LIMESTONE AS GREEN ROOF MEDIA FOR HARVESTED RAINWATER IMPROVEMENT

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By

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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ABSTRAK

Perbandaran telah menghasilkan pengurangan kawasan hijau yang cukup ketara. Walaupun kita tidak dapat menghentikan proses perbandaran ini, tetapi kita boleh meningkatkan kawasan hijau melalui bumbung hijau. Secara amnya, bumbung hijau di persekitaran bandar mempunyai tiga fungsi asas: iaitu melambatkan aliran air hujan, mengurangkat suhu bangunan, dan mengurangkan kesan pulau panas bandar. Walau bagaimanapun, fungsi asas ini hanya dapat dicapai dengan merancang sistem bumbung hijau dengan tepat berdasarkan panduan yang ada. Kajian ini difokuskan pada kriteria reka bentuk bumbung hijau yang luas, kapasiti ketelapan media dan keberkesanan media bumbung hijau untuk merawat air hujan. Untuk penyelidikan ini, batu kapur digunakan sebagai media dengan saiz yang berbeza, yang mana batu kapur halus dan kasar digunakan. Berdasarkan eksperimen yang dilakukan untuk kapasiti ketelapan, kebolehtelapan batu kapur kasar lebih tinggi berbanding dengan batu kapur halus. Sementara itu, beberapa eksperimen juga dijalankan untuk menentukan keberkesanan batu kapur dalam merawat air hujan dan parameter yang dipilih adalah kekeruhan, warna, Ph, keperluan oksigen kimia, besi, zink, jumlah Kjeldahl nitrogen dan jumlah fosforus. Pada akhir penyelidikan ini, didapati batu kapur halus lebih efektif dalam meningkatkan kualiti air hujan berbanding dengan batu kapur kasar kerana luas permukaan yang lebih besar dan masa hubungan yang lebih lama antara batu kapur dan air hujan itu sendiri. Purata peratusan penyingkiran bahan pencemar menggunakan batu kapur halus adalah 35.75% untuk COD, 38.27% untuk besi, 54.73% untuk fosforus, 90.85% untuk zink, dan peratusan penyingkiran purata tertinggi adalah hingga 100% iaitu untuk penyingkiran TKN dari air hujan.

ABSTRACT

Urbanization has resulted in a substantial reduction of greenery. While we cannot stop urbanization, we can increase green coverage in urban development by incorporating green roofing. Generally, green roofs in urban environments have three essential functions: delay rainwater runoff, moderate building temperatures, and reduce the urban heat island effect (UHI). However, these essential functions only can be achieved by designing the green roofs system adequately based on the existing guidelines. This study highlighted the extensive green roof's design criteria with the main focus on media filtration capacity and the efficiency of the green roof media in improving the harvested rainwater quality. For this research, limestone was used as the media with different sizes, classified as fine and coarse limestone. Based on the experiments conducted for the filtration capacity, coarse limestone permeability was higher than fine limestone. Meanwhile, several experiments were also conducted to determine the efficiency of limestone in treating rainwater. The chosen parameters are turbidity, colour, pH, COD, iron, zinc, total Kjeldahl nitrogen, and phosphorus. At the end of this research, it was found that fine limestone was more effective in improving the rainwater quality compared to coarse limestone due to the larger surface area and longer contact time between the limestone and the rainwater itself. The average percentage of pollutants removal for fine limestone is 35.75% for COD, 38.27% for iron, 54.73% for phosphorus, 90.85% for zinc, and the highest average percentage removal is up to 100% which is for TKN removal in rainwater.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Research Background

Urbanization and climate change could be significant factors that shape global development within the decades ahead. These two factors can structure out the global economic patterns of resource use and environmental quality. Urbanization is increasing in most countries, including Malaysia. The global urban population grows from just about 30% in 1950 to 54.4% in 2016 (Sminkey & Le Doux, 2016). The increases in the global urban population are due to rapid economic growth. The uncontrolled growth of roads and building in urban areas will result in limited space left for the greenery of the natural landscape. This issue should be given serious attention as it will have detrimental effects such as air pollution and increasing the average urban temperature.

One of the initiatives that can be taken to minimize the adverse effects of urbanization is by implementing green stormwater management practices such as green roofs. Green roofs are defined as the use of vegetation covering the roof of a building (Refahi & Talkhabi, 2015). A green roof system generally consists of four main components: vegetation layer, growing medium, filter sheets, and drainage layer. Green roofs are usually classified into two types: intense green roofs and extensive green roofs, depending on the depth of the growing media and the size of the plants. (Shao et al., 2021). Intensive green roofs are mainly constructed with a substantial substrate depth of more than 15-20 cm, whereas extensive green roofs have a shallower substrate layer depth of less than 15 cm.

Green roofs significantly reduce the urban heat island effect, as increasing urban vegetation by 10% could reduce air temperature and mean radiant temperature by up to 0.8 degrees Celsius during the day and night. (Cascone et al., 2018a). Other than reducing the heat island effect, green roofs also have various environmental benefits, including minimizing stormwater runoff, improving local air quality, reducing greenhouse gas emissions, and increasing local biodiversity. Therefore, a green roof system should be implemented for a healthier environment, especially in urban areas. Several active green roof systems were developed on buildings in Malaysia, including Sime Darby Oasis, Putrajaya International Convention Centre, and Kl Sentral Park @ Platinum. (Siew et al., 2019).

1.2 Problem Statements

Atmospheric deposition in stormwater can be a significant environmental issue due to concerns over-acidification, bioaccumulation of toxic substances and metal. In addition, air quality is threatened by population growth and industrial expansion. (Marlier et al., 2015). The quality of rainwater is usually affected by heavy metals such as lead (Pb) when the surrounding air conditions are highly polluted (Khayan et al., 2019). Besides lead, the others metal that exists in rainwater are cadmium (Cd^{2+}), nickel (Ni^{2+}), cobalt (Co^{2+}), manganese (Mn^{2+}) and zinc (Zn^{2+}) (Jain et al., 2019). All these metals are harmful as they can affect human health and biodiversity.

The rapid urbanization process will significantly impact the hydrological cycle because of the increase of impervious surfaces. Expanded impervious area in urban areas increases runoff coefficient, runoff, and the risk of urban thunder storms and floods. (McGrane, 2016). Moreover, 40 – 50% of the total impervious surface in the developed urban areas are the roof surface (Jusić et al., 2019). As roofs covered a quite large portion of the urban areas' impervious area, a green roof can be utilized as a tool to manage urban stormwater runoff.

While green roofs may be the best potential stormwater management practice for urban areas with limited space for conventional stormwater practices, their effectiveness at treating stormwater is still unclear. As rainwater may contain various harmful substances, it is very important to minimize the quantity of the pollutants of the harvested rainwater. With this initiative, the harvested rainwater can be reused for non-potable purposes such as flushing toilets, watering gardens, and washing cars without harm.

In designing a green roof, several factors should be taken into consideration as a poor design can lead to structure failure of a green roof. These factors including type of green roofs, location of the installation, slope of the roof, type of plant and type of growing media. For this research, it will focus on the growing media of the green roofs. The media of green roofs need to compositionally satisfactory for the intended structural, lightweight, drainage, and able to retain pollutants.

1.3 Objectives

i. To study the particle size effects of limestone on infiltration ability as green roof media.

ii. To determine the effectiveness of limestone as green roof media to improve the selected water quality parameter: turbidity, color, COD, pH, iron, zinc, total Kjeldahl nitrogen, and total phosphorus.

1.4 Scope of the Study

This study focuses on the green roofs design criteria, focusing on the media which different particle size of limestone was used. In this study, the infiltration ability of two different sizes of limestone, coarse limestone, and fine limestone, was be determined. The coarse limestone and fine limestone were tested for sieve analysis and constant head permeability test. Sieve analysis was conducted to obtain the particle size distribution for identification of the limestone's mechanical properties. The resulting particle size distribution graph was used for several purposes, including determining the soil grading and the percentage of coarse and fine particles. The particles size distribution of the limestone also was hypothesized to affect the drainage performance of the limestone as the green roof media. The next experiment that was conducted was the Constant Head Permeability Test. This test was carried out to determine the permeability coefficient, k, for both coarse limestone and fine limestone.

Other than that, tests regarding water quality will also be conducted to determine the limestone's effectiveness to improve the selected water quality parameters. The water quality of the raw and harvested stormwater from the green roof will be tested in the laboratory and classified based on National Water Quality Standards (NWQS). Classifying water quality based on NWQS will involve eight parameters: pH, turbidity, chemical oxygen demand (COD), iron, zinc, total Kjeldahl nitrogen, and total phosphorus. All these parameters above will be evaluated based on a laboratory test.

1.5 Limitation of the Study

The researcher faces several limitations to carry out this study. The first challenge was to conduct the experiment by using an actual green roof physical model. The limitation of cost and space to carry out the model construction was a significant challenge. Hence, a column study based on an actual green roof design component was used as it is more affordable and only a small space is needed. Other than that, this study was time constraining due to the sample selected. Finally, as this study involves the stormwater treatment, some experiments can only be conducted after a rainy day, and enough sample volume was collected.

1.6 Dissertation Outline

For this research, the dissertation consists of five chapters. The first chapter introduces Green Roof and the importance of green roofs for urban areas, problem statement, objectives, scope of the study, and research limitation. Chapter Two is on the literature review of the previous research paper about a green roof. This literature review will focus more on the media study for green roofs and the quality of the harvested rainwater from the green roof. Chapter Three is the methodology of this research, which explains how the researcher will conduct this study. Chapter Four explains and discusses the results obtained from the experiment conducted for the limestone sample and the quality of the harvested rainwater from the green roof. Finally, Chapter Five concludes this research by stating the achieved objective and recommendations for future research about this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

For this chapter, the literature review will cover the implementation of green roof technology in Malaysia, the importance of green roofs in urban areas, the type of green roof, design component of a green roofs system, and the effectiveness of the green roofs media in removing pollutants in rainwater. Generally, there are three types of green roofs: extensive, semi-intensive, and intensive green roofs. Furthermore, the chemical composition and characteristics of rainwater also will be discussed in this chapter. Besides that, a literature review on the design criteria of growing media of green roofs will be carried out based on the available guideline. As this research focuses on the media of the green roof, several types of media will be discussed based on the drainage performance and its ability to treat rainwater. Finally, the literature review of the efficiency of limestone in water treatment also will be conducted.

2.2 Implementation of Green Roofs Technology in Malaysia

The installation of green roofs in Malaysia went back to 1992 when an extensive green roof was installed in Selangor. From that point forward, green roofs have been developed on residential and commercial buildings, museums, and airports for various reasons, including energy conservation, aesthetics, and recreational space. It is expected that maintaining the longevity and irrigation of green roof plants would be easier than in areas where rain is scarce, and planting is difficult, as Malaysia has a tropical climate. Experts in the construction industry with various backgrounds believe that green roofs have the potential market in this country, but it is not widely adopted in Malaysia (Mahdiyar et al., 2020). For the past 15 years, only a few buildings in Malaysia have used green roofs as a critical green feature element. Based on the previous research, industries were very cautious about having rooftop gardens due to the unknown risk on the maintenance aspects. Even though many commercial buildings have a green garden on their rooftop level as a recreational platform, the green roofs mainly were extensive green roofs rather than intensive green roofs (Chow & Abu Bakar, 2016). Several aspects need to be considered in selecting the type of green roof, and one of the aspects is climate condition. According to a study by Kok et al. (2016) on evaluating the hydrological (quantity and quality) and thermal efficiency of green roofs in HTC, Malaysia, extensive green roofs systems work better in the local tropical environment.

In another study, most green roofs implemented in this county are identified at residential buildings and are intensive green roofs. Due to the limitation of roof area, green roofs are primarily implemented at high-rise residential buildings mainly located at high dense urban areas (Ismail et al., 2018). Based on a survey, residential buildings are the most implemented with green roofs (46.7%), followed by commercial buildings (34.4%) and institutional buildings (10%) (Ismail et al., 2018). Although there are numerous green roofs projects in Malaysia, there are some challenges in implementing the green roofs system. According to another survey, nine factors have been identified as contributors to the obstacles of the application of green roofs in Malaysia, which are past failure, difficult installation and high cost, complicated and hard to maintain, limited local expertise, lack of scientific research, fear of unknown risk, higher cost of materials supply, no design standards and guidelines and the belief that green roof is susceptible to fire (Chow & Abu Bakar, 2016).

Table 2.1: Some examples of green roof projects in Malaysia since 1998 (Chow & Abu Bakar, 2016).

Building	Type of green roofs	Year of Completion
Rice garden museum (Laman Padi), Langkawi	Intensive	1998
Ministry of Finance, Putrajaya	Extensive and Intensive	2002
Putrajaya International Convention Centre (PICC), Putrajaya	Extensive and Intensive	2003
Putrajaya City Hall, Putrajaya	Extensive	2004
Malaysian Design Technology Centre (MDTC), Cyberjaya	Extensive	2004
Serdang Hospital	Intensive	2005
Faculty of Social Sciences and Humanities, Universiti Kebangsaan Malaysia	Retrofit Extensive	2007
Sime Darby Oasis, Damansara	Extensive	2009
KL Sentral Park	Intensive	2009
Newcastle University Medicine Malaysia, Nusajaya	Extensive	2011
Laman PKNS, Shah Alam	Intensive	2013
Heriot-Watt university, Putrajaya	Extensive	2014
Tun Razak Exchange (TRX)	Intensive	2016

2.3 The Benefits of Green Roof in Urban Areas

Green roof is a green infrastructure with various benefits in multiple aspects, including environmental, social, and economic, improving a building's performance and the urban environment. Based on previous research, green roof scientifically can reduce the heat island effects, reduce stormwater runoff, minimize noise pollution, and improve air quality in urban areas.

2.3.1 Reduce the Heat Island Effects

One of the adverse impacts of urbanization is heat island effects, and green roofs can be the answer for this issue. The implementation of green roofs can reduce the heat island effects as it has many thermal benefits. First of all, plants and growing medium in a green roof system can provide thermal insulation. The plants and growing medium can absorb solar radiation up to 60%. Other than that, green roofs help stabilize temperature through the roofing system, especially for the membrane, by adding the thermal mass. Lastly, green roofs can reduce the heat island effect by reducing the heat flow into the building by the effect of evapotranspiration, photosynthesis, and shading during the summer (Yang et al., 2021).

2.3.2 Reduce Stormwater Runoff

A green roof system also reduces the storm water runoff; hence it can prevent flooding in urban areas. Urbanization resulted in the extension of impervious areas such as roads and roofs and soil compaction, and vegetation alteration. Rainfall infiltration will be reduced, and stormwater runoff will increase in both rate and volume due to this change (Ercolani et al., 2018). In a highly built-up metropolitan center where no space is available for new infrastructure, conventional rooftops can account for up to 40–50 percent of the impervious surface. Green roofs can use otherwise underutilized impermeable surfaces to restore predevelopment hydrologic functions, including increasing the infiltration and retention rate (W. Liu et al., 2019). By implementing green roofs in urban areas, this system can retain water in vegetation, substrate, and layered materials, hence providing runoff retention capacity for stormwater management (Zheng et al., 2021).

2.3.3 Minimize Noise Pollution

Green roofs have the potential to reduce noise pollution in urban areas. This is because green roof systems can absorb, disperse, and influence the reflection of airborne sound, thereby enhancing the surrounding environment's soundscape. Not only it can minimize the noise in the surrounding urban area, but green roofs can also reduce sound propagation into the building interior on the surface where the system is installed (Manso et al., 2021). The ability of green roofs to absorb and reflect sound is affected by vegetation and substrate characteristics such as foliage size and shape, root system, and substrate density, all of which change throughout the year (Lunain et al., 2016).

2.3.4 Improve Air Quality

Lastly, green roofs are able to reduce air pollution in urban areas. According to World Health Organization (WHO), carbon monoxide (CO), sulfur dioxide (SO_2), ozone (O_3), nitrogen dioxide (NO_2), respirable fine particle matter (PM) with a diameter of fewer than 10 μm, PM_{10}, and fine particles less than 2.5 μm, $PM_{2.5}$ are the main components of urban air pollutants. The green roof can reduce air pollution in urban areas as the plant species can sequester air pollutants and consume carbon dioxide, but this vital function depends on their form and dimension (Manso et al., 2021). Green roofs' ability to remove air pollutants depends on the type of green roofs, where the purification ability of intensive green roofs is better than extensive green roofs (H. Liu et al., 2021).

2.4 Type of Green Roofs

The green rooftop is the most widely recognized greenery idea, for the most part being used in European, North American, and some tropical Asian countries. Germany is considered the world pioneer in developing green roof technologies. Green roofs consist of different supportive layers that provide conditions for growing vegetation on a sloped or flat rooftop (Raji et al., 2015). Green roofs can be categorized into two major types: extensive green roofs and intensive green roofs (Peng & Jim, 2015). The extensive and intensive types of green roofs are classified according to the substrate thickness (Cascone et al., 2018b). Even so, other articles and guidelines also mentioned that there is a third type of green roofs as a simple-intensive green roof which is semi-intensive green roofs (Mahdiyar et al., 2015), (FLL Guidelines, 2018). Each type of green roof has a significant difference in benefits, cost, maintenance period, and plant species that can be planted, but still, all green roofs type are considered sustainable and environmentally friendly (Mahdiyar et al., 2018). Figure 2.1 shows the criteria for each type of green roof.

	Extensive Green Roof	Semi-Intensive Green Roof	Intensive Green Roof
Maintenance	Low	Periodically	High
Irrigation	No	Periodically	Regularly
Plant communities	Moss-Sedum-Herbs and Grasses	Grass-Herbs and Shrubs	Lawn or Perennials, Shrubs and Trees
System build-up height	60 - 200 mm	120 - 250 mm	150 - 400 mm on underground garages > 1000 mm
Weight	60 - 150 kg/m^2	120 - 200 kg/m^2	180 - 500 kg/m^2
Costs	Low	Middle	High
Use	Ecological protection layer	Designed Green Roof	Park like garden

Figure 2.1: Types of green roofs and their criteria (Raji et al., 2015)

2.4.1 Extensive Green Roofs

Extensive green roofs are designated by a thin layer of soil with 5 – 20cm depth, allowing small vegetation growth. Generally, Sedum and Grass are used for the vegetation layer. Sedum is a succulent plant species that does not require special maintenance and water supply to survive (Cascone et al., 2018b). As the extensive green roofs have a thinner substrate layer, which is relatively lightweight, hence in some cases, little or even no additional support is required. This design makes extensive green roofs applicable to a larger range of buildings (Mahdiyar et al., 2018). Extensive green roof is widely used than other types of green roofs as it has lower maintenance and the need for irrigation is not significant (Mahdiyar et al., 2015). Extensive green roof is designed to initiate vegetation development in a shorter time than spontaneous self-vegetation and establish a lasting population with the help of the natural vegetation dynamics (FLL Guidelines, 2018). An extensive green roof can be a single-coarse and multi-coarse green roof; however, both were still counted under extensive green roofs as there is no significant difference in substrate thickness (Bronz, 2017). Figure 2.2 shows the components of single-coarse and multi-coarse extensive green roofs.

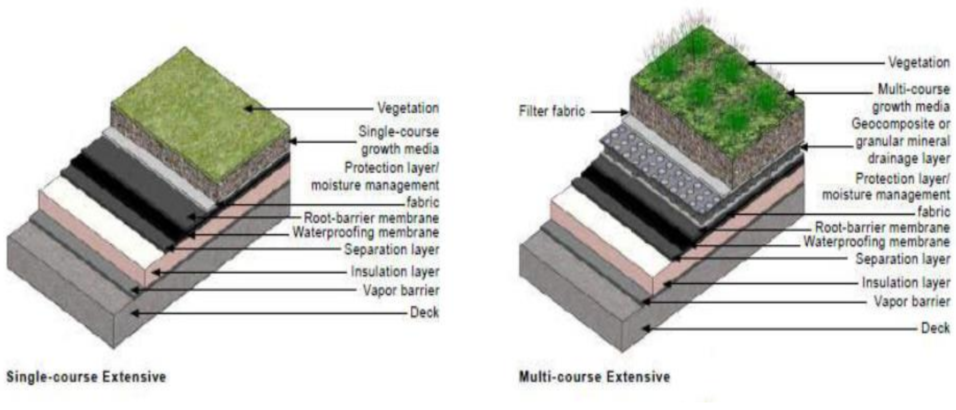

Figure 2.2: Components of Single-coarse and Multi-coarse of Extensive Green Roofs (Bronz, 2017).

2.4.2 Semi-Intensive Green Roofs

A semi-intensive green roof is a combination of intensive and extensive green roofs, but the extensive green roofs type must represent at least 25% of the total green roofs area (Raji et al., 2015). Semi-intensive green roofs need lower additional structural support and maintenance compared to intensive green roofs. Moreover, the soil thickness for semi-intensive green roofs is lower than intensive green roofs, and different types of plants can be used in semi-intensive green roofs (Mahdiyar et al., 2018). The recommended minimum thickness of the substrate for semi-intensive green roofs varies between 12cm for the grass or herbaceous plants and 20cm for smaller shrubs and coppices, and the substrate can be adjusted. For more demanding vegetation, the substrate thickness can be increased. During dry season, the irrigation is needed for this type of green roofs (Vacek et al., 2017). The production cost of semi-intensive green roofs is more economical than intensive green roofs, and maintenance is required to a reduced extent. Some invasive vegetation such as ground cover plants, herbaceous plan and moss can be tolerate depending on the greening aims of the semi-intensive green roofs (FLL Guidelines, 2018). Figure 2.3 shows the components of semi-intensive green roofs.

Figure 2.3: Components of Semi-intensive Green Roofs (Bronz, 2017).

2.4.3 Intensive Green Roofs

An intensive green roof is designed with a thick layer of growing substrate, in which different types of plants can be grown, especially when irrigation is available (Mahdiyar et al., 2015). The depth of the growing substrate for intensive green roofs is about 20 – 100cm, and this type of green roofs requires irrigation and permanent maintenance (Raji et al., 2015). Meanwhile, other researchers stated that intensive green roofs are characterized by a thicker layer of growing substrate of about 20 – 100cm and only can be installed when the increase in roof load is considered at the stage of the bearing structure (Cascone et al., 2018b). Intensive green roofs can be constructed flat, height-differentiated, or punctually. Intensive green roofs can only be sustained by intensive care, especially regular water and nutrient supply (FLL Guidelines, 2018). Figure 2.4 shows the components of intensive green roofs.

Figure 2.4: Components of Intensive Green Roofs (Bronz, 2017).

2.5 Characteristics and Quality of Rainwater

Water treatment in Malaysia depends significantly on surface water, which is considered the primary water resource for treated drinking water. As Malaysia is a tropical country that receives rainfall throughout the year, utilizing rainwater as a resource is an attractive alternative (Shaheed et al., 2017). However, industrialization, increased energy use, anthropogenic activities, and industrialization have resulted in severe air pollution problems, resulting in the accumulation of different gases and particulate matter in the atmosphere, which significantly affects rainwater quality (Szép et al., 2019).

Generally, several aspects affect the presence and concentration of organic, inorganic, physical and biological impurities in rainwater, such as meteorological factors, hydrological aspects, roofs characteristics, location of the roofs, chemical properties of the substance hydrological aspects, and storage materials. Other than that, rainwater quality might worsen during the harvesting and storing process due to leaves, wind-blown dirt, fecal dropping, and contaminants present in the catchment area (Shaheed et al., 2017). This literature review will be focusing on several chemical compositions and characteristics of rainwater, such as turbidity, pH, chemical oxygen demand (COD), and heavy metals.

2.5.1 Turbidity

Turbidity is influenced by particles that exist in water, and it is measured relative to the water's clarity. The increase of suspended and dust particles in the rainwater will increase its turbidity. The turbidity of harvested rainwater is affected by the presence of dust, leaves, and mosses that accumulate at gutter and roof. The range of turbidity for rainwater in Malaysia is between 6 NTU and 19 NTU. At the early duration of rain, the value of turbidity is high as rainwater flushed away from the contaminants away from the roof (Muhamad & Abidin, 2016).

The high value of turbidity of rainwater indicates that the rainwater has been polluted physically, chemically, and biologically. The source of physical pollutants can be from animal waste (bird) and dust particles produced by human activities such as land clearing and open burning. Meanwhile, chemical contaminants can be emitted from automobiles and manufacturing operations, such as chemical-contained tin roof material to absorb and store rainwater. Meanwhile, viruses and bacteria present in the air are the source microbiological contaminants that can raise rainwater turbidity. (Khayan et al., 2019).

The other factor that affects the turbidity of rainwater is the roughness of the roof-covering materials. It is found that the turbidity of rainwater water will be increased with the roughness of the roof surface. Meanwhile, another research demonstrated reverse dependencies and attributed their finding to rough surface capacity to hold the dirt in rainwater. The maximum turbidity value of different roof-covering materials for glass, metal, and the ceramic surface is 92.9, 57.1, and 10.1 NTU, respectively (Zdeb et al., 2020).

2.5.2 pH

The range for pH value of rainwater in Malaysia is between pH 5.84 until pH 7.02. These values show that rainwater tends to have a slightly acidic characteristic. The pH value of rainwater increases to the average value with increasing duration of rain. The high concentration of CO_2 in the atmosphere and the emission of gasses from vehicles can be the cause of the rainwater being acidic. The other reason that contributes to the changes in pH is because of the rainwater that falls through the roof system was mixed with leaves, dust, and bird dung. The acidic rain may negatively impact users, such as corrosion of steel when used to wash vehicles, which is also not the best for agriculture purposes (Muhamad & Abidin, 2016).

A study by Zdeb et al. (2020) found that the roof material also affects the pH value in rainwater. In this study, ceramic and concrete roof tiles positively affect pH when rainwater contact with the roof surface. The pH of rainwater collected from concrete tiles is higher than the pH of rainwater that is directly collected from the air due to the composition of cement. Concrete tiles consist of cement that includes several carbonate compounds, such as calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$), which may, to some extent, be washed away by rainwater and cause an increase of pH in the rainwater. As the study was conducted in urban areas, the high pH value of rainwater collected directly from the sky may be caused by the combustion of fuels, which resulted in the formation of nitrogen oxides (NO) and sulphur dioxide (SO_2).

2.5.3 Chemical Oxygen Demand (COD)

Based on a study in Johor by Muhamad and Abidin (2016), the range value of COD of rainwater is between 1.0 mg/L and 35.0 mg/L. Meanwhile, the maximum limit value of COD of raw water set by WHO is 10 mg/L. The average reading for the COD value of rainwater in this research was 15.083 mg/L. This study also found the concentration of COD decrease along with the increase of time. The high value of COD at the early spill of rainwater may be because of the high number of contaminants from the air that existed on the roof, such as lead and plumbum (Pb) from vehicles. The roof was cleaner as the rain intensity increased, and all the contaminants were flushed away from the roof. Hence, the value of COD decreased as time increase.

2.5.4 Heavy Metals

Iron (II) (Fe^{2+}) and Zinc (Zn^{2+}) are among the heavy metals that are mainly found in rainwater. The range value for Iron in rainwater can be found between 0.01mg/L and 0.38mg/L. The corrosion of galvanized iron used for connecting the roof, gutter, and downpipe in some buildings can be the source of iron in rainwater. The concentration of Fe^{2+} in the rainwater can increase as the corrosion of the gutter, and the downpipe is higher. Moreover, the concentration of the Fe^{2+} will be lower as the duration of rainfall increases. This is because, as the duration of rain increases, the corrosion from the roof will be flushed away.

Meanwhile, the range value for zinc concentration in rainwater is between 0.05 mg/L and 0.2 mg/L. The source of zinc in rainwater is from the material of roofs exposed to the atmospheric and change of weather that led to the corrosion of the roof materials. Similar to Iron, the concentration of zinc will decrease as the rain intensity increase as the zinc is taken away by the earlier rainfall (Muhamad & Abidin, 2016)

Another study by Zdeb et al.(2020) also mentions that heavy metal in rainwater is from the surfaces washed by it as they are points of pollutants accumulation due to dry deposition. The rainwater pH will affect the solubility of nonferrous metals such as lead. Metals such as Zn, Cd, Cu, and V show higher solubility than Pb, Ni, and Cr in both wet and dry deposition. Based on the result of the analysis of heavy metals of rainwater in South Poland, it was found that the sample tested to contain a trace amount of chromium, lead, nickel, and arsenic at a concentration slightly exceeding 1 µg/L. At the same time, ions of copper, manganese, bromine, and strontium were measured at levels of around 10 µg/L, and the concentrations of iron, zinc, titanium, and silver often exceeded 100 µg/L (Zdeb et al., 2020).

The presence of heavy metals in rainwater can be treated by using activated carbon. Activated carbon has the ability to absorb heavy metals in rainwater as it has relatively big microspore and mesopore volume which is possible to absorb pollutants in adequate amount. Activated carbon is an absorbent with an amorphous carbon atom structure, mainly consisting of free carbon and a deep surface. Hence it has good absorption ability (Khayan et al., 2019).

2.6 Design Criteria of Growing Media in a Green Roofs System

Based on a research article, designing a guideline for green roof systems in Malaysia by (Siew et al., 2019), the selection of types of green roof media materials is based on the material's availability. The media used must consider its technical requirements, and a total of thirteen technical requirements mentioned in this article which are design loads, granulometric distribution, organic content, structural and bedding stability and settlement of substrate, the behaviour of substrate boards under compression, water permeability, water storage ability, air content, pH value, salt content, nutrient content, seed germination, the proportion of foreign substances. However, there are no specific acceptable range values stated in this article for each technical requirement.

Meanwhile, another guideline Landscape Development and Landscaping Research Society e.V. (FLL), (2018), the requirement depends on the material group. The following properties must be considered: the compatibility of materials, environmental compatibility, plant compatibility, fire characteristics, particle distribution, weatherability, structure and layer stability, compression behaviour, water permeability, water-storage capacity, pH–value, and salt content. The particle size distribution depended on coarse depth, and the diameter for 0.063mm particles must not exceed 10% by mass. In terms of water permeability, the media must have a high water permeability for the rapid removal of excess rainwater into the roof drains. The permeability of the media can be determined by water infiltration rate mod, and the permeability coefficient K_f must be greater than 0.3cm/s or 180mm/min. Furthermore, the pH of the media should have approximately the same pH as the vegetation stratum and not differ by more than 1.5 units. The pH for both extensive and intensive should be between 6.0 and 8.5.

Another guideline, Green Roof Design: State of the Art on Technology and Materials (Cascone, 2019), the media need to be designed to achieve numerous long-term benefits of green roofs such as water quality improvement, reduce the peak flow, noise, and thermal insulation, which are associated to the substrate characteristics. Designing the thickness and weight of the growing media depends on the vegetation, roof geometry, climate condition, and irrigation strategy. The weight of the growing media varies, based on the type of green roofs, from 12–14 kg/m^2 with a thickness of 8 cm for extensive green roofs to about 600 kg/m^2 with a thickness of 50–60 cm for intensive green roofs. As green roof media represent the main load on the roof bearing structure, it should be characterized by low dry and wet bulk densities. Utilization of low-densities organic material can be one of the fundamental approaches for decreasing the weight of the substrate.

Furthermore, hydraulic performance, water retention, and permeability also need to be considered in designing green roof growing media. The porosity of extensive green roofs should be not less than 58%, while for intensive green roofs not less than 48%. Next, the water holding capacity of the growing media is vital for the survival of the vegetation, as it slows down the peak flow during stormwater events, also held the plant to resist drought conditions. It was suggested that the water holding capacity for extensive green roofs should be more than 20%, while intensive green roofs were not stated.

Table 2.2: Summary of design requirement of green roof media from different guidelines

Source of Guidelines	Parameter	Guidelines Requirement
Designing a Guideline for Green Roof System in Malaysia (Siew et al., 2019)	Type of Media	The selection of types of materials of green roofs media based on avaibility of the materials
Landscape Development and Landscaping Research Society e.V. (FLL), (2018)	Particles size distribution	Depend on media depth, and the diameter of 0.063mm must not exceed 10% by mass
	Permeability	The permeability coefficient K_f must greater than 0.3cm/s or 180mm/min
	pH	The pH for both extensive and intensive should be between 6.0 and 8.5
Green Roof Design: State of the Art on Technology and Materials (Cascone, 2019)	Weight	12–14 kg/m^2 for extensive green roof and 600 kg/m^2 for intensive green roofs
	Porosity	Should not less than 58% for extensive green roof and not less than 48% for intensive green roofs
	Water holding capacity	Should be more than 20% for extensive green roofs

2.7 Ability of Green Roofs Media in Treating Stormwater

One of the ideal design criteria of green roofs media is able to retain pollutants. Research on the ability of green roofs in controlling stormwater runoff water quality has been broadly carried out in recent years all around the world. Based on previous research, green roofs can reduce the concentration of pollutants in urban stormwater runoff by absorbing and filtering pollutants by its components, which are the media and vegetation layer (Gong et al., 2020). Adsorption is mostly based on the utilization of solid adsorbents, among organic, inorganic, biological or low-cost materials. Heavy metals can be effectively removed by adsorption on organic adsorbents, which is typically done through the use of polymeric ion exchangers, which promote the binding and interaction of metal species with these adsorbents through an ion-exchange mechanism (Elmorsy et al., 2019).

2.7.1 Composite Media

Based on a study by Vijayaraghavan and Joshi (2015), to achieve low dense, minimal nutrient and highly stable substrate, the growing media of the green roofs is designed mainly composed of inorganic material and minimal organic constituents. In this research, the growing media was designed to be composed of 80% inorganic materials consists of perlite, vermiculite, sand, and crushed brick, and 20% organic materials consists of coco-peat and rochomorpha conoides. In this column study, the mixed substrate was able to retain copper and chromium to unpredictable limits until 75 and 40 min of column operation, respectively. Generally, the removal efficiency of the mixed substrate is strongly influenced by the initial metal concentration; however, it was encouraging to find out that substrate mix has good sorption efficiency towards various metal ions.

Table 2.3 Down-flow packed column experimental parameters during treatment of metal-spiked DI water using substrate mix (Vijayaraghavan & Joshi, 2015).

	Al	Fe	Cu	Cr	Ni	Zn	Pb	Cd
(C/C_O) at 24h	0.125	0.256	0.139	0.157	0.987	0.108	0.059	0.076
Uptake (mg/g)	0.612	0.588	0.126	0.123	0.072	0.124	0.062	0.063
Removal efficiency (%)	95.1	91.7	95.5	94.6	54.7	96.6	98.3	97.8

Many researchers have studied the leaching tendency and sorption ability of green roof growing media. Even so, the presence of inorganic components in green roof growing media has reduced the sorption ability. For instance, commonly used substrate constituent such as expanded perlite showed no more than 8.6 and 13.4 mg/g sorption abilities on Cu(II) and Pb(II) ions, respectively. Furthermore, pumice which is an alternative broadly utilized substrate element, adsorbed only 3.5 and 1.6 mg/g of Cu(II) and Cr(III), respectively (Cascone, 2019).

2.7.2 Biochar

Biochar can be emended into green roofs substrate in order to increase the absorption of phosphorus or boost the availability for plant uptake. Biochar is produced through the thermal and pressurized decomposition of organic matter, such as agriculture residues of forestry trimming. Furthermore, because of variations in feedstock, pyrolysis cycle duration, maximum temperature, and final particle size, biochar has various physical and chemical properties. Biochar is characterized by a large pore volume and high surface area due to the expansion and volatilization of organic species during pyrolysis. Hence, this criteria media amended with biochar to have high water and nutrient holding capacity. Biochar has the capability to decrease the total phosphorus to the colloid surface and increase plant-available P pools through increases in total soil cation exchange capacity (Jennett & Zheng, 2018)

Natural biochar and modified biochar have been applied to the stormwater treatment system. Recent research has shown that aluminum-impregnated biochar can effectively remove arsenic (As^{3+}) and various other runoff pollutants such as lead (Pb^{2+}), zinc (Zn^{2+}), copper (Cu^{2+}), and phosphate ($PO^{3-}{}_4$). Meanwhile, the maximum adsorption capacity of As^{3+} by biochar that was produced from paper mill sludge was 34.1 mg/g.

Other than arsenic, biochar that produced separately from sugarcane straw, rice husk, sawdust, and chicken manure were mixed with sawdust were able to remove cadmium Cd^{2+} in water (Xiang et al., 2020). Furthermore, biochar also can remove lead (Pb^{2+}) in water and the removal efficiencies of biochar that produced from fresh and dehydrated banana peels are 359 mg/g and 193 mg/g, respectively (Zhou et al., 2017).

2.8 Efficiency of Limestone in Water Treatment

The main component of limestone is calcite; however, its physical and chemical properties strongly influence its impurities as it often consists of variable impurities such as clay minerals, silt, and sand. The impurity of limestone is very important for usability in industrial applications. Natural limestone is well known for its application for softening and clarification of municipal water, removing harmful bacteria as a neutralizing agent in acid mine, and industrial discharge. Furthermore, limestone is widely used for statues and buildings; hence acid rain can be a significant threat to this structure as limestone is very reactive to the acid solution. Despite that, the reactive property of limestone with acid water leads to the development of various technologies such as passive treatment technology, active treatment technology, and batch sorption to neutralize acidic (Sdiri & Bouaziz, 2014).

Based on research done in Korea, limestone can be used to reduce acidity and to increase the pH and alkalinity in acid mine drainage. Furthermore, limestone is efficient for accelerating the oxidation rate of ferrous iron and promoting the precipitation of metals present in the water. The limestone treatment also can stabilize the pH around 4.5 – 5 within ten years; however, the pH did not increase further, and the neutralization capacity of the limestone added could have decrease leading to lower performance. Other than pH, the limestone treatment also reduces the concertation of metals such as iron