_{5\ Cotton\ Candy}$ was 28.35±6.30°C all day and T_{amb} on October 11, 2014 was 32.04±7.54 °C.

- Cotton Candy roof with a 20 cm wide air gap

During the day-time, the comparison of the average surface temperature between Cotton Candy roof (density 1,000 g/0.144m^3) and control roof on October 25, 2014 was different. The average difference temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Cotton Candy (T5 $_{Cotton\ Candy}$) was as 3.72°C and it decreased in the range of 0.60-9.20°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 0.69°C, which was lower than T5 $_{Cotton\ Candy}$. The average of T_{amb} during the daytime was 38.17±7.53°C and the relative humidity (RH) was 55.14±19.99%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Cotton\ Candy}$ was 2.72°C. It decreased in the range of 1.50-3.30°C and $T_{dif\ control}$ was 3.26 °C. T_{amb} during the night time was 26.39±0.45°C and RH was 89.11±0.81%.

The average of $T_{5\ Cotton\ Candy}$ was 29.04±7.66°C all day and T_{amb} on October 25, 2014 was 32.26±7.94 °C.

- Cotton Candy roof with a 30 cm wide air gap

During the day-time, the comparison of the average surface temperature between Cotton Candy roof (density 1,000 g/0.144m^3) and control roof on October 28, 2014 was different. The average of difference temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Cotton Candy (T5 $_{Cotton\ Candy}$) was as 5.01°C and it decreased in the range of 0.80-12.6°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 2.30°C, which was lower than T5 $_{Cotton\ Candy}$. The average of T_{amb} during the daytime was 38.92±8.51°C and the relative humidity (RH) was 53.60±19.46%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Cotton\ Candy}$ was 2.96°C. It decreased in range 2.10-3.60°C and $T_{dif\ control}$ was 3.47°C. T_{amb} during the night time was 26.41 ±0.61°C and RH was 85.76±2.30%.

The average of $T_{5\ Cotton\ Candy}$ all day was 28.66±7.83°C and T_{amb} on October 31, 2014 was 32.64±8.69°C.

- Cotton Candy roof with a 40 cm wide air gap

During the day-time, the comparison of the average surface temperature between Cotton Candy roof (density 1,000 g/0.144m^3) and control roof on October 31, 2014 was different. The average of difference temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Cotton Candy ($T5_{Cotton\ Candy}$) was as 5.93°C and it decreased in the range of -0.10-15.30 °C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 4.47°C, which was lower than $T5_{Cotton\ Candy}$. The average of T_{amb} during the daytime was 39.06±6.57°C and the relative humidity (RH) was 53.01±15.97%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Cotton\ Candy}$ was 3.05°C. It decreased in the range of 2.30-3.60 °C and $T_{dif\ control}$ was 3.60°C. T_{amb} during the night time was 27.36±1.62°C and RH was 84.18±4.64%.

The average of $T_{5\ Cotton\ Candy}$ was 28.70±5.75 °C all day and T_{amb} on October 31, 2014 was 33.19±7.51 °C.

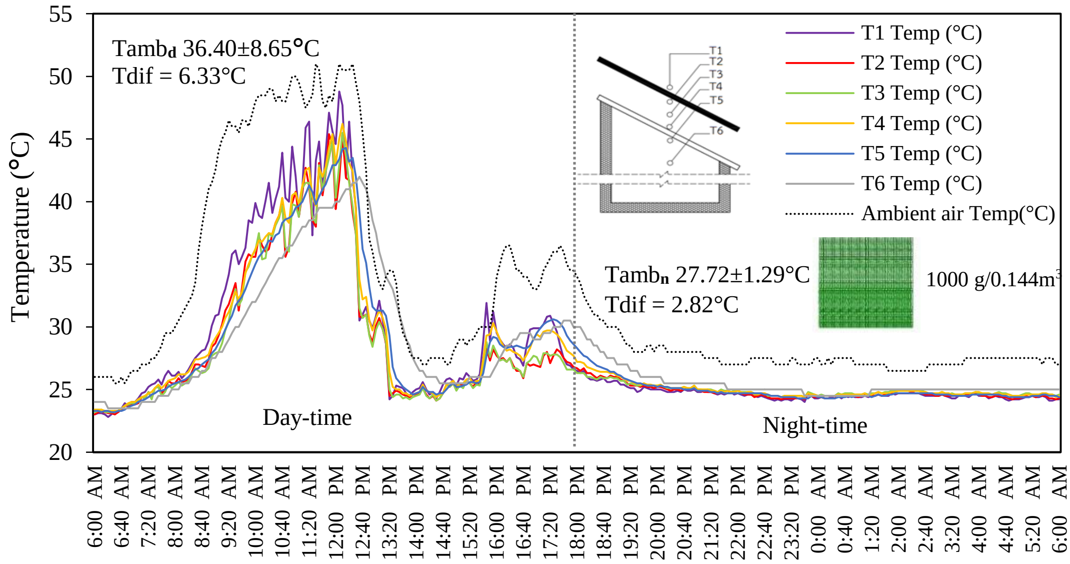


Figure 5.11 The temperature variation of Spanish Moss green roof on density 1,000g/0.144m^3 at air gap 10 cm

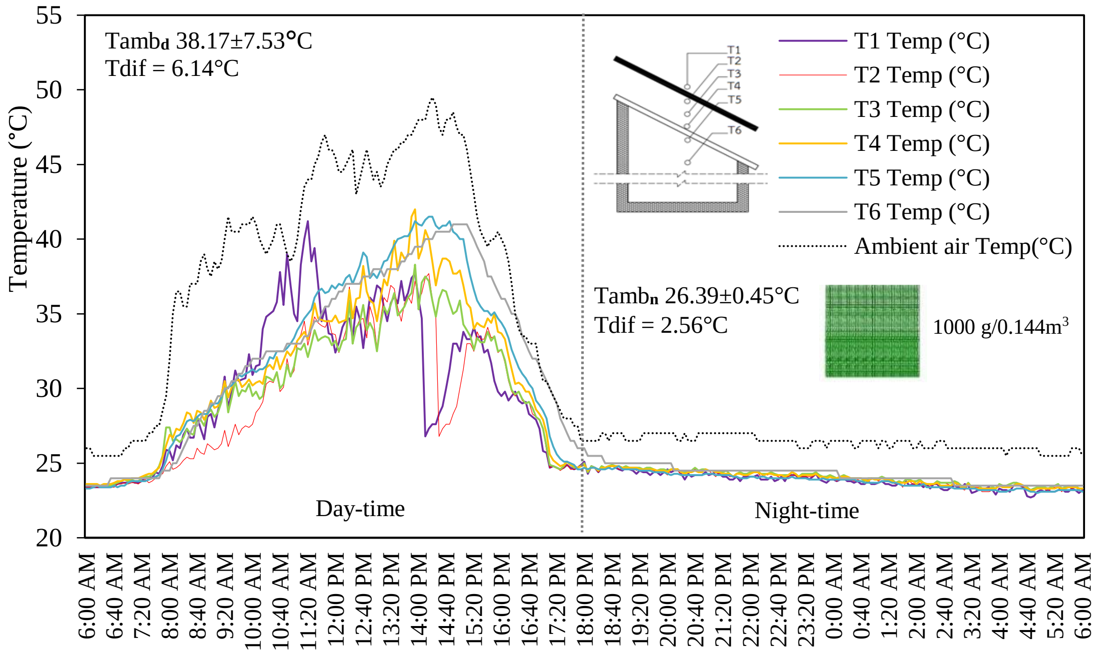


Figure 5.12 The temperature variation of Spanish Moss green roof on density 1,000g/0.144m^3 at air gap 20 cm.

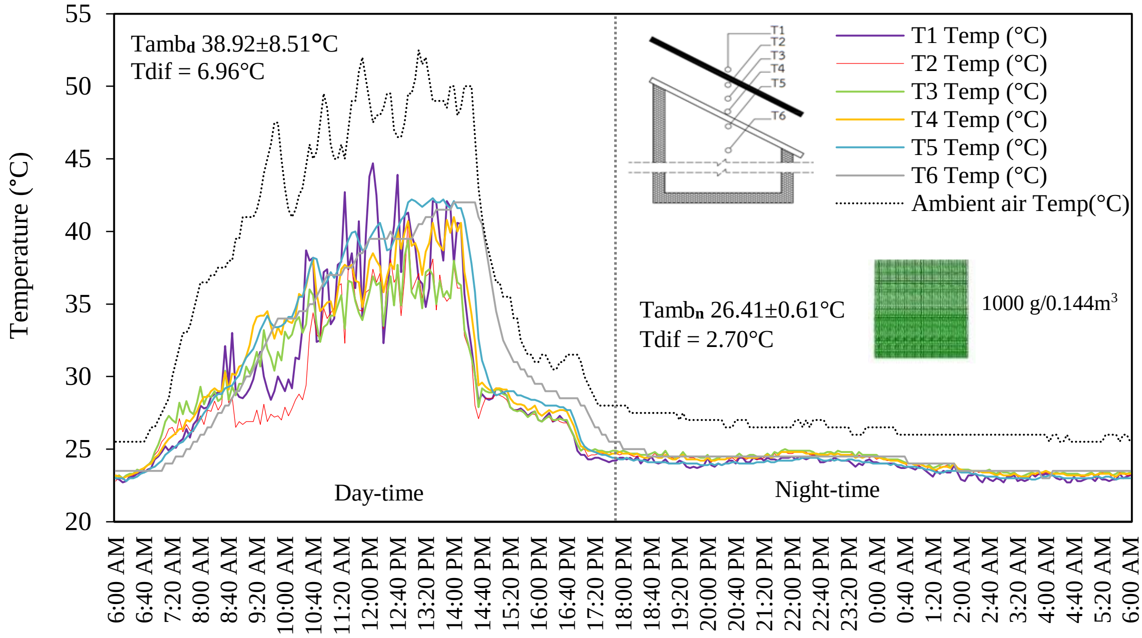


Figure 5.13 The temperature variation of Spanish Moss green roof on density 1,000g/0.144m^3 at air gap 30 cm

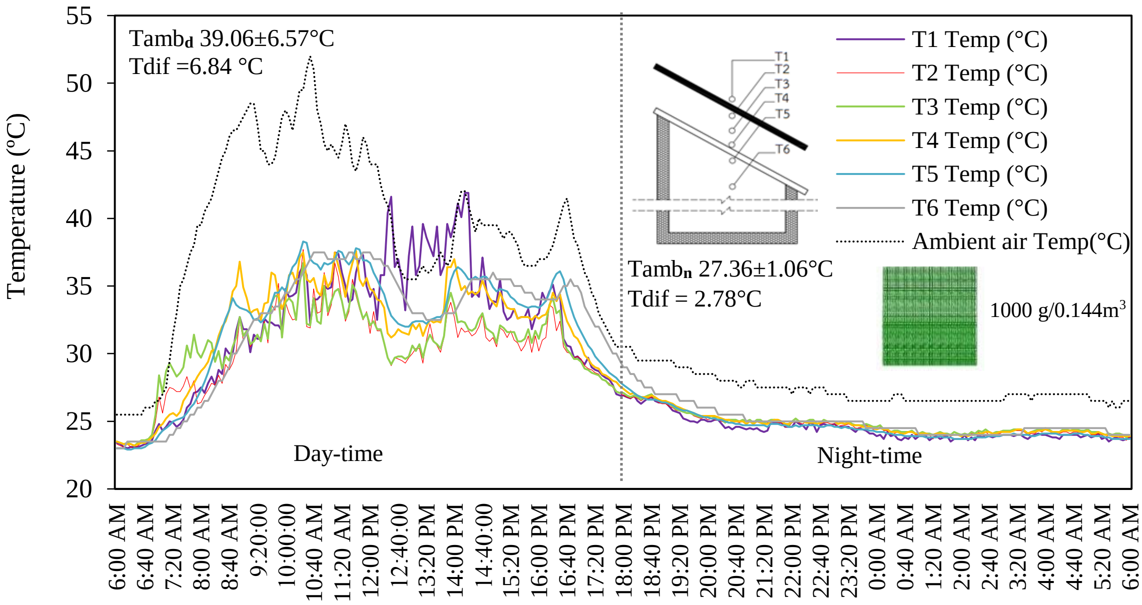


Figure 5.14 The temperature variation of Spanish Moss green roof on density 1,000g/0.144m^3 at air gap 40 cm

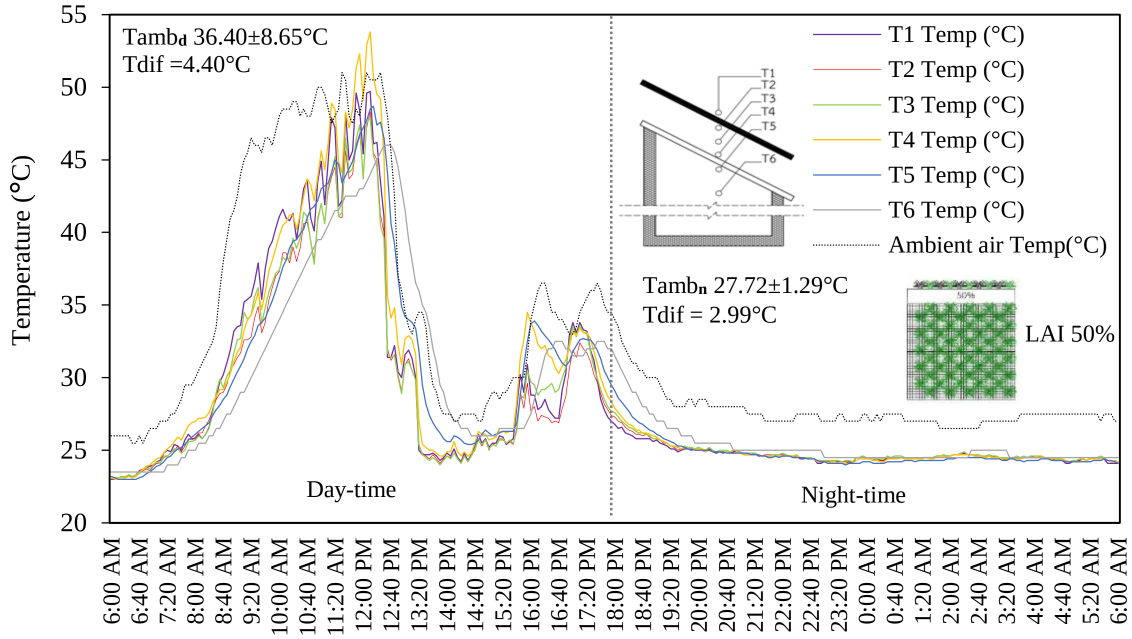


Figure 5.15 The temperature variation of Cotton Candy green roof on density 1,000g/0.144m^3 at air gap 10 cm

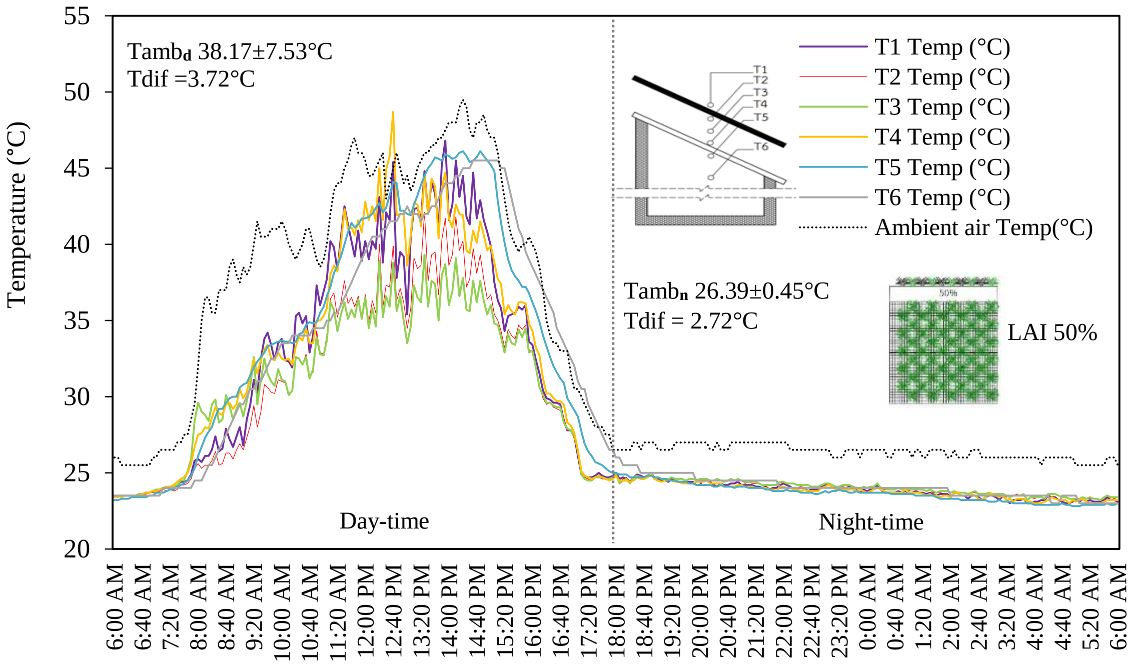


Figure 5.16 The temperature variation of Cotton Candy green roof on density 1,000g/0.144m^3 at air gap 20 cm

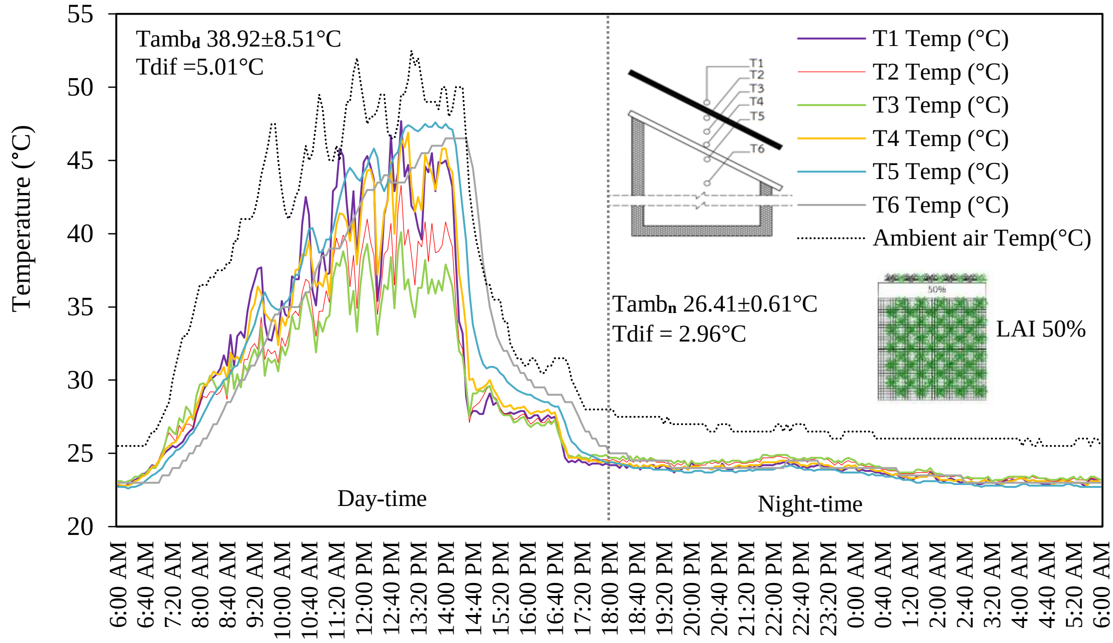


Figure 5.17 The temperature variation of Cotton Candy green roof on density 1,000g/0.144m^3 at air gap 30 cm

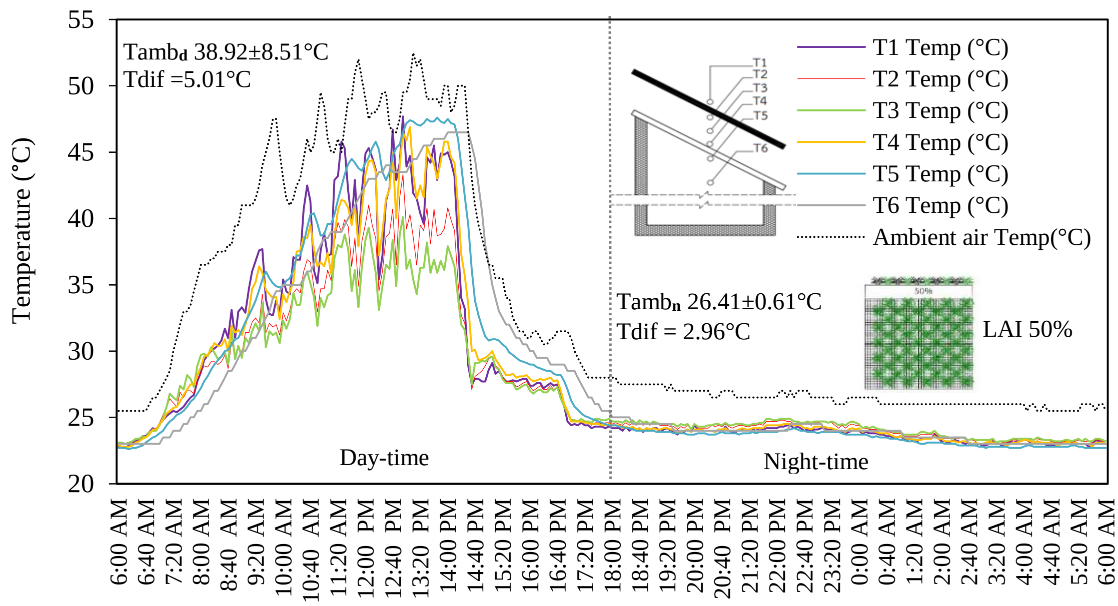
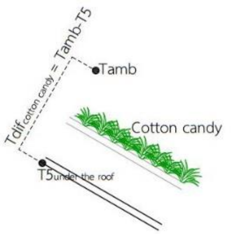


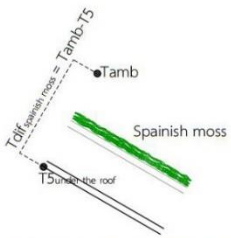
Figure 5.18 The temperature variation of Cotton Candy green roof on density 1,000g/0.144m^3 at air gap 40 cm

Table 5.4 Comparison of the different temperature (T_{dif}) on Air gab 10, 20, 30 and 40 cm of Spanish Moss and Cotton Candy roof (Weight per Volume (1,500g/0.144m³)

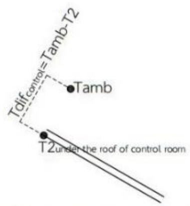
Date	Air gap (cm)	**Spanish Moss of weight per volume (1,500g/0.144m³ (Average temperature)**															
		Temperature(°C) Day-time								**Temperature(°C) Night-time**							
		$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)
21/8/2014	10	5.40	6.08	38.66 ±6.43		50.08 ±19.10		25.26 ±1.17	33.26 ±5.18	1.53	1.67	28.92 ±2.54		76.91 ±11.95		24.20 ±0.56	27.39 ±2.20
18/8/2014	20	6.71	1.84	37.81 ±8.14	0.00	53.90 ±20.73	0.00	25.45 ±1.87	31.09 ±4.36	1.16	2.46	26.32 ±1.18	0.00	86.42 ±4.72	0.00	23.84 ±0.37	25.16 ±0.98
27/8/2014	30	**8.1**	4.42	35.94 ±5.42		55.93 ±17.15		25.00 ±1.23	27.87 ±2.41	2.90	3.72	26.98 ±1.92		79.64 ±8.67		23.06 ±0.27	24.08 ±1.17
14/8/2014	40	4.87	6.03	31.61 ±6.60		70.75 ±18.85		24.77 ±1.45	26.75 ±3.45	**4.10**	4.92	28.14 ±3.60		79.80 ±13.13		24.01 ±0.56	24.05 ±1.14
Date	Air gap (cm)	**Cotton Candy of weight per volume (1,500g/0.144m³ (Average temperature)**															
		Temperature(°C) Day-time								**Temperature(°C) Day-time**							
		$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)
21/8/2014	10	1.44	6.08	38.66 ±6.43		50.08 ±19.10		25.26 ±1.17	37.49 ±7.93	2.21	1.67	28.92 ±2.54		76.91 ±11.95		24.20 ±0.56	26.48 ±1.99
18/8/2014	20	5.15	1.84	37.81 ±8.14	0.00	53.90 ±20.73	0.00	25.45 ±1.87	32.65 ±6.02	1.52	2.46	26.32 ±1.18	0.00	86.42 ±4.72	0.00	23.84 ±0.37	24.80 ±1.07
27/8/2014	30	**6.87**	4.42	35.94 ±5.42		55.93 ±17.15		25.00 ±1.23	29.06 ±3.12	3.00	3.72	26.98 ±1.92		79.64 ±8.67		23.06 ±0.27	23.99 ±1.27
14/8/2014	40	-	6.03	31.61 ±6.60		70.75 ±18.85		24.77 ±1.45	-	**4.20**	4.92	28.14 ±3.60		79.80 ±13.13		24.01 ±0.56	23.95 ±1.23



Tamb = Aimbient air temperature
T5 = Surface temperature under Cotton candy roof
Tdif cotton candy = Tamb - T5



Tamb = Aimbient air temperature
T5 = Surface temperature under Spainish moss roof
Tdif spainish moss = Tamb - T5



Tamb = Aimbient air temperature
T2 = Surface temperature under the control room roof
Tdif control = Tamb - T2

5.5 Node 1: Boundary surface temperature of Spanish Moss roof (density 1,500 g/0.144m^3)

- Spanish Moss roof with a 10 cm wide air gap

During the day-time, the comparison of the average surface temperature between Spanish Moss roof (density 1,500 g/0.144m^3) and control roof on August 21, 2014 was different. The average different temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Spanish Moss ($T5_{Spanish\ Moss}$) was as 5.40°C and it decreased in the range of 0.7-11.4°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 6.08°C, which was lower than $T5_{Spanish\ Moss}$. The average of T_{amb} during the daytime was 38.66±6.43°C and the relative humidity (RH) was 50.08±19.10%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Spanish\ Moss}$ was 1.53°C. It decreased in the range of 0.7-3.7°C and $T_{dif\ control}$ was 1.67°C. T_{amb} during the night time was 28.92±2.54°C and RH was 76.91±11.95%.

The average of $T_{5\ Spanish\ Moss}$ was 30.31±4.94°C all day and T_{amb} on August 21, 2014 was 33.77±6.90 °C.

- Spanish Moss roof with a 20 cm wide air gap

During the day-time, the comparison of the average surface temperature between Spanish Moss roof (density 1,500 g/0.144m^3) and control roof on August 18, 2014 was different. The average different temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Spanish Moss ($T5_{Spanish\ Moss}$) was as 6.71°C and it decreased in the range of 1.1-16°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 1.84°C, which was lower than $T5_{Spanish\ Moss}$. The average of T_{amb} during the daytime was 37.81±8.14°C and the relative humidity (RH) was 53.90±20.73%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Spanish\ Moss}$ was 1.16°C. It decreased in the range of 0.7-2.3°C and $T_{dif\ control}$ was 2.46°C. T_{amb} during the night time was 26.32 ±1.18 °C and RH was 86.42±4.72%.

The average of $T_{5\ Spanish\ Moss}$ was 28.11±4.33°C all day and T_{amb} on August18, 2014 was 32.04±8.16 °C.

- Spanish Moss roof with a 30 cm wide air gap

During the day-time, the comparison of the average surface temperature between Spanish Moss roof (density 1,500 g/0.144m^3) and control roof on August 27, 2014 was different. The average different temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Spanish Moss ($T5_{Spanish\ Moss}$) was as 8.1°C and it decreased in the range of 0.6-15.2°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 4.42°C, which was lower than T5 $_{Spanish\ Moss}$. The average of T_{amb} during the daytime was 35.94±5.42°C and the relative humidity (RH) was 55.93±17.15%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Spanish\ Moss}$ was 2.90°C. It decreased in the range of 1.3-4.9°C and $T_{dif\ control}$ was 3.72ºC. T_{amb} during the night time was 26.98 ±1.92°C and RH was 79.64±8.67%.

The average of $T_{5\ Spanish\ Moss}$ was 25.97±2.68°C all day and T_{amb} on August 27, 2014 was 31.44±6.04 °C.

- Spanish Moss roof with a 40 cm wide air gap

During the day-time, the comparison of the average surface temperature between Spanish Moss roof (density 1,500 g/0.144m^3) and control roof on August 27, 2014 was different. The average different temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Spanish Moss (T5 $_{Spanish\ Moss}$) was as 4.87°C and it decreased in the range of 0.5-10.5°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 6.03°C, which was lower than T5 $_{Spanish\ Moss}$. The average of T_{amb} during the daytime was 31.61±6.60 °C and the relative humidity (RH) was 70.75±18.85%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Spanish\ Moss}$ was 4.10°C. It decreased in the range of 1.3-11.2°C and $T_{dif\ control}$ was 4.92°C. T_{amb} during the night time was 28.14±3.60°C and RH was 79.80±13.13%.

The average of $T_{5\ Spanish\ Moss}$ was 24.78±2.36°C all day and T_{amb} on August 27, 2014 was 29.12±4.89°C.

5.6 Node 2: Boundary surface temperature of Cotton Candy roof (density 1,500 g/0.144m^3)

– Cotton Candy roof with a 10 cm wide air gap

During the day-time, the comparison of the average surface temperature between Cotton Candy roof (density 1,500 g/0.144m^3) and control roof on August 21, 2014 was different. The average different temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Cotton Candy (T5 $_{Cotton\ Candy}$) was as 1.44°C and it decreased in the range of -5.70-8.50°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 6.08°C, which was lower than T5 $_{Cotton\ Candy}$. The average of T_{amb} during the daytime was 38.66±6.43°C and the relative humidity (RH) was 50.08±19.10%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Cotton\ Candy}$ was 2.21°C. It decreased in the range of 1.50-3.80°C and $T_{dif\ control}$ was 1.67°C. T_{amb} during the night time was 28.92±2.54°C and RH was 76.91±11.95%.

The average of $T_{5\ Cotton\ Candy}$ was 31.97±7.98°C all day and T_{amb} on August 21, 2014 was 33.79±6.87°C.

– Cotton Candy roof with a 20 cm wide air gap

During the day-time, the comparison of the average surface temperature between Cotton Candy roof (density 1,500 g/0.144m^3) and control roof on August 18, 2014 was different. The average different temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Cotton Candy (T5 $_{Cotton\ Candy}$) was as 5.15°C and it decreased in the range of 1-14 °C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 1.84°C, which was lower than T5 $_{Cotton\ Candy}$. The average of T_{amb} during the daytime was 37.81±8.14°C and the relative humidity (RH) was 53.90 ±20.73%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Cotton\ Candy}$ was 1.52°C. It decreased in the range of 1.10-2.20°C and $T_{dif\ control}$ was 2.46°C. T_{amb} during the night time was 26.32±1.18°C and RH was 86.42±4.72%.

The average of $T_{5\ Cotton\ Candy}$ was 28.71±5.84°C all day and T_{amb} on August 18, 2014 was 32.04±8.16°C.

– Cotton Candy roof with a 30 cm wide air gap

During the day-time, the comparison of the average surface temperature between Cotton Candy roof (density 1,500 g/0.144m^3) and control roof on August 27, 2014 was different. The average different temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Cotton Candy (T5 $_{Cotton\ Candy}$) as 6.87°C and decreased in range 0.70-14.50°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 4.42°C, which was lower than T5 $_{Cotton\ Candy}$. The average of T_{amb} during the daytime was 35.94±5.42°C and the relative humidity (RH) was 55.93±17.15%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Cotton\ Candy}$ was 3°C. It decreased in the range of 1.50±4.60°C and $T_{dif\ control}$ was 3.72°C. T_{amb} during the night time was 26.98 ±1.92°C and RH was 79.64±8.67%.

The average of $T_{5\ Cotton\ Candy}$ was 26.52°3.48°C all day and T_{amb} on August 27, 2014 was 31.44±6.04°C

– Cotton Candy roof with a 40 cm wide air gap

During the day-time, the comparison of the average surface temperature between Cotton Candy roof (density 1,500 g/0.144m^3) and control roof on August 14, 2014 was different. The average different temperature (T_{dif}) between the ambient air temperature (T_{amb}) and surface temperature under the roof of Cotton Candy ($T5_{Cotton\ Candy}$) was as -°C and it decreased in the range of -°C. T_{dif} between T_{amb} and surface temperature under the control roof (T_2) was as 6.03°C, which was lower than $T5_{Cotton\ Candy}$. The average of T_{amb} during the daytime was 31.61±6.60°C and the relative humidity (RH) was 70.75±18.85%.

During the night time, the average of T_{dif} between T_{amb} and $T_{5\ Cotton\ Candy}$ was -°C. It decreased in the range of -°C and $T_{dif\ control}$ was 4.20°C. T_{amb} during the night time was 28.14±3.60°C and RH was 79.80±13.13%.

The average of $T_{5\ Cotton\ Candy}$ was 23.95±1.23°C all day and T_{amb} on August 14, 2014 was 29.12±3.60°C.

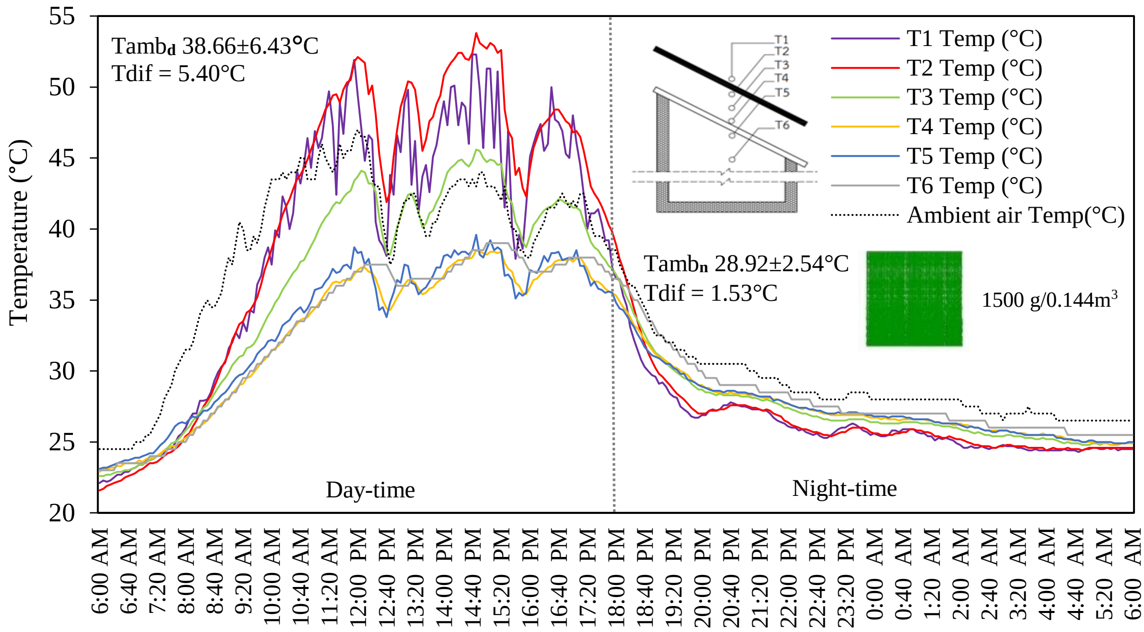


Figure 5.19 The temperature variation of Spanish Moss green roof on density 1,500g/0.144m^3 at air gap 10 cm.

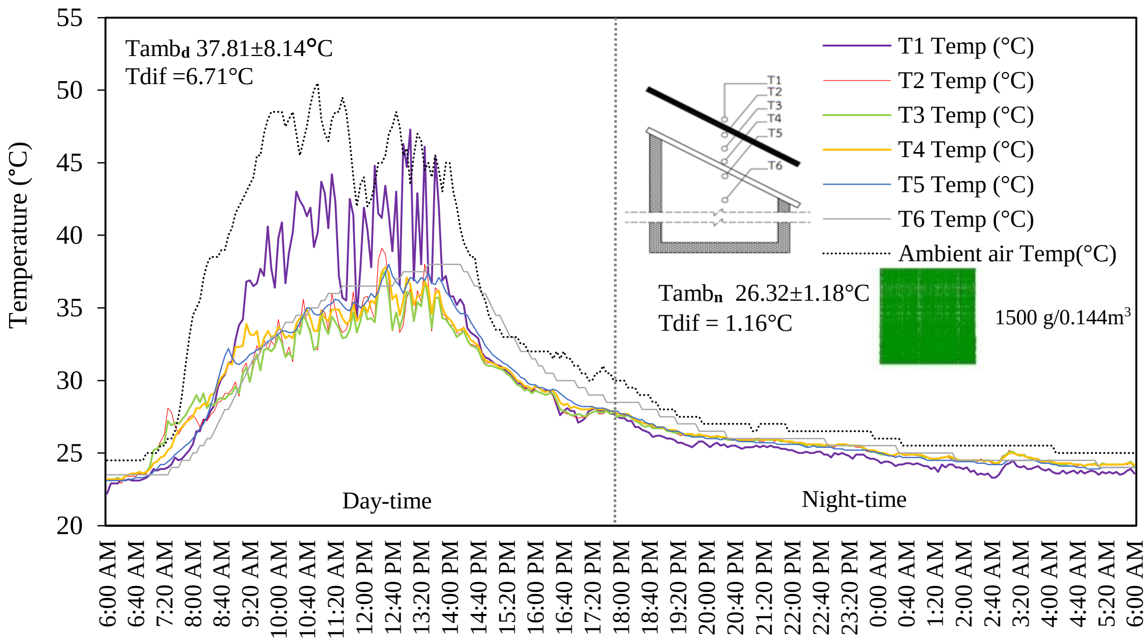


Figure 5.20 The temperature variation of Spanish Moss green roof on density 1,500g/0.144m^3 at air gap 20 cm.

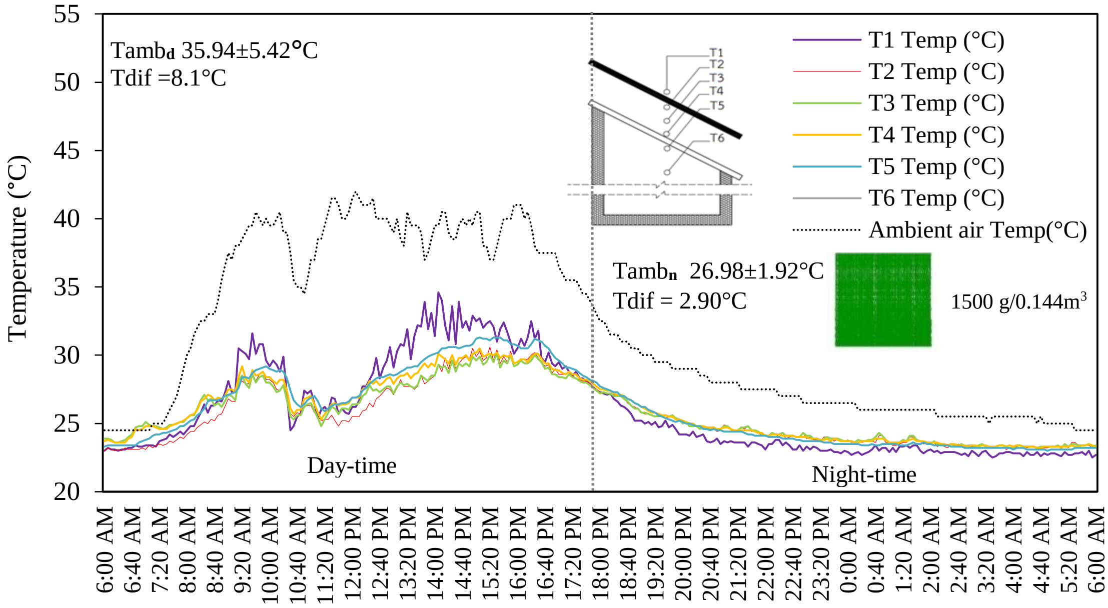


Figure 5.21 The temperature variation of Spanish Moss green roof on density 1,500g/0.144m^3 at air gap 30 cm.

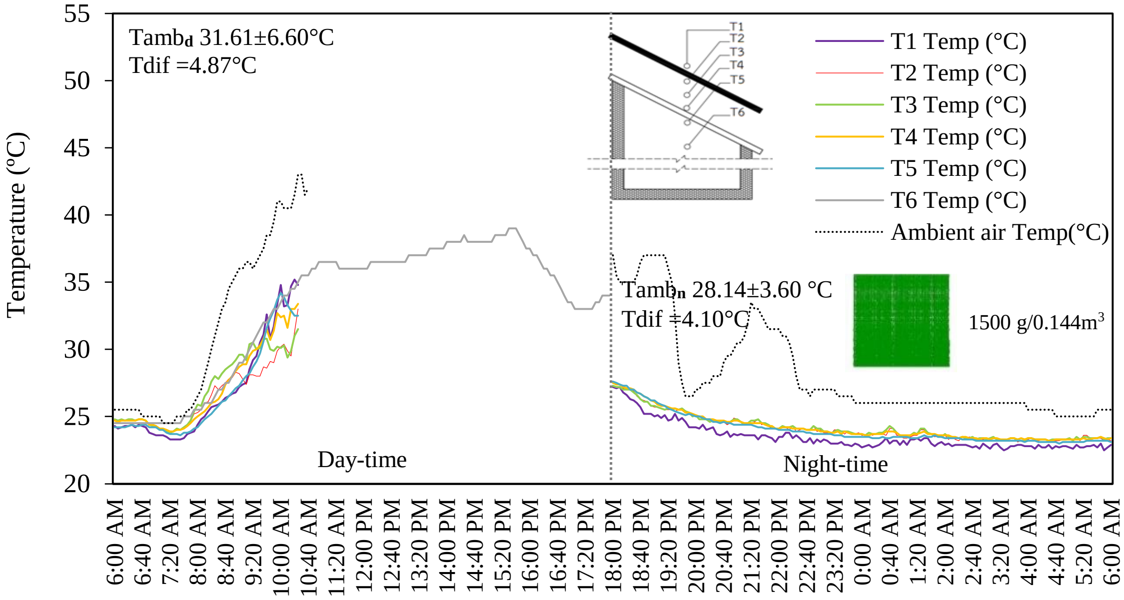


Figure 5.22 The temperature variation of Spanish Moss green roof on density 1,500g/0.144m^3 at air gap 40 cm.

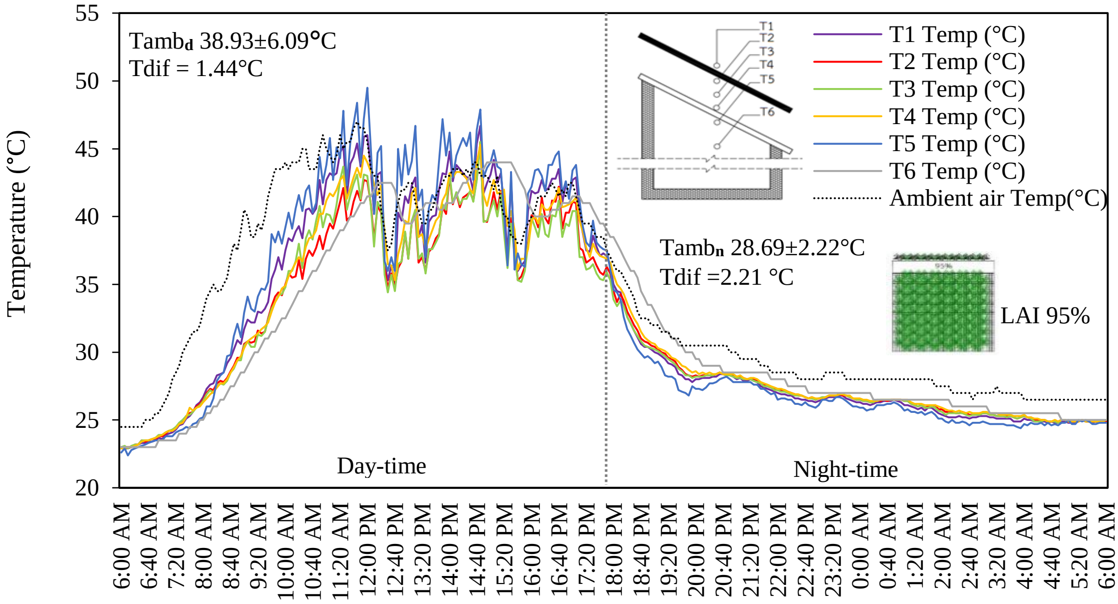


Figure 5.23 The temperature variation of Cotton Candy green roof on density 1,500g/0.144m^3 at air gap 10 cm.

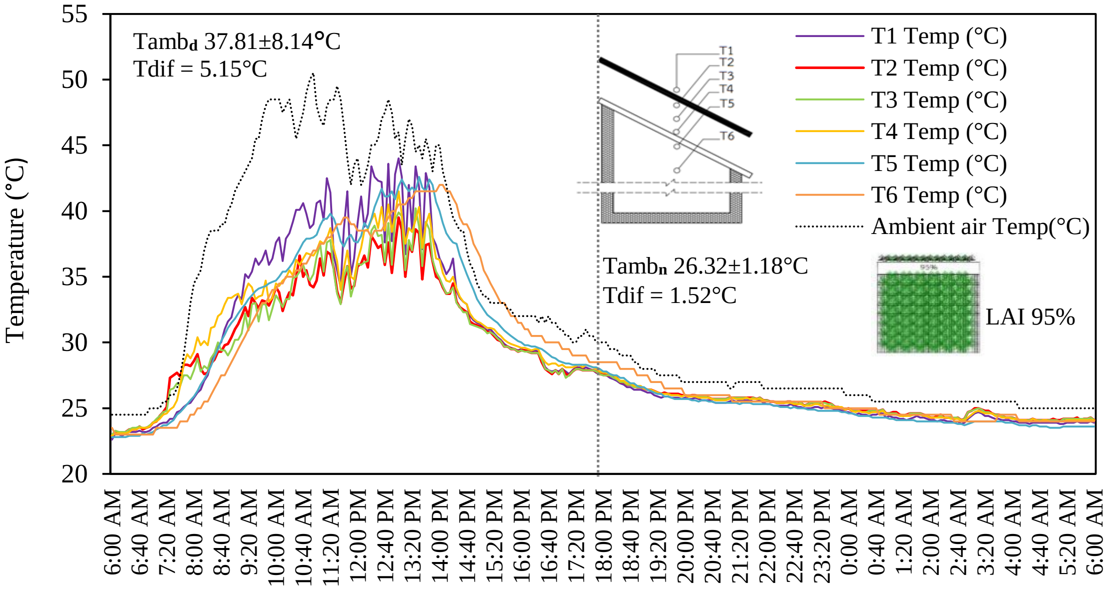


Figure 5.24 The temperature variation of Cotton Candy green roof on density 1,500g/0.144m^3 at air gap 20 cm.

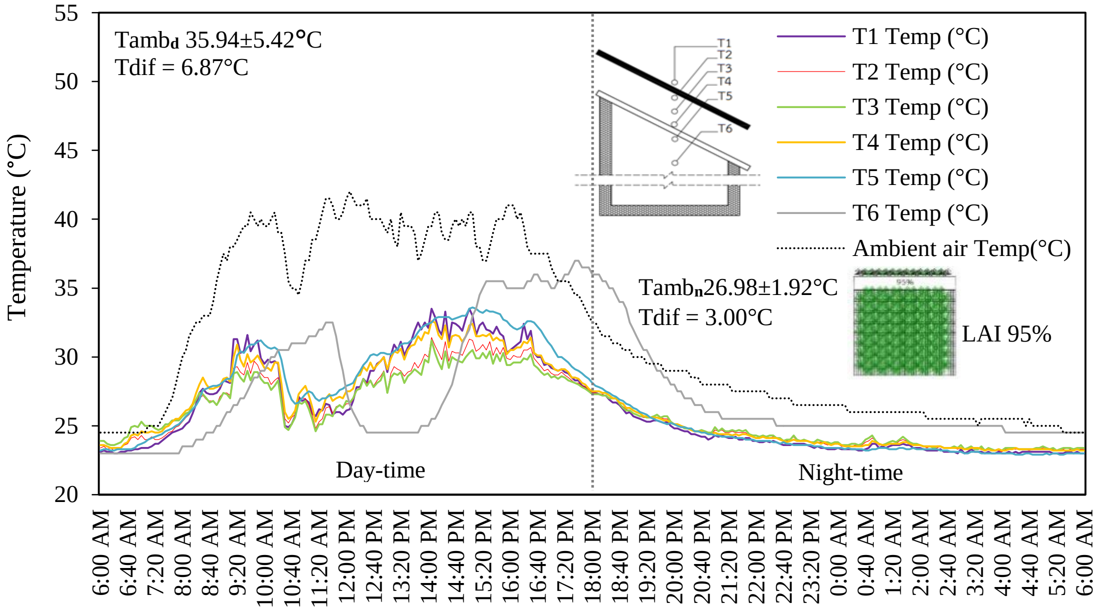


Figure 5.25 The temperature variation of Cotton Candy green roof on density 1,500g/0.144m^3 at air gap 30 cm.

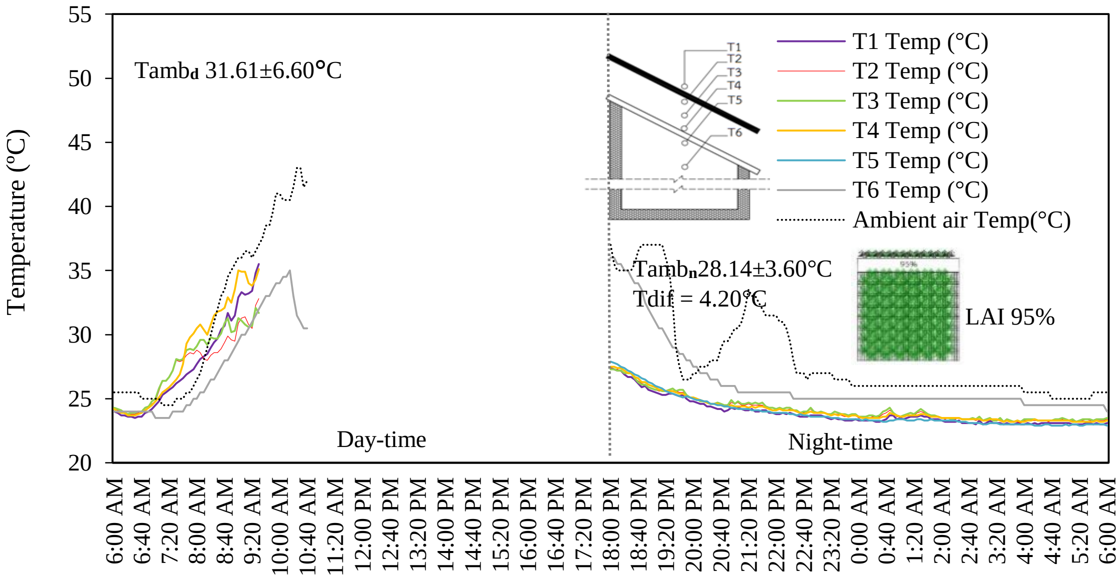


Figure 5.26 The temperature variation of Cotton Candy green roof on density 1,500g/0.144m^3 at air gap 40 cm.

5.7 Conclusion

According to the research, the experiments can be divided in to 2 main categories. The first one aimed at comparing Spanish Moss green roof temperature. The variable was the density of the green roof. The second one aimed at comparing green roof across crops, Spanish Moss and Cotton Candy. The result from each experiment can be concluded as followed;

5.7.1 Density S500, T41

During day-time, the temperature of Spanish Moss with a 10 cm wide air gap decreased more than those 40, 30 and 20 respectively. During night-time, the temperature of Spanish Moss with a 20 cm wide air gap decreased more than those 30, 10 and 40 respectively. During day-time, the temperature of Cotton Candy with a 10 cm wide air gap decreased more than those 40, 30 and 20 respectively. During in night-time, the temperature of Cotton Candy with a 20 cm wide air gap decreased more than those 30, 10 and 40 respectively.

5.7.2 Density S1,000, T55

During day-time, the temperature of Spanish Moss with a 30 cm wide air gap decreased more than those 40, 10 and 20 respectively. During night-time, the temperature of Spanish Moss with a 10 cm wide air gap decreased more than those 40, 30 and 20 respectively. During day-time, the temperature of Cotton Candy with a 40 cm wide air gap decreased more than those 30, 10 and 20 respectively. During night-time, the temperature of Cotton Candy with a 40 cm wide air gap decreased more than those 10, 30 and 20 respectively.

5.7.3 Density S1500, T98

During day-time, the temperature of Spanish Moss with a 30 cm wide air gap decreased more than those 20, 10 and 40 respectively. During night-time, the temperature of Spanish Moss with a 40 cm wide air gap decreased more than those 30,10 and 20 respectively. During day-time, the temperature of Cotton Candy with a 30 cm wide air gap decreased more than those 20 and 10 respectively. During night-time, the temperature of Cotton Candy with a 40 cm wide air gap decreased more than those 30, 10 and 20 respectively.

5.7.4 Comparison across crops

- **Density S500, T41**

During day-time, it was found out that the temperature of Spanish Moss (3.58) decreased more than Cotton Candy (3.33). During night-time, it was found out that the temperature of Spanish Moss (3.43) decreased more than Cotton Candy (3.42).

- **Density S1,000, T55**

During day-time, it was found out that the temperature of Spanish Moss (6.96) decreased higher than Cotton Candy (5.93). During night-time, it was found out that the temperature of Cotton Candy (3.05) decreased more than Spanish Moss (2.82).

- **Density S1,500, T98**

During day-time, it was found out that the temperature of Spanish Moss (8.1) decreased more than Cotton Candy (6.87). During night-time, it was found out that the temperature of Cotton Candy (4.20) decreased more than Spanish Moss (4.10).

CHAPTER VI

DISCUSSION

6.1 Discussion

The positive interactions among the high density of air plant green roofs suitable into buildings for using during the daytime. Plant density results in completely reduced heat transfer rates for the rooms that use during daylight hours, such as living rooms, and multi-purpose areas that use during daylight hours. When comparing the efficiency of plant density between two aerial plants, the result is noticeably less noticeable, and Cotton Candy is more prominent in reducing the temperature than Spanish Moss, as a result of leaf blades with overlapping leaves. As a result, LAI of Cotton Candy is higher than Spanish Moss.

The air gap is useful for heat transfer during the night time. The room used during the night and it needs to be exhaled to the outside so that it is suitable for the air plant with air gap. The bedroom is suitable for air plant with high air ventilation. Air gap bring indoor temperature or heat mass storage to the outside air.

The comparing on the reducing peak temperature between the air plant and other plants, the air plant has the same efficiency but if consider the economy in long term. It is an attractive alternative for integrating energy efficiency and temperature comfort. Environmental benefits are one thing that makes Air plant more distinctive than other types of insulation.

The different species of leaf area index (density of plant), this is the main factors which influencing the decrease in temperature. In the day-time at the density of 1,500 g/0.144 m^3 was found that Spanish moss can reduce the temperature more than Tillandsia Cotton Candy which is reduced up to 8.1 to 6.87 degree respectively. During the night time, Tillandsia Cotton Candy at density of 1,500g/0.144m^3 can reduce the temperature was more than Spanish moss at density of 500g/0.144m^3 which is reduced up to 4.20 and 3.43 degrees respectively. The research concluded that air plant species, density affect the decreasing temperature of the surface and ambient in residential buildings which is the green roof at the density of 1,500g/0.144m^3 can reduce the highest temperature during day and night time.

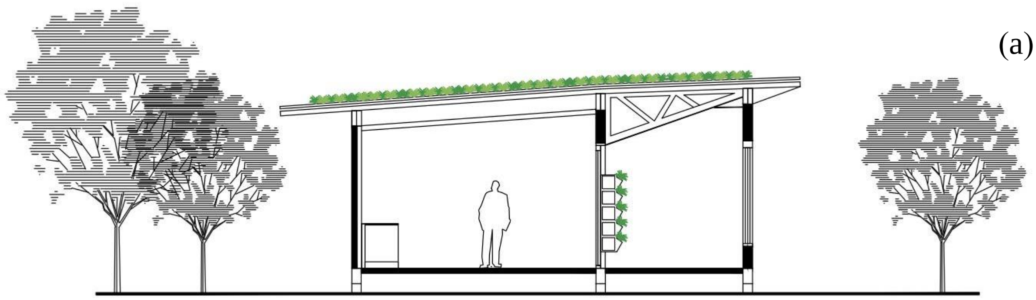
The results of this study can be applied to the green roof as follows. The application of air plant green roof on Tillandsia usneoides L. (Spanish moss) is ideal for applications on both existing and new buildings, especially those that are used during daylight hours, such as living rooms and offices. High density of leaf reduce heat before transferring into the building and create a shade to the roof surface material.

The green roofing application of Tillandsia recurvifolia Hooker (Tillandsia Cotton Candy) is suitable for buildings which require ventilation into the atmosphere. The gap between the leaves will transfer the heat from the building into outside during night time such as the bedroom. The roof of bedroom is suitable for the application of Tillandsia Cotton Candy roofs.

The application of green roofs encourages sustainable buildings, architectural aesthetic value, architectural and urban sustainability and enhances building value. It also promotes the image of green buildings and environmentally-friendly buildings and it also adding green space to the city.

Figure 6.1 The green roof design guidelines by air plants for residential buildings in a humid climate for the efficiency of energy savings.

Air plant green roofs can contribute to the development of ratings under such schemes. Green roofs have a very visible and attendance that can contribute to increase property value and energy efficiency in building.



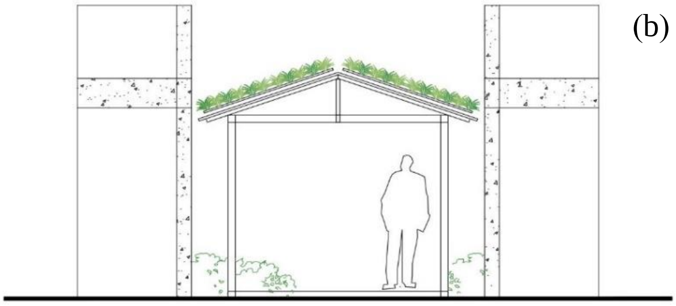


Figure 6.2 (a) and (b) The application of air plant green roofs with a roof slope, according to the existing roof and green façade.

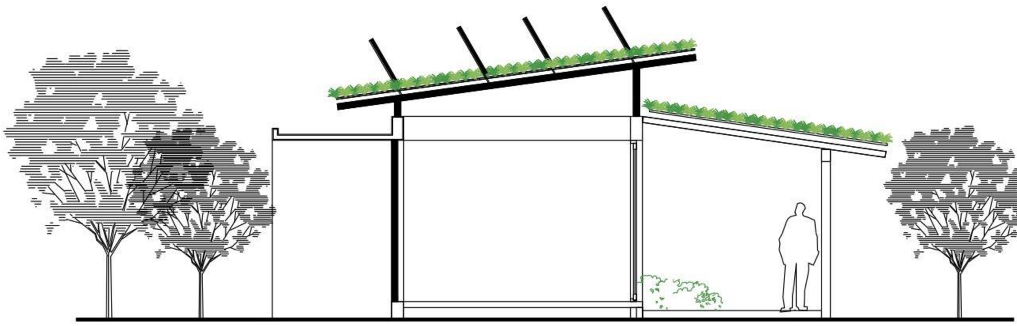


Figure 6.3 The application of air plant green roofs with a roof slope and solar panel which air plants can reduce the heat and increase the efficiency of the solar panel.

Many researches explained that sedum species are plant which commonly used for extensive green roofs. Sedum species roofs can be applied in various climates such as Mediterranean climate, hot and dry climate and Tropical climate. The benefit of reducing peak temperature on sedum roof presented that the temperature reduced approximately 4-12◦C (see in table 6.1). Meanwhile, the results of this research regarding the decrease in the temperature of air plant green roof shown that the efficiency of Spanish Moss roofs can decreased the temperature as 8.1 °C and Cotton Candy roofs can reduced the temperature as 6.87 °C. The applications of green roofs for buildings need to be considered in economics. It is very important ways for decision maker such as building owner, architect and stakeholder. The considerations on life cycle cost both air plant green roofs was less or zero with compared with other roofs. Moreover, the initial construction costs of air plant green roof are low because of less construction and it can grow without substrate. Air plants can combined with old and new building roofs. Air plant green roofs are an important alternative to reducing energy consumption to building and sustainable building in future.

Table 6.1 The review of the reducing peak temperature on several plant species

Plant species	Reducing peak temperature	Type of green roof	Weather	Ref
Sedum (*S. sediforme)*	5–7 °C	Extensive green roofs	Mediterranean climate hot and dry climate	Gravatt and Martin, 1992
Sedum species	5.2°C	Extensive green roofs	Humid-subtropical	Jim and Peng, 2012
Sedum species (*Dianthus grantianopolitanus*, *Carpobrotus edulis* and Cerastiumtomentosum)	4-12◦C	Extensive green roofs	Mediterranean area hot and dry	Bevilacqua et al., 2016
Sedum species	2.8-3.8 ºC	Extensive green roofs	Sub-tropical climatic region	Yang et al., 2015
Sedum species	2.5 -5 ºC	Extensive green roofs	Coastal city with hot and humid summer	He et al.,
Torenia concolor, Ixora williamsii, Ruellia brittoniana, Mesona chinensis, Asporagus densiflorus,	42%	Extensive green roof	Sub-tropical island climate	Lin et al., 2013
S. spurium,D. nubigenum	25%	Green roof	Laboratory setup	Cesar et al., 2011
Heliconi, Spider lily, Ophiopogon, Raphis palm, Pandanus, Erythrina	30%	Green roof	Tropical climate	Wong et al., 2003
Lawn gardens	10 ºC	Roof lawn gardens	Hot climate	Ommura et al., 2001

Table 6.2 The review of insulating materials that widespread for utilization in the building.

	Type	Characteristic	Advantages	Disadvantages	R-value per inch of thickness	Cost
	Aluminium foil	Low Emissivity	High reflective properties, Moisture resistant, Non-flammable and Not tear easily	Lack of sound protection		25- 38 Bath / 5000 Square mete Width:1000-1500mm
	Polyurethane Foam	Insulation and cool storage	Low heat transfer, Support weight and sound protection	Toxic gas on fire	5.5 - 6.5	375 Bath (60X60X1CM)
	Fiberglass insulation	Glass or glass to melt and is a fine fiber to compress together.	Heat resistant, high temperature insulation materials and sound protection	Fibers cause irritation. Not suitable for open use without cover.	2.9 -3.8	2,321 Bath (The thickness 1 inch ,density 24 Kg / m^3 Width 1.22 meters Length 15.25 meters)
	Mineral Wool	Natural fiber, Asbestos and Health hazards	Heat resistant, Fire resistance and Sound protection	Not resistant to wet	3.1 - 3.4	2,692 Bath 1 Box / 4 pc (46" X 24" X 4")
	Cellulose	Recycle material mixed with chemical to help attractions	Heat resistance , sound protection and save the environment	Not resistant to water and moisture. The risk on chance to loose.	3.8 - 3.9	143- 383 Bath / Piece
	Calcium Silicate	Powder plate	Could be to cut and like a gypsum board. Heat resistance, fire resistance and painted able	Very weighty and not resistant to moisture		3,835 Bath Size:400 * 250 Thickness:4-16 mm

Table 6.2 The review of insulating materials that widespread for utilization in the building (continued).

	Type	Characteristic	Advantages	Disadvantages	R-value per inch of thickness	Cost
	Vermiculite	Made from Mica. It looks like glass. Powdered to mix cement or sand leading to concrete with low thermal conductivity.	Can be molded into various shapes and fire resistance	Very weighty	2.08	750 Bath/ 100 liter
	Ceramic Coating	The liquid used to spray or spray. And helps to reflect heat.	Easy to install and heat resistant to the surface of the building.	Low shelf life due to weather conditions and the installation is based on high technical skills.	3.5 - 3.6	1,118- 2,237/100 liter

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Paper I

Thomas Brudermann and Tachaya Sangkakool*, Green roofs in temperate climate cities – An analysis of key decision factors, Urban Forestry & Urban Greening 21 (2017): 224–234

Paper II

Tachaya Sangkakool and KuaananTechato, Life cycle cost of air plant green roofs in hot and humid climate, International Journal of Applied Business and Economic Research 2016 (IJABER), Vol. 14, No. 10 (2016): 7145-7160

APPENDIX

Air gap set 1 (S1,500,T98)

Table 1 Comparison of the difference temperature (Tdif) of Spanish moss and Cotton candy (Weight per Volume (g/0.144m^3)

Air gap (cm)	Spainish moss															
	Temperature(°C) Day-time								Temperature(°C) Night-time							
	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	$\overline{RH}$ Humidity (%)	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$5 (mim) (°C)	$\overline{T}$5 (max) (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	$\overline{RH}$ Humidity (%)\	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$5 (mim) (°C)	$\overline{T}$5 (max) (°C)
10	5.40	6.08	38.66 ±6.43	50.08 ±19.10	25.26 ±1.17	33.26 ±5.18	0.7	11.4	1.53	1.67	28.92 ±2.54	76.91 ±11.95	24.20 ±0.56	27.39 ±2.20	0.7	3.7
20	5.68	-0.31	36.22 ±5.51	56.97 ±18.01	25.52 ±1.51	30.53 ±3.55	1.1	15.1	1.84	2.55	26.44 ±1.11	89.01 ±4.51	24.44 ±0.29	24.60 ±0.64	1	6.1
30	4.75	-1.32	35.94 ±5.42	55.93 ±17.15	25.00 ±1.23	31.18 ±3.73	0.2	10.1	1.50	2.84	26.98 ±1.92	79.64 ±8.67	23.06 ±0.27	25.49 ±1.76	1	2.2
40	4.87	6.03	31.61 ±6.60	70.75 ±18.85	24.77 ±1.45	26.75 ±3.45	0.5	10.5	-	-	-	-	-	-	-	-
Air gap (cm)	Cotton candy															
	Temperature(°C) Day-time								Temperature(°C) Night-time							
	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	$\overline{RH}$ Humidity (%)	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$5 (mim) (°C)	$\overline{T}$5 (max) (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	$\overline{RH}$ Humidity (%)	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$5 (mim) (°C)	$\overline{T}$5 (max) (°C)
10	1.44	6.08	38.66 ±6.43	50.08 ±19.10	25.26 ±1.17	37.49 ±7.93	-5.70	8.50	2.21	1.67	28.92 ±2.54	76.91 ±11.95	24.20 ±0.56	26.48 ±1.99	1.50	3.80
20	3.63	-0.31	36.22 ±5.51	56.97 ±18.01	25.52 ±1.51	32.59 ±4.64	-0.90	12.70	1.91	2.55	26.44 ±1.11	89.01 ±4.51	24.44 ±0.29	24.53 ±0.86	1.30	4.80
30	2.73	-1.32	35.94 ±5.42	55.93 ±17.15	25.00 ±1.23	33.21 ±5.20	-2.20	8.50	1.84	2.84	26.98 ±1.92	79.64 ±8.67	23.06 ±0.27	25.14 ±1.90	1.30	2.30
40	-	6.03	31.61 ±6.60	70.75 ±18.85	24.77 ±1.45	-	-	-	-	-	-	-	-	-	-	-

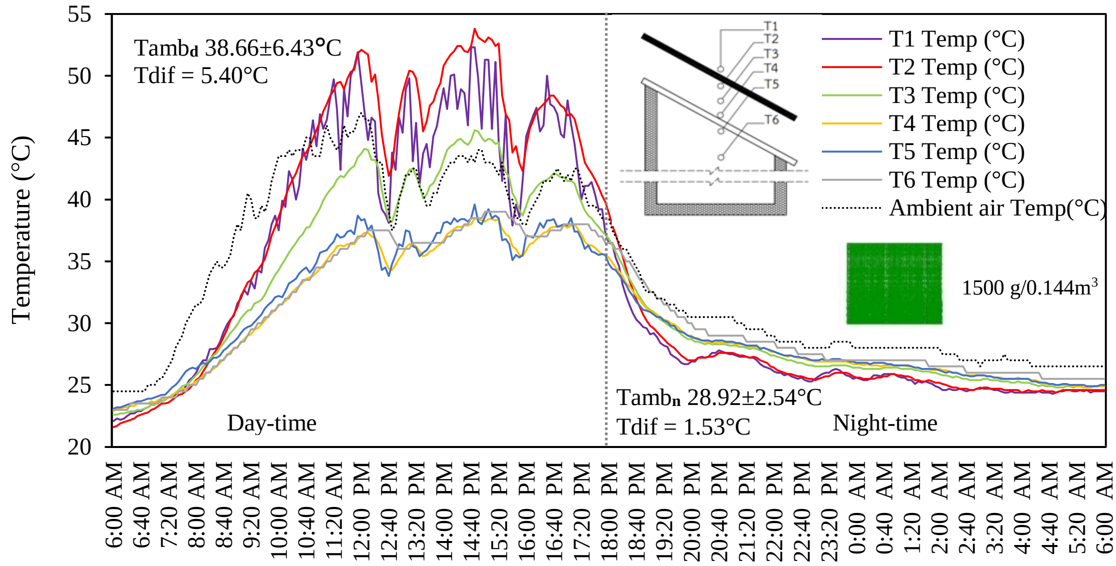

Figure 1 The temperature variation of Spainish moss green roof on density 1,500g/0.144m^3 at air gap 10 cm.

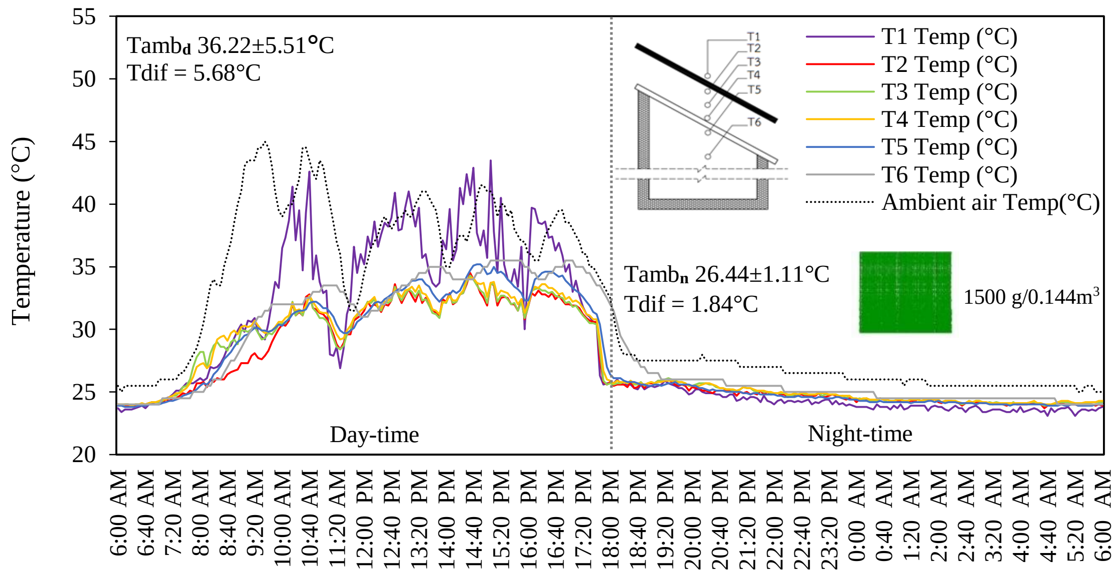

Figure 2 The temperature variation of Spainish moss green roof on density 1,500g/0.144m^3 at air gap 20 cm.

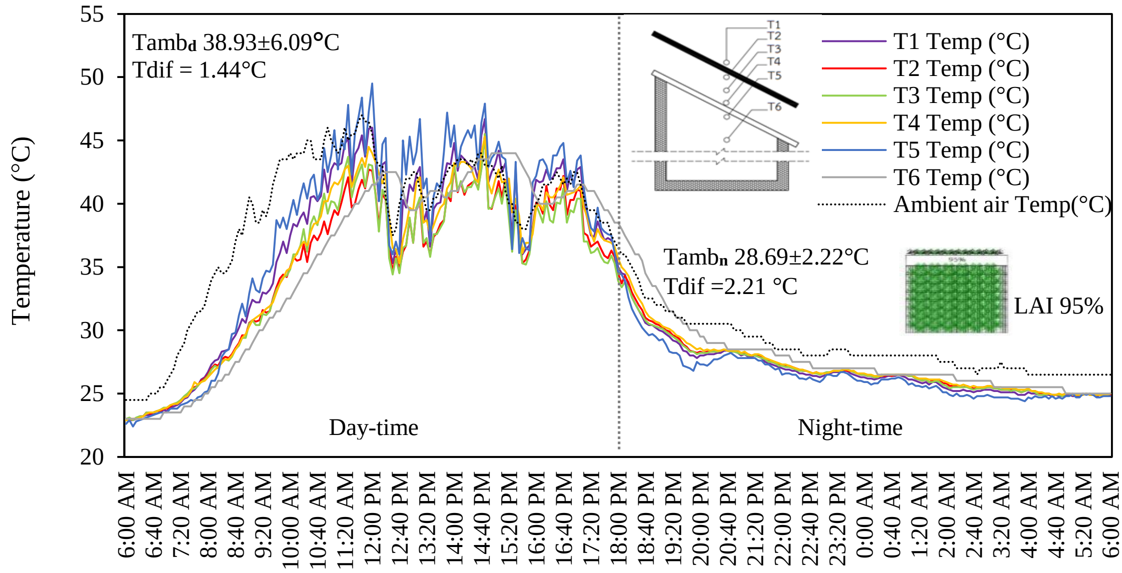

Figure 3 The temperature variation of Cotton Candy green roof on density 1,500g/0.144m^3 at air gap 10 cm.

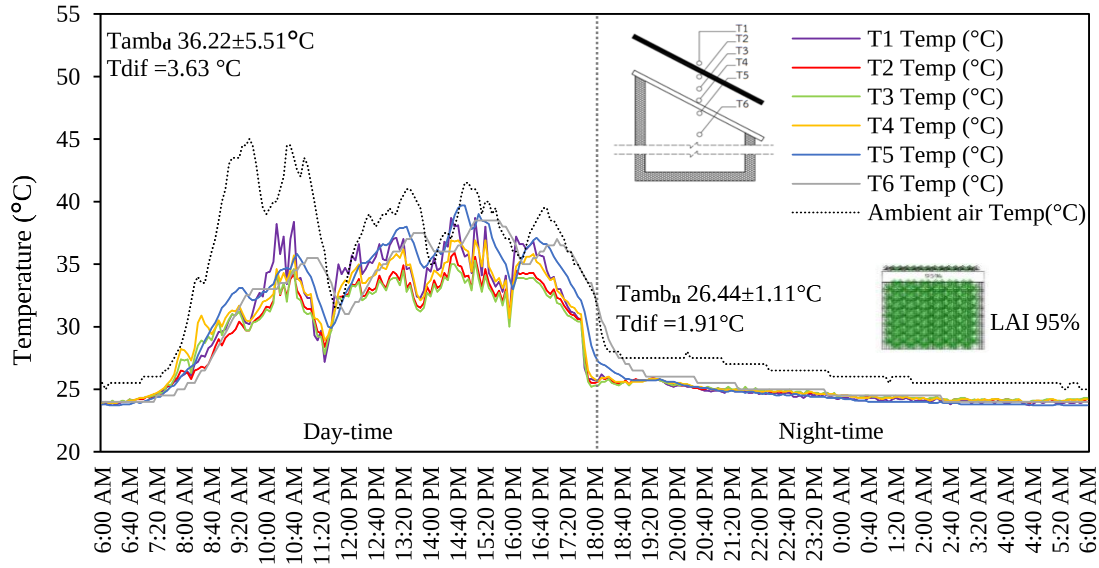

Figure 4 The temperature variation of Cotton Candy green roof on density 1,500g/0.144m^3 at air gap 20 cm.

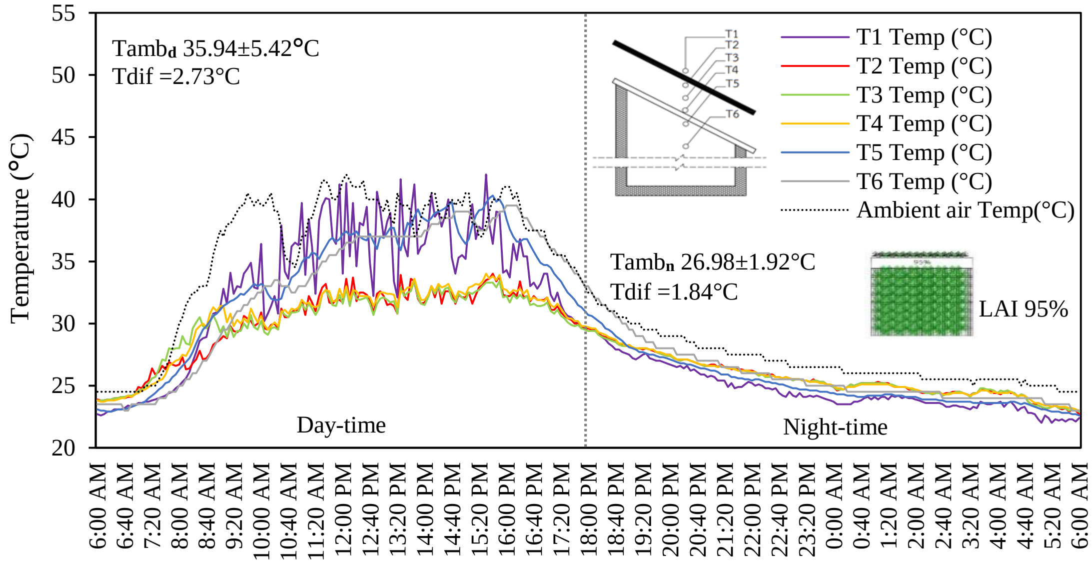

Figure 5 The temperature variation of Cotton Candy green roof on density 1,500g/0.144m^3 at air gap 30 cm.

Air gap set 2 (S1,500, T98)

Table 2 Comparison of the difference temperature (Tdif) of Spanish moss and Cotton Candy (Weight per Volume (g/0.144m^3)

Air gap (cm)																
	Spainish moss															
	Temperature(°C) Day-time								**Temperature(°C) Night-time**							
	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	$\overline{RH}$ Humidity (%)	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$5 (mim) (°C)	$\overline{T}$5 (max) (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	$\overline{RH}$ Humidity (%)\	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$5 (mim) (°C)	$\overline{T}$5 (max) (°C)
10	1.79	1.61	24.76 ±1.74	87.54 ±6.13	22.49 ±0.49	22.98 ±1.59	0.60	3.50	4.13	0.72	30.00 ±5.50	71.37 ±19.06	23.52 ±1.19	25.87 ±3.51	1.00	9.80
20	3.43	-4.84	31.17 ±5.00	70.56 ±14.86	24.71 ±1.45	27.74 ±3.79	0.6	6.1	1.65	1.11	24.03 ±0.16	90.42 ±1.39	22.35 ±0.22	22.38 ±0.19	1.7	2.1
30	8.07	4.42	35.94 ±5.42	50.08 ±19.10	25.26 ±1.17	27.87 ±2.41	0.6	15.2	2.90	3.72	26.98 ±1.92	76.91 ±11.95	24.20 ±0.56	24.08 ±1.17	1.3	4.9
40	3.12	0.08	28.44 ±5.79	79.61 ±18.09	23.95 ±1.30	25.33 ±3.92	1.2	8.3	2.01	0.45	28.14 ±3.60	79.80 ±13.13	24.01 ±0.56	26.64 ±3.78	-0.40	3.40
Air gap (cm)	**Cotton candy**															
	Temperature(°C) Day-time								**Temperature(°C) Night-time**							
	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	$\overline{RH}$ Humidity (%)	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$5 (mim) (°C)	$\overline{T}$5 (max) (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	$\overline{RH}$ Humidity (%)\	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$5 (mim) (°C)	$\overline{T}$5 (max) (°C)
10	1.55	1.61	24.76 ±1.74	87.54 ±6.13	22.49 ±0.49	23.21 ±2.05	-2.30	2.40	2.81	0.72	30.00 ±5.50	71.37 ±19.06	23.52 ±1.19	27.19 ±4.87	1.10	6.50
20	-1.52	-4.84	31.17 ±5.00	70.56 ±14.86	24.71 ±1.45	32.69 ±5.98	-8.70	3.80	-0.74	1.11	24.03 ±0.16	90.42 ±1.39	22.35 ±0.22	24.77 ±1.05	-3.10	0.60
30	6.87	4.42	35.94 ±5.42	50.08 ±19.10	25.26 ±1.17	29.06 ±3.12	0.70	14.50	3.00	3.72	26.98 ±1.92	76.91 ±11.95	24.20 ±0.56	23.99 ±1.27	1.50	4.60
40	2.30	0.08	28.44 ±5.79	79.61 ±18.09	23.95 ±1.30	26.14 ±4.99	1.20	6.00	1.50	0.45	28.14 ±3.60	79.80 ±13.13	24.01 ±0.56	26.64 ±3.78	-0.40	3.40

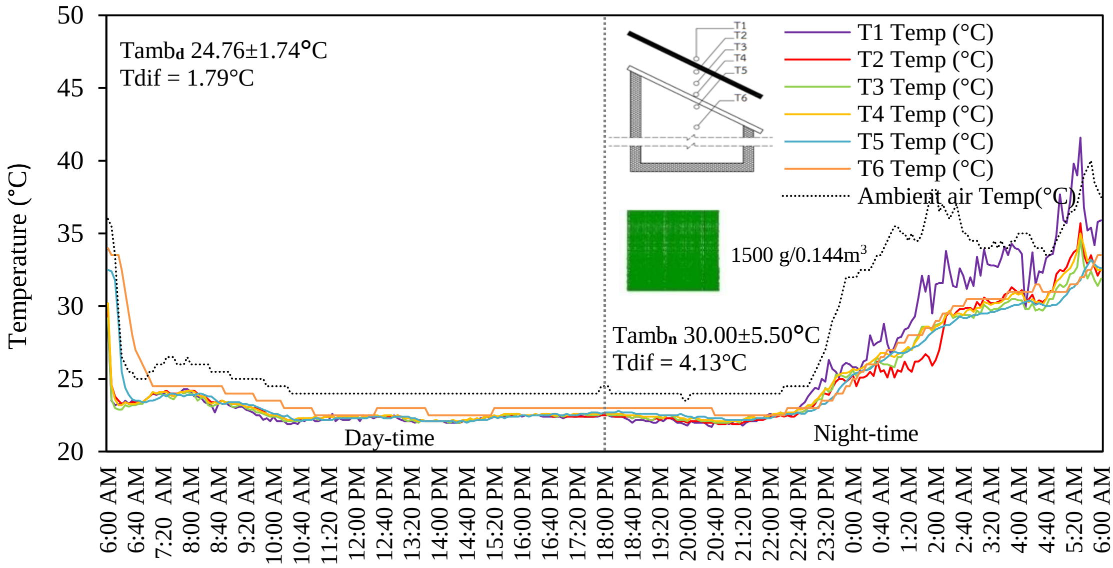

Figure 6 The temperature variation of Spainish moss green roof on density 1,500g/0.144m^3 at air gap 10 cm.

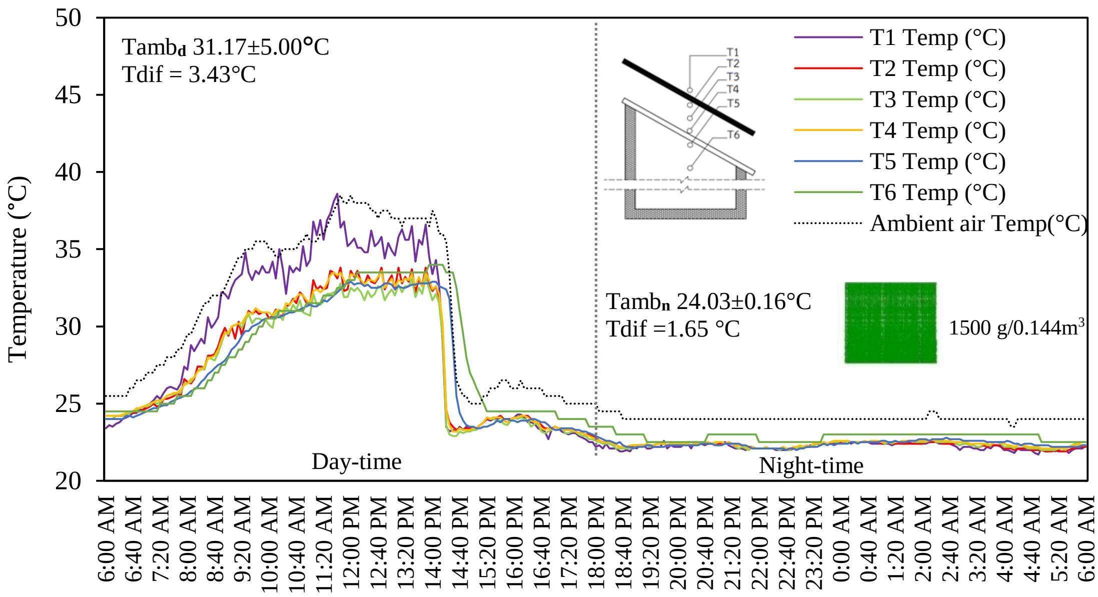

Figure 7 The temperature variation of Spainish moss green roof on density 1,500g/0.144m^3 at air gap 20 cm.

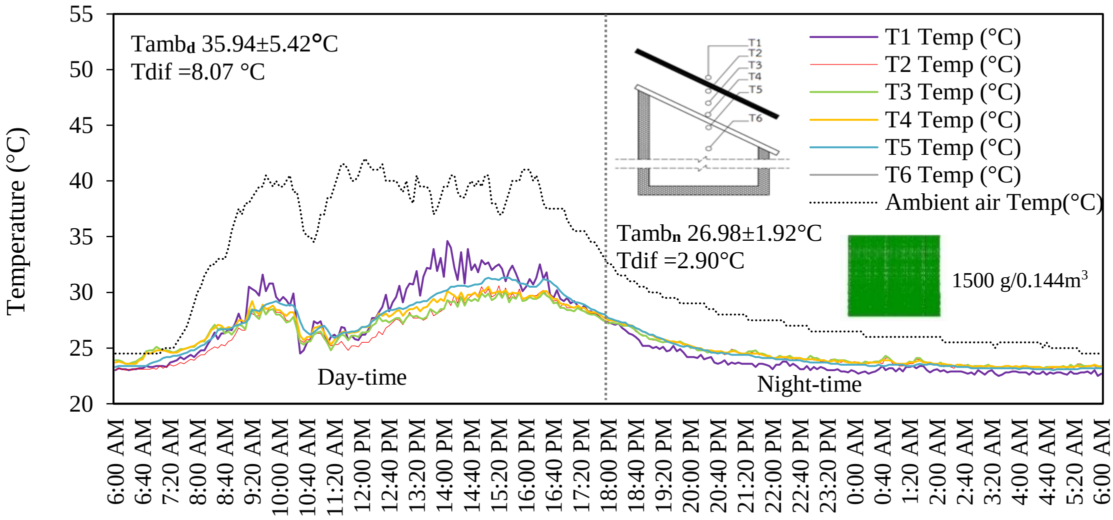

Figure 8 The temperature variation of Spainish moss green roof on density 1,500g/0.144m^3 at air gap 30 cm.

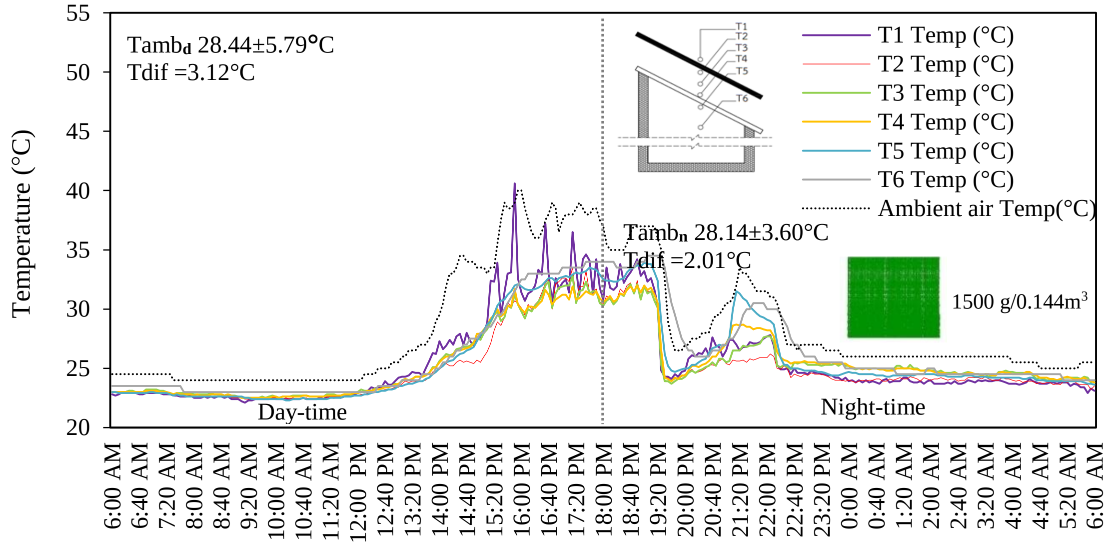

Figure 9 The temperature variation of Spainish moss green roof on density 1,500g/0.144m^3 at air gap 40 cm.

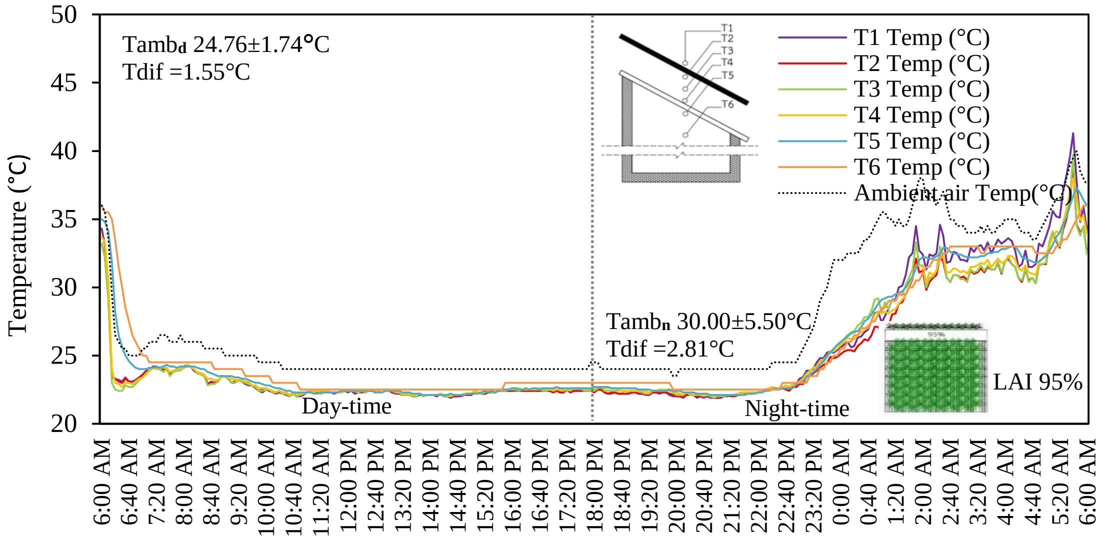

Figure 10 The temperature variation of cotton candy green roof on density 1,500g/0.144m^3 at air gap 10 cm.

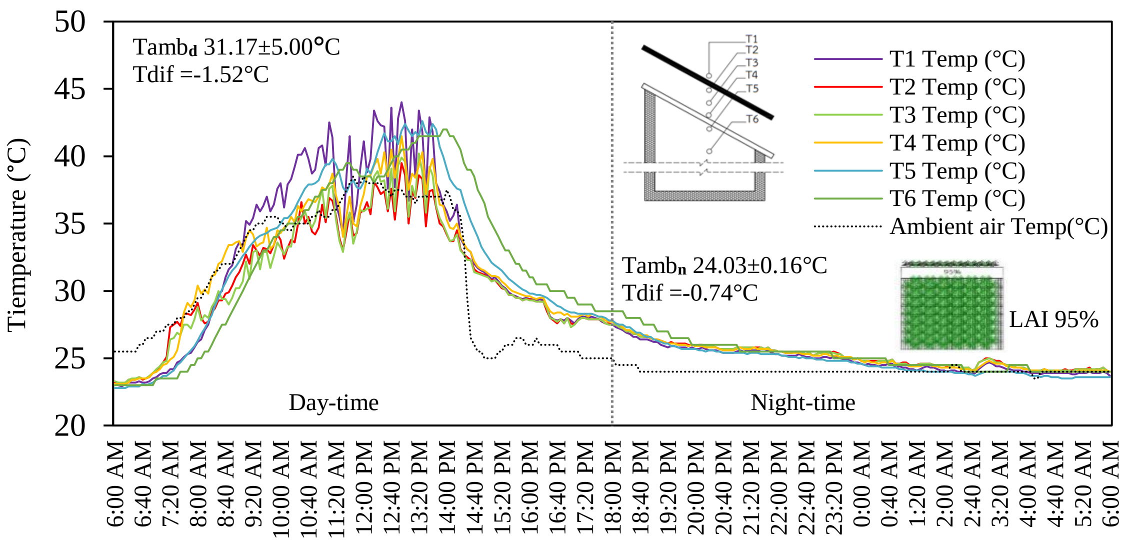

Figure 11 The temperature variation of cotton candy green roof on density 1,500g/0.144m^3 at air gap 20 cm.

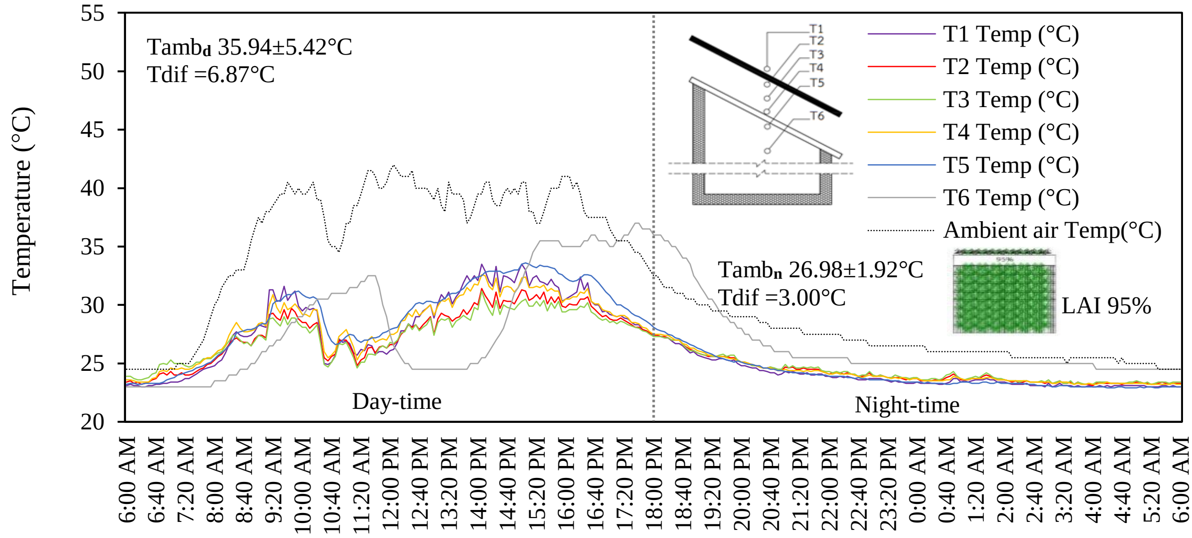

Figure 12 The temperature variation of cotton candy green roof on density 1,500g/0.144m^3 at air gap 30 cm.

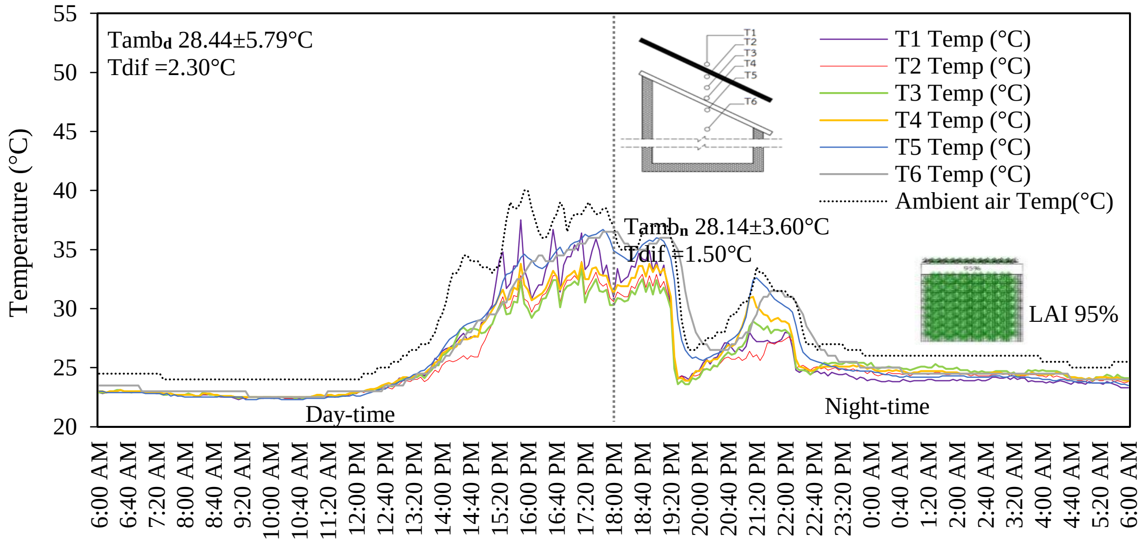

Figure 13 The temperature variation of cotton candy green roof on density 1,500g/0.144m^3 at air gap 40 cm.

Air gap set 3 (S1,500, T98)

Table 3 Comparison of the difference temperature (Tdif) of Spanish moss and cotton candy (Weight per Volume ($g/0.144m^3$)

Air gap (cm)	**Spainish moss**															
	Temperature(°C) Day-time								**Temperature(°C) Night-time**							
	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	$\overline{RH}$ Humidity (%)	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$5 (mim) (°C)	$\overline{T}$5 (max) (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	$\overline{RH}$ Humidity (%)	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$5 (mim) (°C)	$\overline{T}$5 (max) (°C)
10	1.69	1.70	25.00 ±1.44	90.39 ±4.27	23.29 ±0.60	23.31 ±0.88	0.8	7.4	1.70	-1.24	31.52 ±4.82	68.86 ±15.58	24.57 ±0.93	24.30 ±3.52	0.5	8.3
20	6.71	1.84	37.81 ±8.14	53.90 ±20.73	25.45 ±1.87	31.09 ±4.36	1.1	16	1.16	2.46	26.32 ±1.18	86.42 ±4.72	23.84 ±0.37	25.16 ±0.98	0.7	2.3
30	8.1	4.42	35.94 ±5.42	55.93 ±17.15	25.00 ±1.23	27.87 ±2.41	0.6	15.2	2.90	3.72	26.98 ±1.92	79.64 ±8.67	23.06 ±0.27	24.08 ±1.17	1.3	4.9
40	0.55	-3.11	28.44 ±5.79	79.61 ±18.09	23.95 ±1.30	27.90 ±2.37	-5.2	10.5	4.20	4.92	28.14 ±3.60	79.80 ±13.13	24.01 ±0.56	24.05 ±1.14	1.3	11.2
Contton candy																
Air gap (cm)	**Temperature(°C) Day-time**								**Temperature(°C) Night-time**							
	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	$\overline{RH}$ Humidity (%)	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$5 (mim) (°C)	$\overline{T}$5 (max) (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	$\overline{RH}$ Humidity (%)	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$5 (mim) (°C)	$\overline{T}$5 (max) (°C)
10	1.67	1.70	25.00 ±1.44	90.39 ±4.27	23.29 ±0.60	23.32 ±1.04	1.10	5.40	2.10	-1.24	31.52 ±4.82	68.86 ±15.58	24.57 ±0.93	29.42 ±4.42	-0.40	6.00
20	5.15	1.84	37.81 ±8.14	53.90 ±20.73	25.45 ±1.87	32.65 ±6.02	1.00	14.00	1.52	2.46	26.32 ±1.18	86.42 ±4.72	23.84 ±0.37	24.80 ±1.07	1.10	2.20
30	6.87	4.42	35.94 ±5.42	55.93 ±17.15	25.00 ±1.23	29.06 ±3.12	0.70	14.50	3.00	3.72	26.98 ±1.92	79.64 ±8.67	23.06 ±0.27	23.99 ±1.27	1.50	4.60
40	-0.65	-3.11	28.44 ±5.79	79.61 ±18.09	23.95 ±1.30	29.10 ±3.08	-7.20	10.10	4.20	4.92	28.14 ±3.60	79.80 ±13.13	24.01 ±0.56	23.95 ±1.23	1.30	11.20

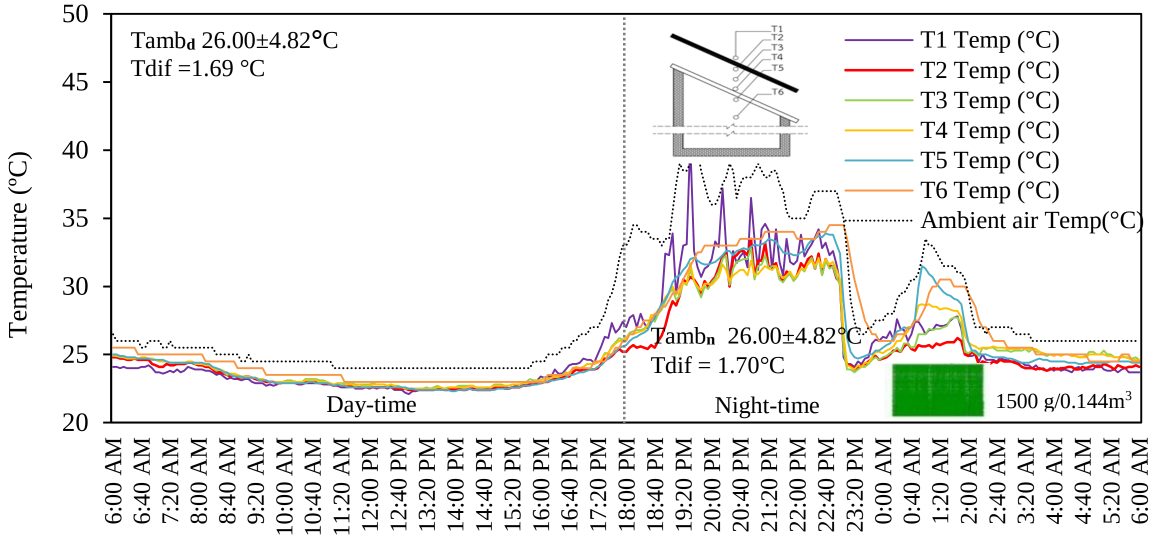

Figure 14 The temperature variation of Spainish moss green roof on density 1,500g/0.144m^3 at air gap 10 cm.

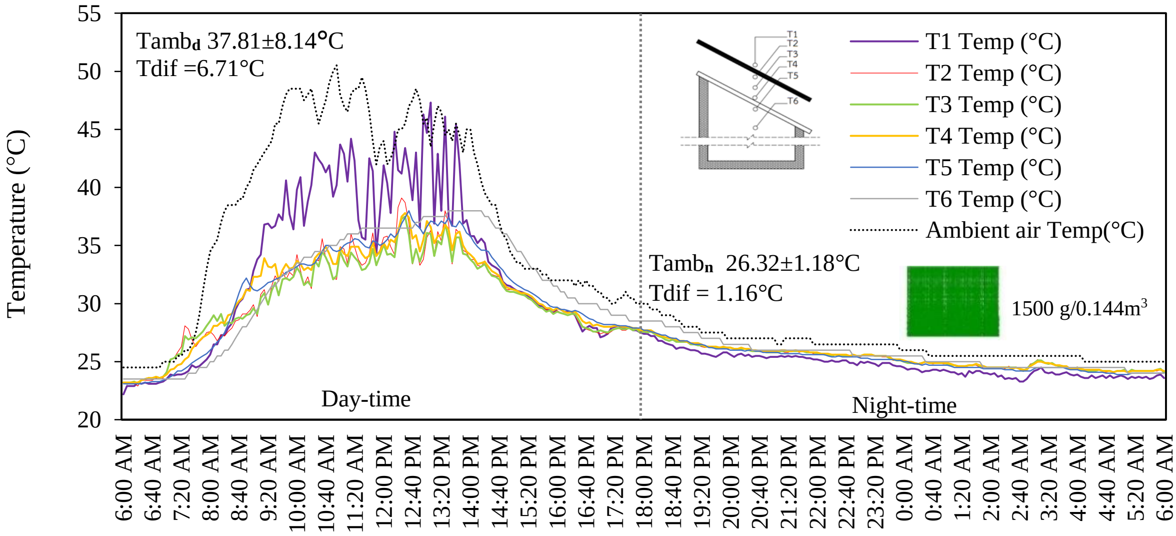

Figure 15 The temperature variation of Spainish moss green roof on density 1,500g/0.144m^3 at air gap 20 cm.

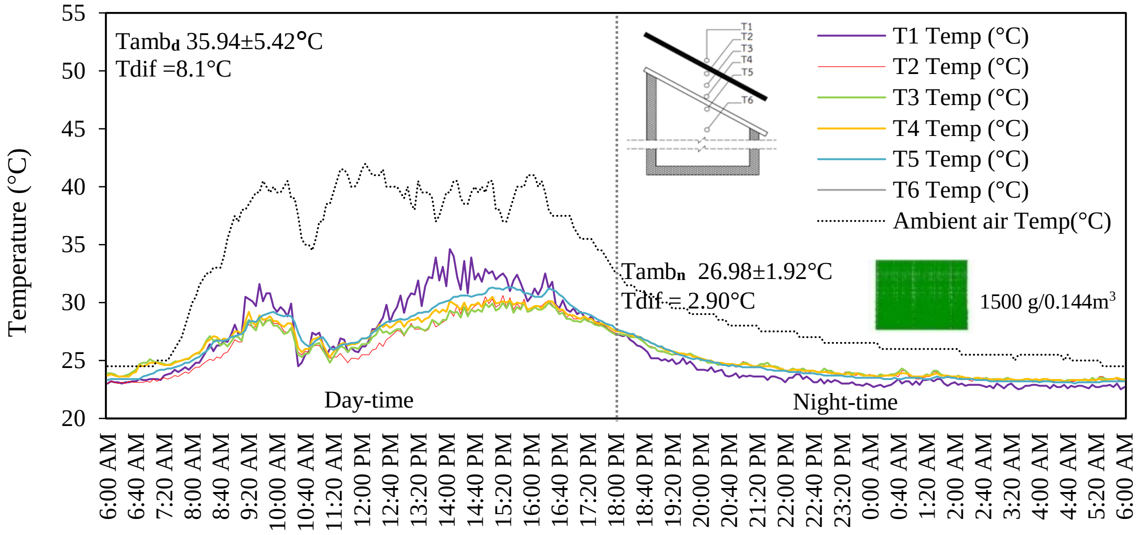

Figure 16 The temperature variation of Spainish moss green roof on density 1,500g/0.144m^3 at air gap 30 cm.

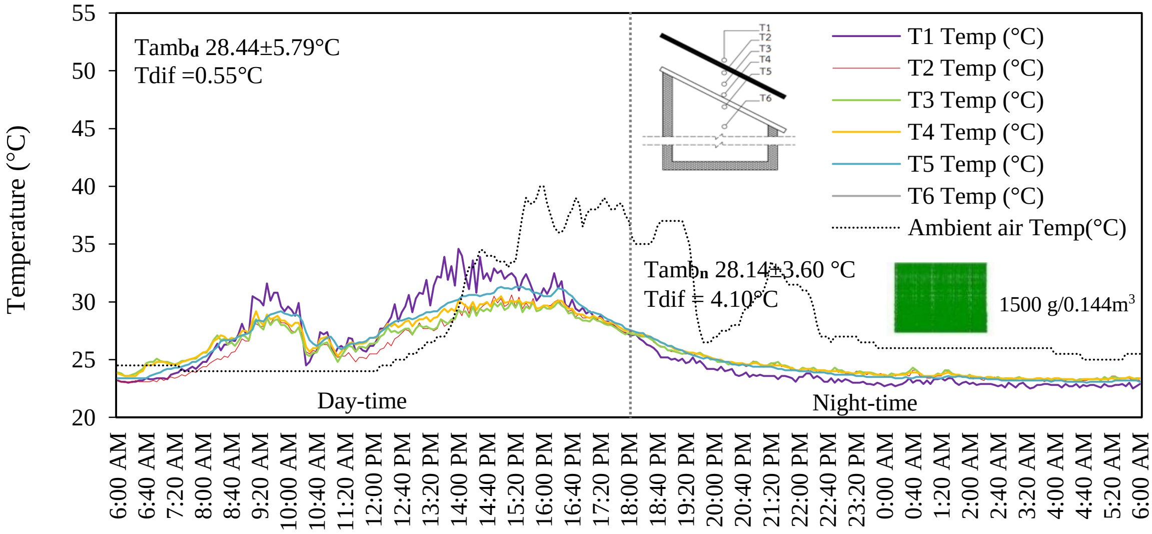

Figure 17 The temperature variation of Spainish moss green roof on density 1,500g/0.144m^3 at air gap 40 cm.

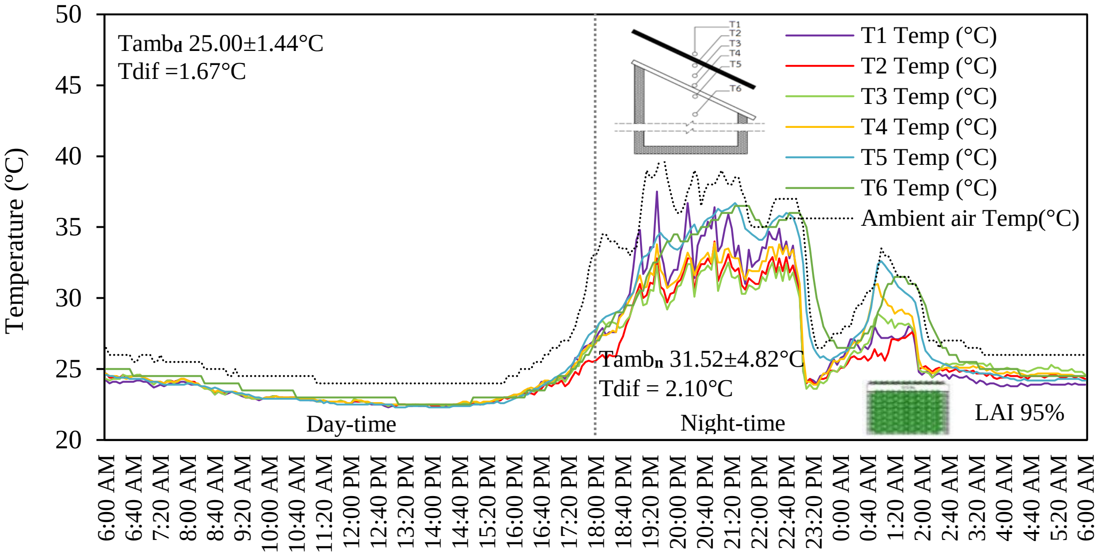

Figure 18 The temperature variation of cotton candy green roof on density 1,500g/0.144m^3 at air gap 10 cm.

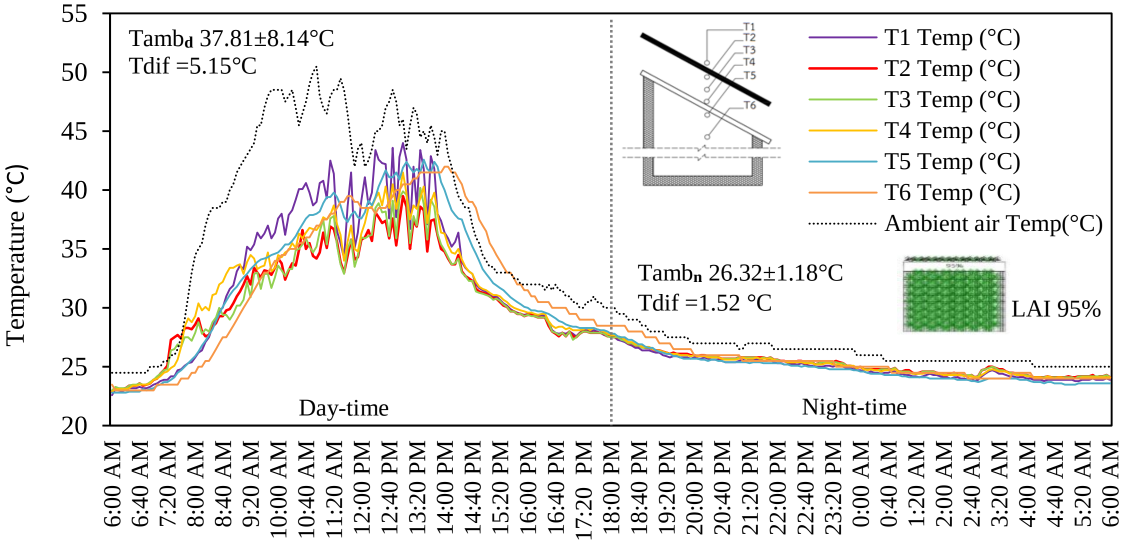

Figure 19 The temperature variation of cotton candy green roof on density 1,500g/0.144m^3 at air gap 20 cm.

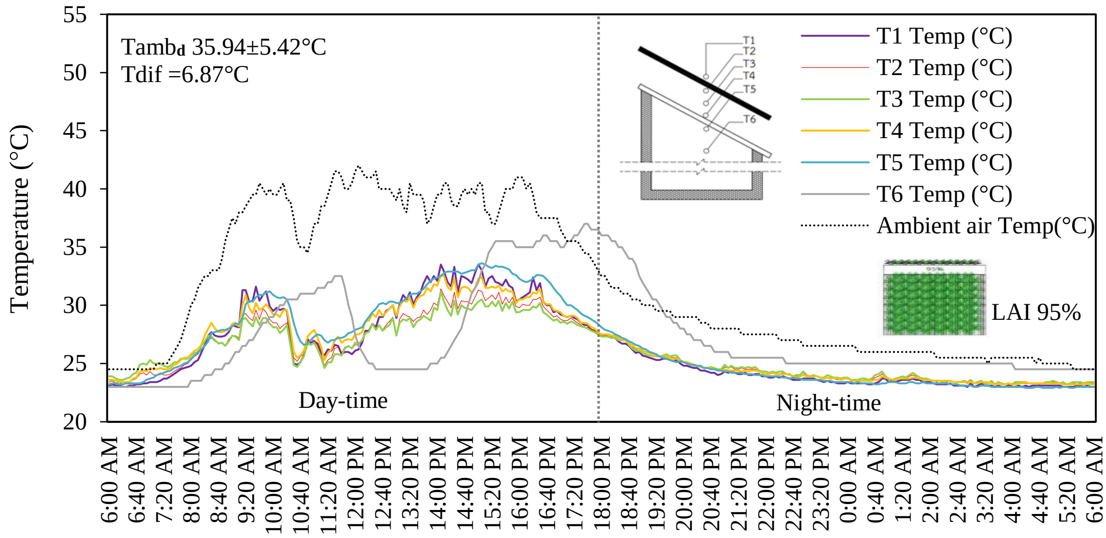

Figure 20 The temperature variation of cotton candy green roof on density 1,500g/0.144m^3 at air gap 30 cm.

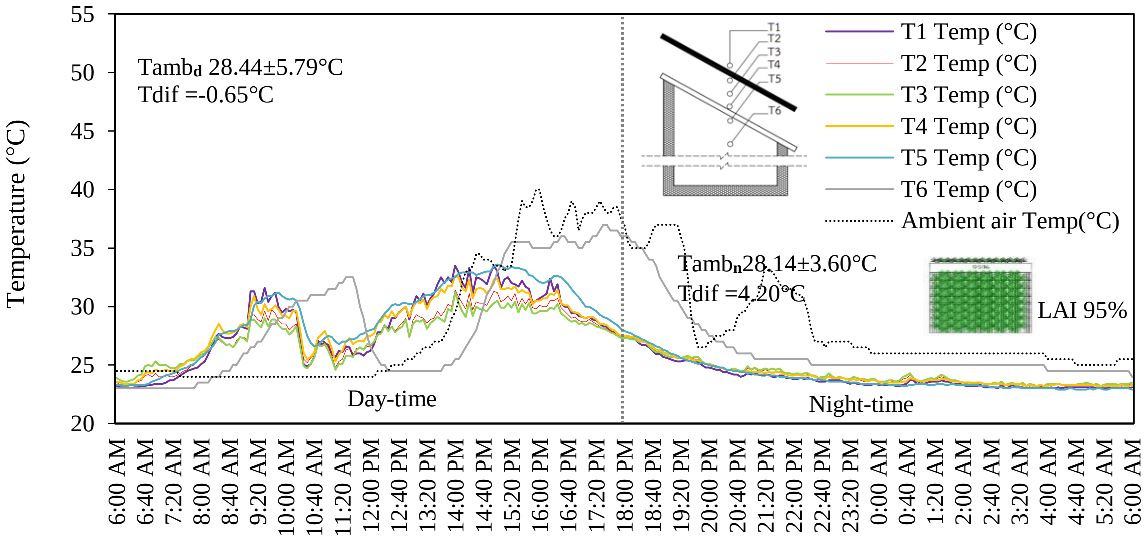

Figure 21 The temperature variation of cotton candy green roof on density 1,500g/0.144m^3 at air gap 40 cm.

Density set 1

Table 4 Comparison of the difference temperature (Tdif) of Spanish moss and cotton candy (Weight per Volume (g/0.144m^3)

Date	Weight per Volume (g/0.144m^3)	Spainish moss															
		Temperature(°C) Day-time								Temperature(°C) Night-time							
		$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)
4/11/2014	500	3.58	2.70	36.67 ±7.44	0.29	55.42 ±16.15	0.00	26.65 ±1.65	33.10 ±8.25	3.00	3.33	24.04 ±0.41	0.00	84.78 ±4.35	0.00	24.28 ±0.30	24.04 ±0.41
11/10/2014	1,000	6.33	2.6	36.40 ±8.65	0.01	59.88 ±19.58	0.00	26.07 ±2.19	30.06 ±6.06	2.82	3.20	27.72 ±1.29	0.00	83.93 ±5.18	0.00	24.70 ±0.24	24.91 ±0.78
21/8/2014	1,500	5.40	6.08	38.66 ±6.43	0.04	50.08 ±19.10	0.00	25.26 ±1.17	33.26 ±5.18	1.53	1.67	28.92 ±2.54	0.00	76.91 ±11.95	0.00	24.20 ±0.56	27.39 ±2.20
Contton candy																	
Date	Weight per Volume (g/0.144m^3)	Temperature(°C) Day-time								Temperature(°C) Night-time							
		$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)
4/11/2014	500	3.33	2.70	36.67 ±7.44	0.29	55.42 ±16.15	0.00	26.65 ±1.65	33.34 ±8.27	3.00	3.33	24.04 ±0.41	0.00	84.78 ±4.35	0.00	24.28 ±0.30	24.05 ±0.43
11/10/2014	1,000	4.40	2.6	36.40 ±8.65	0.01	59.88 ±19.58	0.00	26.07 ±2.19	31.99 ±7.24	2.99	3.20	27.72 ±1.29	0.00	83.93 ±5.18	0.00	24.70 ±0.24	24.73 ±0.93
14/8/2014	1,500	-	6.03	31.61 ±6.60		70.75 ±18.85		24.77 ±1.45	-	4.20	4.92	28.14 ±3.60		79.80 ±13.13		24.01 ±0.56	23.95 ±1.23

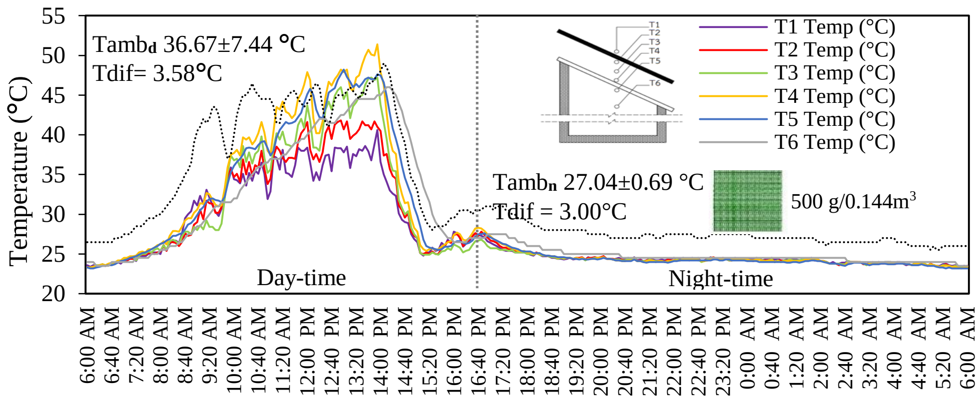

Figure 22 The temperature variation of Spanish moss green roof on density 500g/0.144m^3

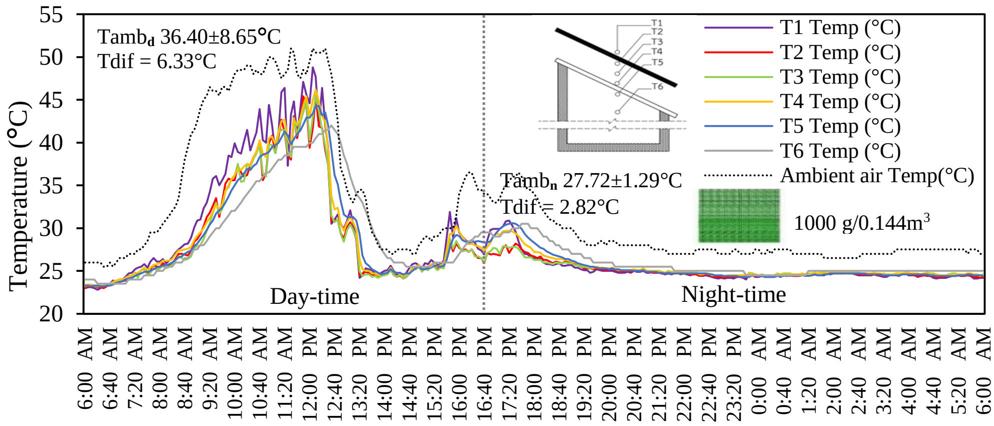

Figure 23 The temperature variation of Spanish moss green roof on density 1,000g/0.144m^3

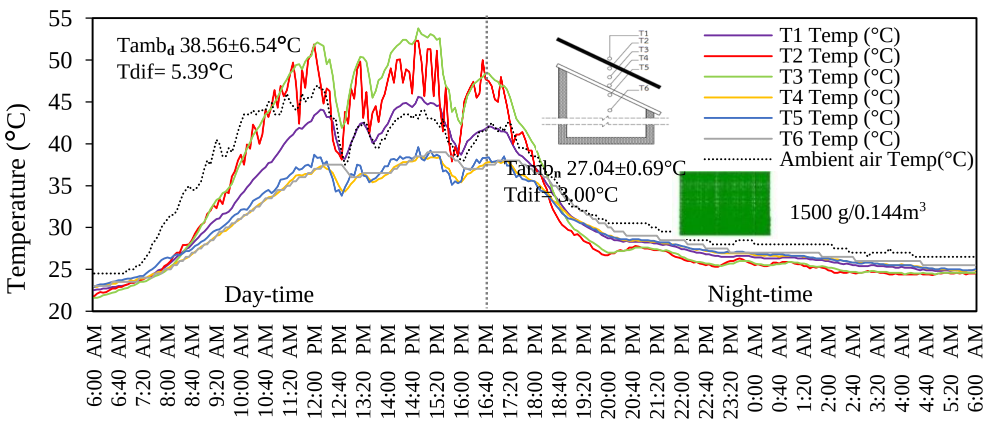

Figure 24 The temperature variation of Spanish moss green roof on density 1,500g/0.144m^3

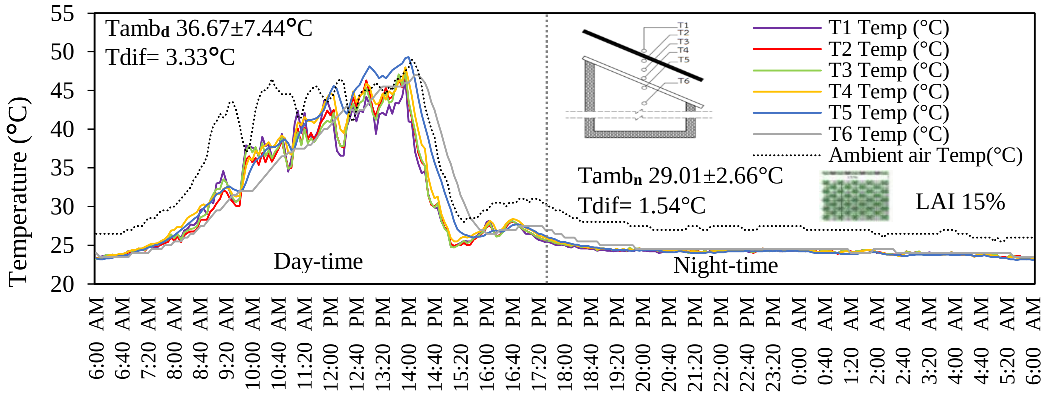

Figure 25 The temperature variation of cotton candy green roof on density 500g/0.144m^3

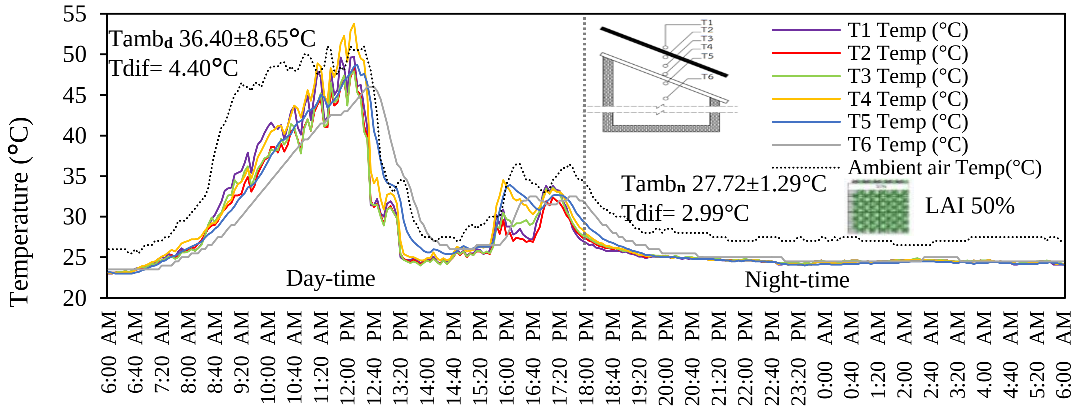

Figure 26 The temperature variation of cotton candy green roof on density 1,000g/0.144m^3

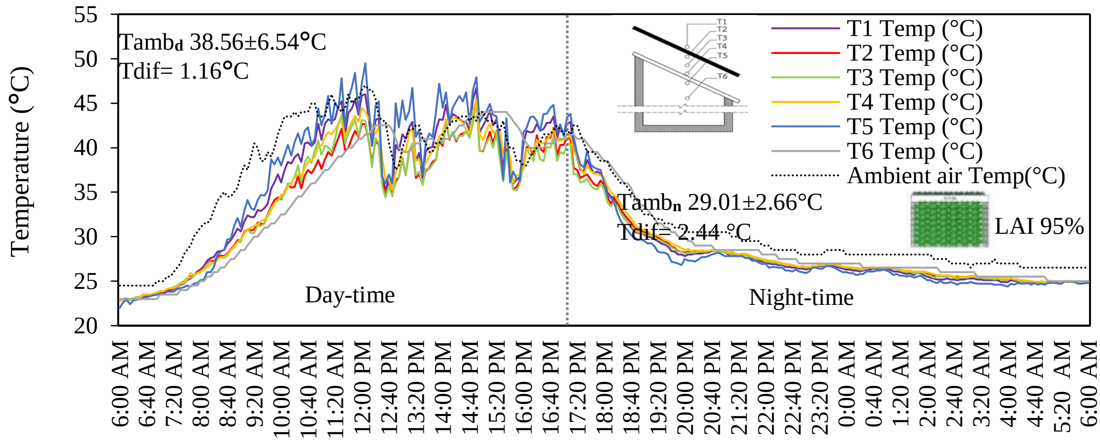

Figure 27 The temperature variation of cotton candy green roof on density 1,500g/0.144m^3

Density set 2

Table 5 Comparison of the difference temperature (Tdif) of Spanish moss and (Weight per Volume (g/0.144m^3)

Date	Weight per Volume (g/0.144**m^3**)		**Spainish moss**														
		Temperature(°C) Day-time								**Temperature(°C) Night-time**							
		$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)
9/11/2014	500	2.01	0.38	36.33 ±6.68	0.00	59.01 ±20.09	0.00	25.96 ±1.22	34.31 ±7.48	3.43	3.86	27.76 ±1.87	0.00	82.02 ±7.09	0.00	24.32 ±0.35	24.32 ±1.56
25/10/2014	1,000	6.14	0.69	38.17 ±7.53	0.02	55.14 ±19.99	0.04	26.33 ±1.59	32.03 ±5.89	2.56	3.26	26.39 ±0.45	0.29	89.11 ±0.81	0.00	24.41 ±0.34	23.83 ±0.50
18/8/2014	1,500	6.71	1.84	37.81 ±8.14	0.00	53.90 ±20.73	0.03	25.45 ±1.87	31.09 ±4.36	1.16	2.46	26.32 ±1.18	0.00	86.42 ±4.72	0.00	23.84 ±0.37	25.16 ±0.98
Cotton candy																	
Date	Weight per Volume (g/0.144m^3)	**Temperature(°C) Day-time**								**Temperature(°C) Night-time**							
		$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)
9/11/2014	500	1.79	0.38	36.33 ±6.68	0.00	59.01 ±20.09	0.00	25.96 ±1.22	34.53 ±7.69	3.42	3.86	27.76 ±1.87	0.00	82.02 ±7.09	0.00	24.32 ±0.35	24.34 ±1.60
25/10/2014	1,000	3.72	0.69	38.17 ±7.53	0.02	55.14 ±19.99	0.04	26.33 ±1.59	34.45 ±7.68	2.72	3.26	26.39 ±0.45	0.29	89.11 ±0.81	0.00	24.41 ±0.34	23.66 ±0.59
18/8/2014	1,500	5.15	1.84	37.81 ±8.14	0.00	53.90 ±20.73	0.03	25.45 ±1.87	32.65 ±6.02	1.52	2.46	26.32 ±1.18	0.00	86.42 ±4.72	0.00	23.84 ±0.37	24.80 ±1.07

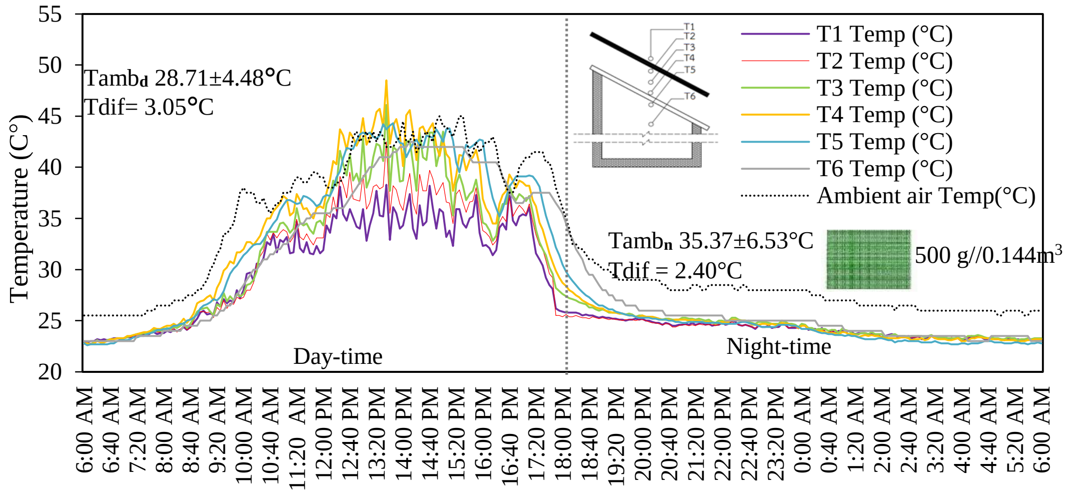

Figure 28 The temperature variation of Spanish moss on density 500g/0.144m^3

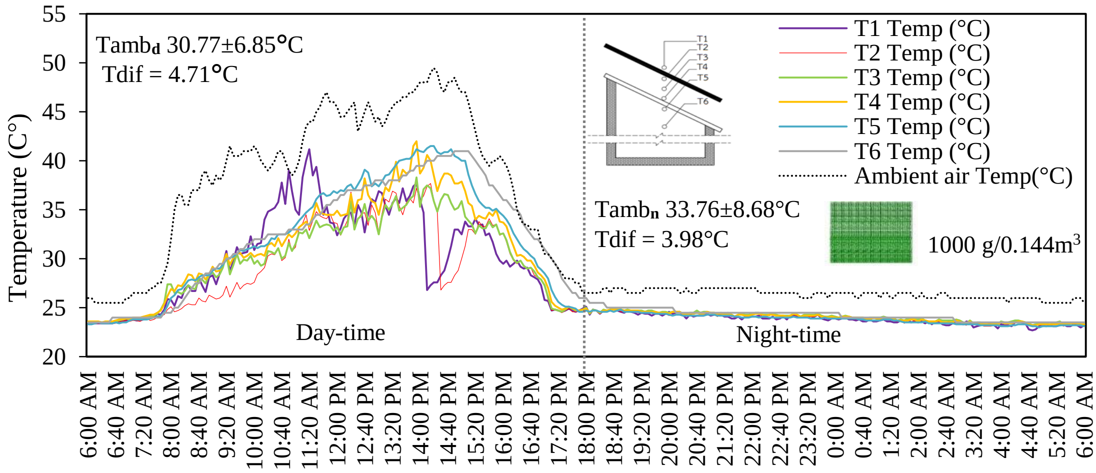

Figure 29 The temperature variation of Spanish moss on density 1,000g/0.144m^3

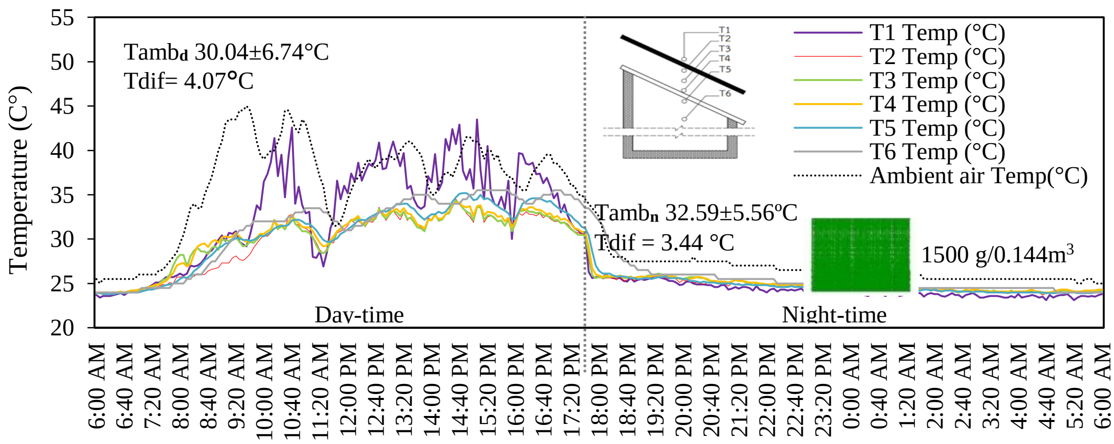

Figure 30 The temperature variation of Spanish moss on density 1,500g/0.144m^3

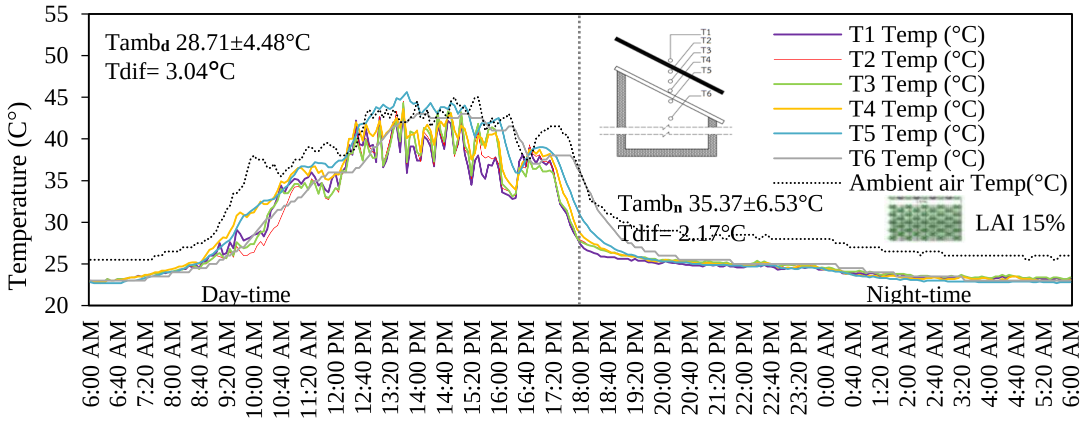

Figure 31 The temperature variation of cotton candy on density 500g/0.144m^3

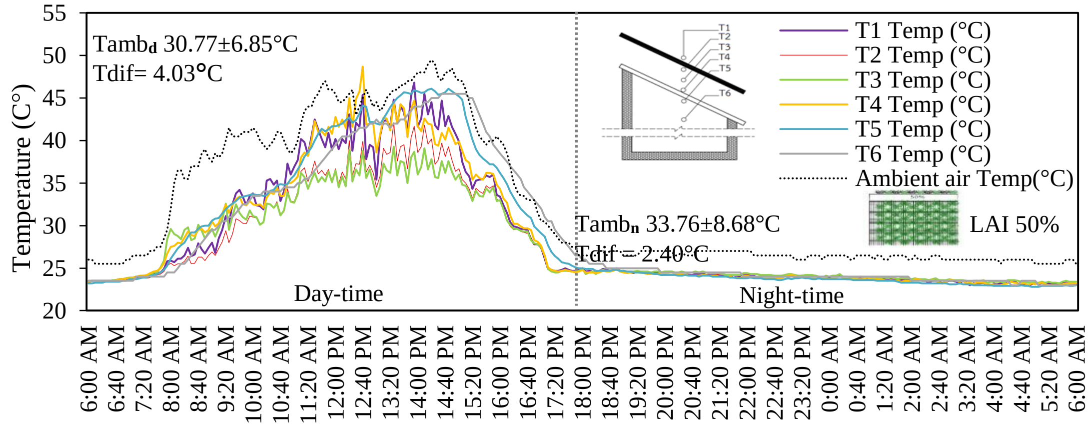

Figure 32 The temperature variation of cotton candy on density 1,000g/0.144m^3

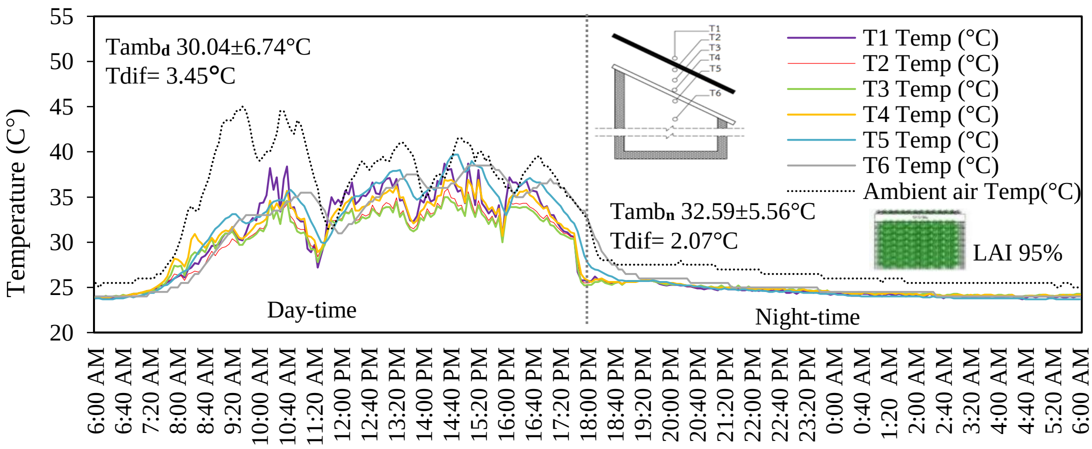

Figure 33 The temperature variation of cotton candy on density 1,500g/0.144m^3

Density set 3

Table 6 Comparison of the difference temperature (Tdif) of Spanish moss and Cotton candy (Weight per Volume (g/0.144m^3)

Date	Weight per Volume (g/0.144**m^3**)	Spainish moss															
		Temperature(°C) Day-time								**Temperature(°C) Night-time**							
		$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)
15/11/2014	500	2.12	1.27	30.31 ±2.99	0.00	77.22 ±10.31	0.00	25.68 ±0.78	28.19 ±3.05	3.15	3.77	26.16 ±1.54	0.00	86.87 ±5.07	0.00	23.75 ±0.61	23.01 1.18
28/10/2014	1,000	6.96	2.30	38.92 ±8.51	0.40	53.60 ±19.46	0.29	26.40 ±1.82	31.97 ±6.37	2.70	3.47	26.41 ±0.61	0.00	85.76 ±2.30	0.00	23.85 ±0.24	23.45 ±0.52
27/8/2014	1,500	8.1	4.42	35.94 ±5.42	0.00	55.93 ±17.15	0.00	25.00 ±1.23	27.87 ±2.41	2.90	3.72	26.98 ±1.92	0.00	79.64 ±8.67	0.39	23.06 ±0.27	24.08 ±1.17
Cotton candy																	
Date	Weight per Volume (g/0.144**m^3**)	**Temperature(°C) Day-time**								Temperature(°C) Night-time							
		$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)	$\overline{T}$dif (°C)	$\overline{T}$dif, Control (°C)	$\overline{T}$amb (°C)	Variance	$\overline{RH}$ Humidity (%)	Variance	$\overline{T}$dew point (°C)	$\overline{T}$5 (°C)
15/11/2014	500	1.90	1.27	30.31 ±2.99	0.00	77.22 ±10.31	0.00	25.68 ±0.78	28.41 ±3.06	3.20	3.77	26.16 ±1.54	0.00	86.87 ±5.07	0.00	23.75 ±0.61	22.96 ±1.29
28/10/2014	1,000	5.01	2.30	38.92 ±8.51	0.40	53.60 ±19.46	0.29	26.40 ±1.82	33.92 ±8.23	2.96	3.47	26.41 ±0.61	0.00	85.76 ±2.30	0.00	23.85 ±0.24	23.45 ±0.52
27/8/2014	1,500	6.87	4.42	35.94 ±5.42	0.00	55.93 ±17.15	0.00	25.00 ±1.23	29.06 ±3.12	3.00	3.72	26.98 ±1.92	0.00	79.64 ±8.67	0.39	23.06 ±0.27	23.99 ±1.27

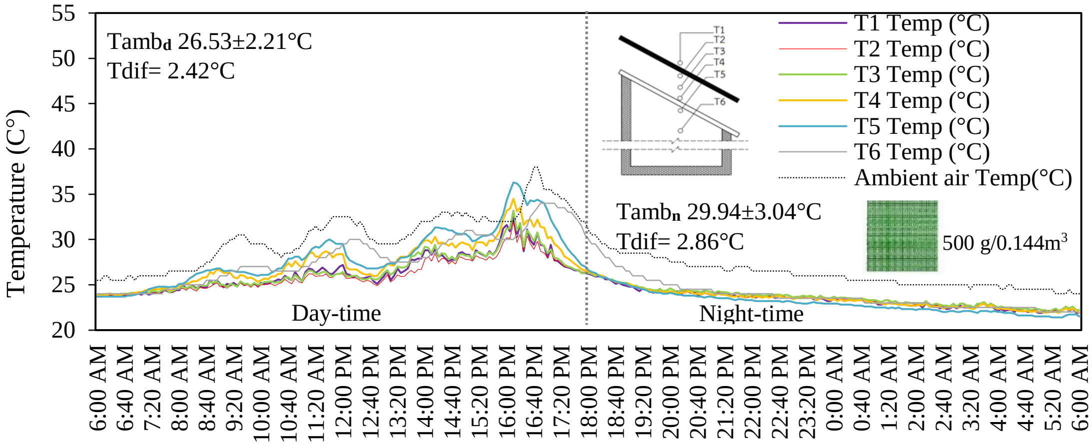

Figure 34 The temperature variation of Spanish moss on density 500g/0.144m^3

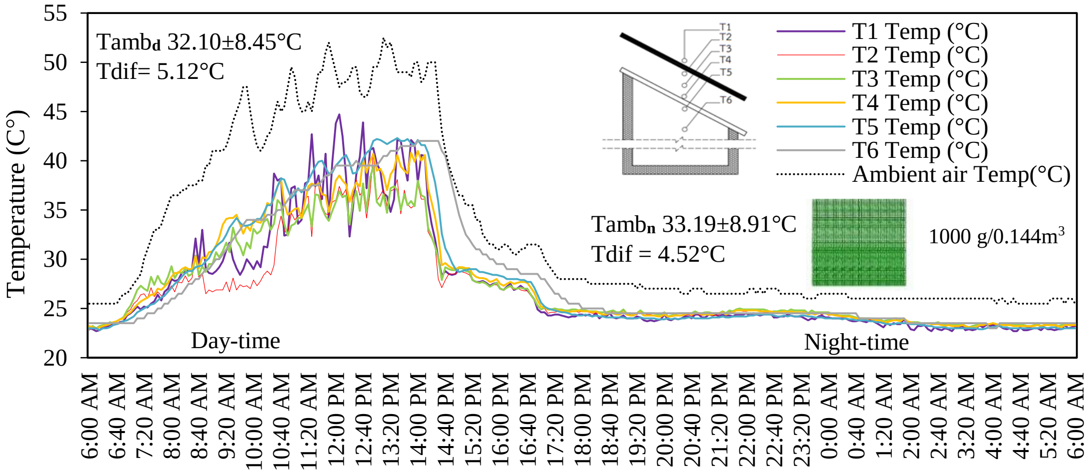

Figure 35 The temperature variation of Spanish moss on density 1,000g/0.144m^3

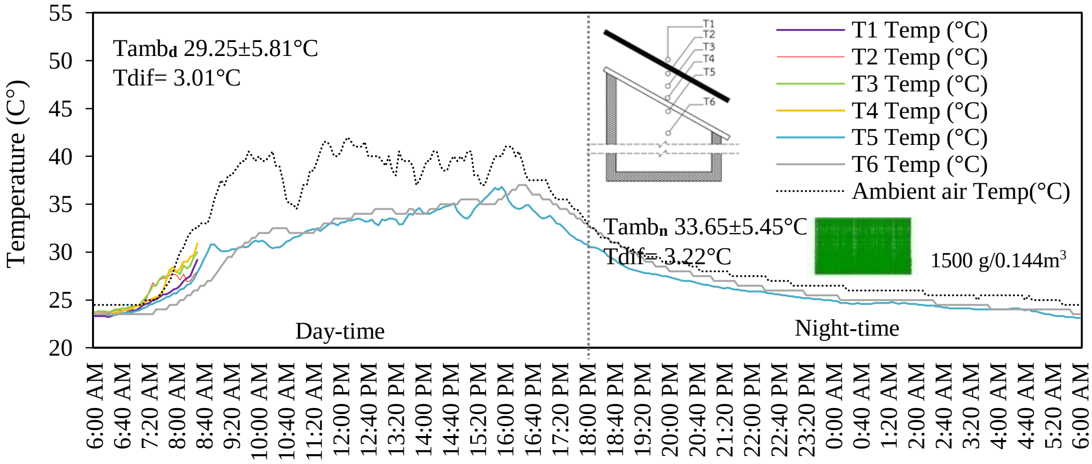

Figure 36 The temperature variation of Spanish moss on density 1,500g/0.144m^3

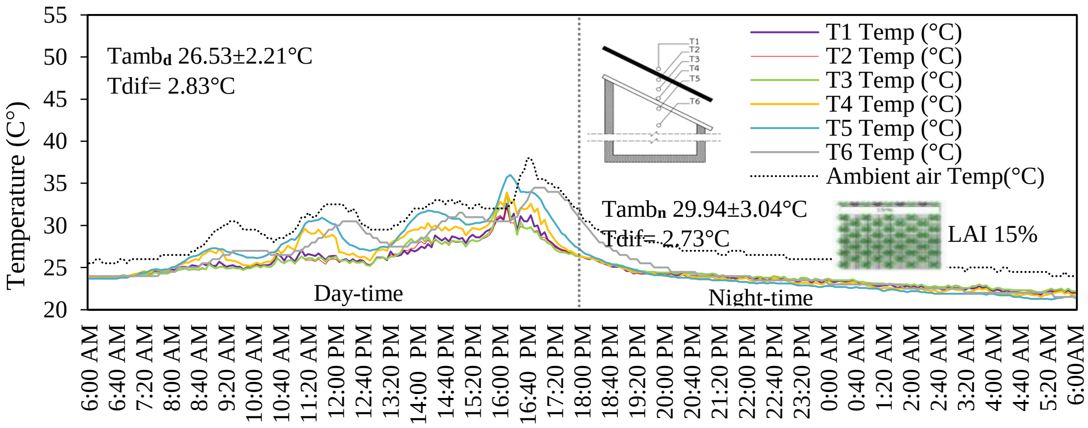

Figure 37 The temperature variation of Cotton candy on density 500g/0.144m^3

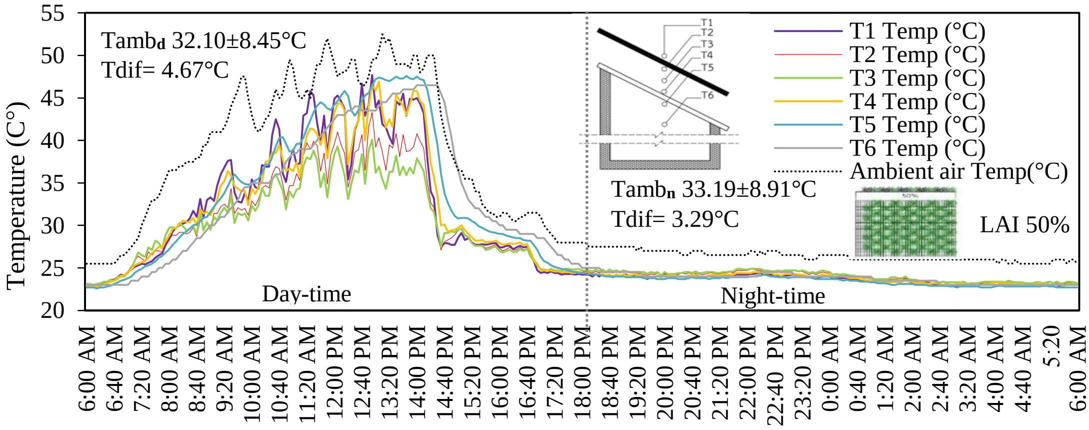

Figure 38 The temperature variation of Cotton candy on density 1,000g/0.144m^3

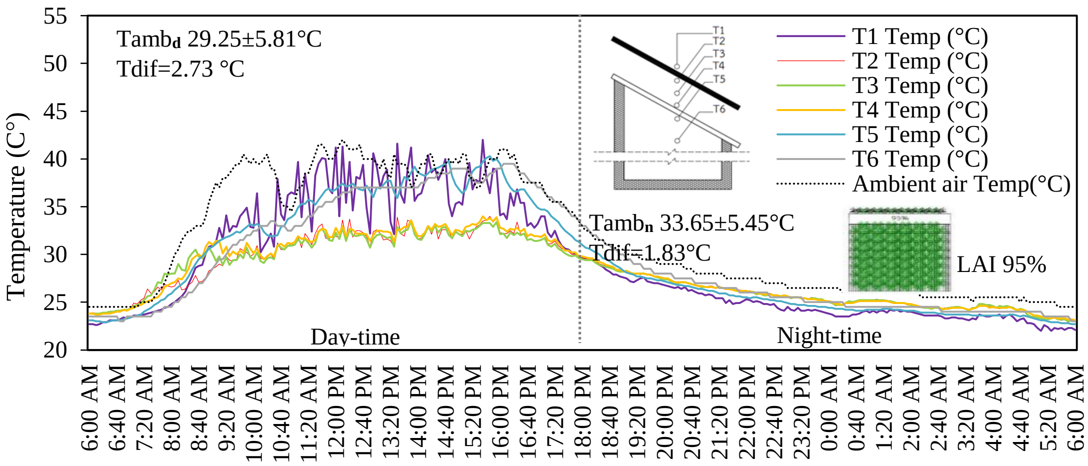

Figure 39 The temperature variation of Cotton candy on density 1,000/0.144m^3

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List of Publication

Thomas Brudermann and Tachaya Sangkakool*, Green roofs in temperate climate cities – An analysis of key decision factors, Urban Forestry & Urban Greening 21 (2017): 224–234

Tachaya Sangkakool and KuaananTechato, Life cycle cost of air plant green roofs in hot and humid climate, International Journal of Applied Business and Economic Research 2016 (IJABER), Vol. 14, No. 10 (2016): 7145-7160

Tachaya Sangkakool and KuaananTechato, Environmental Benefits of Air Plant Green Roofs in Hot and Humid Climate, ADVANCED SCIENCE LETTERS ISSN: 1936-6612 (Print): EISSN: 1936-7317 (Online) Copyright © 2000-2016 American Scientific Publishers

List of Proceeding

Tachaya Sangkakool and KuaananTechato,Environmental Benefits of Air Plant Green Roofs in Hot and Humid Climate, International Conference in Environmental and Civil Engineering Technology (ENVICET 2016) on Oct 4 – 6, 2016, Malaysia

Tachaya Sangkakool and KuaananTechato,Heat reduction by using of Spanish mosses as green roof with zero maintenance in hot and humid climate, International Conference on Architecture, Landscape and Built Environment (ICALBE 2016), The New Zealand Academy of Applied Research Limited (NZAAR), June 25-26, 2016, Malaysia