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The Application of Rainwater as Architectural Design Elements For Green Technology Solution In Low Rise Office Building

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ABSTRACT

Performance of workers in terms of productivity level is determined by many related factors including a comfortable work space. Nevertheless, the discussion on the condition of work space environment namely in low rise office buildings and its related issues on thermal comfort in Malaysia are fairly new and is not well addressed. Past studies indicate that low rise offices found in many well-developed countries tend to utilize air conditioning as easiest ways to create a comfortable work space and to cool down the building interior. This factor had indirectly contributed to the increment of energy consumption namely in urban areas due to the rise of air condition consumption from 40% to 60% annually. As a result, contributed to the formation of urban heat island (UHI) which affect community's environment and quality of life involving health and comfort. The objective of this paper therefore is to discuss and propose approaches on how to apply rainwater elements in architectural design for achieving thermal benefits through passive cooling. This is vital as Malaysia receives large amount of rainfall throughout the year in which this nature resources may provide advantages as sustainable source in cooling down the building temperature. For this purpose, case study as research strategy is adopted using mixed methodology combining qualitative and quantitative method. To conduct the data analysis, ECOTECT simulation and small field experiments are performed to investigate the cooling effect in low rise office building. Findings indicate that low rise office building which integrates rainwater elements in architectural design potentially improve the building thermal performance thus reducing building's energy demand for space conditioning. This study is important as by adopting appropriate methods in addressing ecology issues will not only provide a comfortable living environment to the users but also established referential guideline in low rise office design.

1. Introduction

The cumulative negative effects from urbanisation such as pollution and production of waste heat from human activity, namely the usage of air conditioners and internal combustion engines had led to an environmental phenomenon called the urban heat island (UHI) (Stone Jr & Rodgers, 2001). The UHI factor occurs due to the rise in temperature in man-made area favourable in cities since their surfaces are prone to release large quantities of heat. Hence, directly impacted not only to residents of urban-related environments, but also humans and their associated ecosystems located far away from cities. Past scholars agreed that this matter occurred due to arising issues in the building industry which portrays buildings design that lack in energy and resources savings as well as built form that inharmonic with the local climate and surrounding environment(Stone Jr & Rodgers, 2001). As a result, led to significant non-operational savings and decrease of human productivity as well as lack of comfort among users notably in homes and workplaces. Nevertheless, the most effected building types are workplaces like office buildings since they are mainly located in central urban districts(Stone Jr & Rodgers, 2001). According to scholars, there are various approaches that can be adopted by construction sectors to conserve the environment notably in workplaces involving usage of efficient energy, proper management of indoor quality environment, usage of recycle materials and renewable resources that minimize emission of toxic substance and waste as well as practical adaptation of innovative design with minimal building operational and managing costs(Kibert, 2016). However, there is lack of discourse in discussing the issue of minimal design cost to produce a sustainable office building design using green technology solution like rainwater in the Malaysian context. To date, literature much highlights on aspects like thermal comfort (Kwong, Adam, & Sahari, 2014) and daylighting (Zain-Ahmed, Sopian, Othman, Sayigh, & Surendran, 2002), the implementation of mechanical ventilation system (Syazwan Aizat, Juliana, Norhafizalina, Azman, & Kamaruzaman, 2009) and natural ventilation for cooling factors (Daghigh, 2015), energy management and maintenance(Elyna Myeda, Nizam Kamaruzzaman, & Pitt, 2011), building life cycle assessment covering material production(Darus et al., 2009), construction, occupation, maintenance, demolition, and disposal of office building (Cabeza, Rincón, Vilariño, Pérez, & Castell, 2014) as well as built form design shape and orientation for energy efficiency (Bay & Ong, 2007). The scope of this paper therefore, is to highlight the utilization of rainwater as passive cooling agent to naturally cool the office building rather than using large scale of energy consumption in the areas of air conditioning to mechanically lower the indoor room temperature. This is because past studies indicated that in average most of office building in urban context tend to consume high usage of electricity than the recommended usage about 135 kWh/m2/year for commercial sectors, out of which 57% was used on air conditioning system and 17% by lighting 19%, followed by other equipment which is 24% (Saidur (2009). According to past study, '*the Energy Commission, Malaysia also reveals that the commercial sector is the second largest consumer of the total energy use in Malaysia (32%) after the industrial sector (48%)*' (Taib et al., 2010; 153).Therefore, the use of rainwater is viewed as the best measure to produce an environmentally friendly office building notably in the Malaysian context due to the abundant rainfall that is received in Malaysia which is about 2500mm annually in Peninsular Malaysia, while 5080mm a year in Sabah and Sarawak (Lim & Samah, 2004). This large number of rainwaters provides many advantages in which its implementation can be used for indoor plumbing, cooling or heating purposes, landscape watering and others. At present, consideration only much given to the usage of collecting rainwater for reducing water supply into building for toilet usage, watering and irrigating plants rather than for areal climate control and cooling purposes. Hence there is a need to improvise and innovatively utilize the usage of rainwater for saving energy consumption to cool the buildings. There are two main objectives of this study. First, is to identify the suitable rainwater architectural design strategies to achieve thermal benefits through passive cooling. Second, is to highlight the importance of rainwater as passive cooling strategy for short- and long-term usage towards energy saving consumption in low rise office buildings. For the benefit of the study and to fulfil the above objectives the next section will firstly define the meaning of rainwater in building design by elucidating on the characteristic and type of rainwater as natural cooling agent in building followed by the discussion on architectural elements using the application of rainwater system and its purposes to strengthen the need of the study.

2. Literature Review

2.1 Definition and the importance of rainwater in building design

Rainwater is a natural resource that can be easily collected from surrounding context like rivers, deep pit, drains, reservoir as well as from roof structures in building. The usage of rainwater had been acknowledged as part of architectural design since the early Greek architecture period when scholars discover that there were descriptions of outlet systems of rain water in the chart concerning kavediums which highlighted the five types (kinds) knowns as the Tuskian, the Corinthian, the four columned, the flowing and the roofed which exemplifies different methods of rain water channelling and diversion (Zayats and Murgul (2015). Since then, the practice of rainwater harvesting or method to collect rainwater runoff during raining time is widely accepted till modern context as cost saving methods of self-supply of water in buildings for daily usage (Zayats and Murgul (2015). Nevertheless, in realising its natural importance and physical quality characteristics in terms of volumetric heat capacity as quick heat absorber, water usage also need to be considered in building design for passive cooling purposes and areal climate control(Breesch, Bossaer, & Janssens, 2005). According to scholar, there are three methods of passive cooling approach which are – evaporative cooling, direct evaporative cooling and radiant cooling that can be adopted in building design(Santamouris & Kolokotsa, 2013). These three approaches of passive cooling are important to explain as it uses water as basic medium for heat dissipation for cooling strategies and are referred to as main indicator in analysing the case study.

2.2 Methods and types of passive cooling approaches in building design by using rainwater

The term passive cooling is defined as building design approach that focuses on heat gain control and heat dissipation in a building in order to achieve balanced indoor environment with low or no energy consumption (Kamal 2012). In other words, passive cooling is preventing excessive heat from entering the interior (heat gain prevention) or by removing heat from the building using (natural cooling) methods that utilizes on-site energy, available from the natural environment, combined with the architectural design of building components, rather than mechanical systems to dissipate heat (Kamal 2012). In brief, the purpose of passive cooling serves four main aspects to produce building with much indoor comfort, adopt low maintenance, emphasis on zero energy consumption; implement low running cost towards promoting a healthy environment. To achieve indoor passive cooling and to promote heat sink , scholars outlined four promotion of heat transfer involving the circulation of outdoor air (heat transfer mainly by convection through openings); using the (night) sky concept (heat transfer by long wave radiation through the roof and/or other surface adjacent to a building; ground (heat transfer by conduction through the building envelope) and water (heat transfer by evaporation inside and / or outside the building envelope) (Kamal 2012).In elaborating the above, there are several passive cooling techniques involved like solar shading, insulation, induced ventilation techniques, radiative cooling, evaporative cooling , earth coupling and desiccant cooling that can decrease cooling load in building up to 50% to 70% (Kamal 2012). From all the above, evaporative and radiative cooling techniques will be highlighted in this study as rainwater is involved in both methods to help in releasing heat out of the building.

2.3 Evaporative cooling techniques

Evaporative cooling is a methods of exchanging heat in the air by vaporisation of water droplets on wetted surfaces (Heidarinejad, Bozorgmehr, Delfani, & Esmaeelian, 2009). Simple ways to induce evaporative cooling in a building such as designing a fountain or water feature into a building space or orientate the building near pond or lake. This may also include the use of mist jets in a dry space to elevate the temperature. In brief, evaporative cooling technique is induced in two ways; directly (by evaporation) or indirectly (by contacting the indoor air with surface that previously cooled by direct evaporative) (Heidarinejad et al., 2009). Thus, in order to achieve evaporative cooling and cools the surrounding, the sensible heat must come along with the presence of wind and water to cool the air. This water may be tapped from rainwater resources as rainwater is the most easily available self supply of source and cost saving (Heidarinejad et al., 2009). In other words, evaporative cooling happens when liquid (water) evaporate into air. Then the air cools any substance that touch or in contact with it as diagrammatically shown in Figure 1.

2.4 Direct evaporative cooling

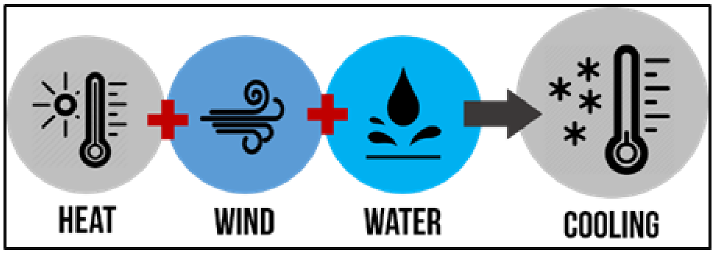

Figure 1 *Evaporative cooling definition in conceptual diagrams*

Direct evaporative cooling is way to cool air mechanically or non-mechanically. The hot air is blown through wet medium (water-saturated) and the hot air is cool by evaporation process(Wu, Huang, & Zhang, 2009). Direct evaporative cooling elevate moisture in the air when the sensible air temperature (dry bulb temperature) is reduced, while the lowest air temperature (wet bulb temperature) is maintain (Wu et al., 2009). The air that have been humidified and cooled is then moved into the building.

2.5 Indirect evaporative cooling

This type of cooling happens when the secondary air which is cooled by water is introduce into heat exchanger. The cooled secondary air acts to cools the primary air(Costelloe & Finn, 2007). The cooled primary air is then cool the building space. Indirect evaporative cooling does not elevate the humidity of surrounding air(Costelloe & Finn, 2007). Thus it is the most suitable for hot-humid climate of Malaysia.

In applying the evaporative cooling method, passive downdraft evaporative cooling (PDEC) and roof surface evaporative cooling (RSEC) system can be applied in building design. Applications incorporating PDEC technology can be categorized into three different types according to evaporative devices: wind tower, a PDEC tower with pad, and a PDEC tower with spray (Janakkumar 2017). Referring to Janakkumar (2017; 284-285),*'the cooling performance of these applications is dependent on various factors such as climatic conditions, tower configuration such as the height and cross-sectional area, volume of the water and air, and types of evaporative devices. Physical tower configurations of these systems are similar to each other. However, the cooling capacities of these systems are different, and PDEC towers with evaporative devices are known to be better than conventional wind tower. PDEC towers are thus classified into these three different types in that the cooling capacity and system response to cooling demand substantially change due to the presence of evaporative devices and their types such as wetted pads and sprays'*. According to Kamal (2012; 93), *'passive downdraft evaporative cooling systems consist of a downdraft tower with wetted cellulose pads at the top of the tower. Water is distributed on the top of the pads, collected at the bottom into a sump and recirculated by a pump. Certain designs exclude the recirculation pump and use the pressure in the supply water line to periodically surge water over the pads, eliminating the requirement for any electrical energy input. In some designs, water is sprayed using micro-nisers or nozzles in place of pads, in others, water is made to drip. Thus, the towers are equipped with evaporative cooling devices at the top to provide cool air by gravity flow. These towers are often described as reverse chimneys. While the column of warm air rises in a chimney, in this case the column of cool air falls. The air flow rate depends on the efficiency of the evaporative cooling device, tower height and cross section, as well as the resistance to air flow in the cooling device, tower and structure (if any) into which it discharges.'*

The roof surface evaporative cooling (RSEC) system, on the other hand in accordance to Kamal (2012; 93-94) much involved *'-roof surfaces that can be effectively and inexpensively cooled by spraying water over suitable water-retentive materials spread over the roof surface'*. Kamal (2012; 93-94) also added that,'*-as the water evaporates, it draws most of the required latent heat from the surface, which acts as a radiative cooling panel for the space, thus lowering its temperature and reducing heat gain. The indoor temperature gets lowered without elevating the humidity level. The solar radiation falling on the water film is utilized in water evaporation and thus being prevented from entering the room below. Besides, evaporation also cools the air above the roof. The cool air slides down and enters the living space through infiltration and ventilation, providing additional cooling'*.

Even though both PDEC and RSEC system are costly to assemble at the initial stage, the application of both systems in the long run are proven to be economically practical and sustainable as both uses available natural resources which can be in form of rainwater and air to operate the system for building interior cooling purposes.

2.6 Radiant cooling techniques

Radiant cooling is the process of radiation and convection to remove sensible heat in buildings by using cooled surface. To achieve this, systems known as hydronic is applied which used water to cool the radiant surface. In other words, this hydronic system involves cooled water between the temperature of 2-4°C below the desired indoor air temperature that are circulate in pipes through specially-mounted panels or a building's floor or ceiling to provide thermal comfort in building interior spaces (Gwerder, Lehmann, Tödtli, Dorer, & Renggli, 2008). According to building technologists, there are there are two primary types of radiant cooling systems. The first type is systems that deliver cooling through the building structure, usually slabs. These systems are also named thermally activated building systems (TABS)(Gwerder et al., 2008) The second type is systems that deliver cooling through specialized panels(Gwerder et al., 2008).

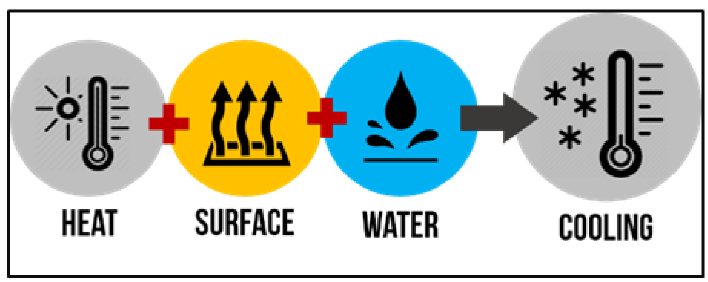

Figure 2 *Radiant cooling definition in conceptual diagrams*

Systems using concrete slabs are generally cheaper than panel systems and offer the advantage of thermal mass, while panel systems offer faster temperature control and flexibility(Gwerder et al., 2008).

Figure 2 clearly indicates that water element namely rainwater can be used to cool the building to provide comfortable temperatures for building users. Based on this understanding, next section will elaborate on several design strategies that related to the evaporative and radiant cooling techniques that can be applied in office design in the Malaysian context. This is important as the discussed the design strategies using rainwater for passive cooling then will be tested and analysed on its effectiveness using mock-up model building design to see its appropriateness in the local climate.

2.7 Design strategies using rain water application in relation to passive cooling techniques

In designing a sustainable building to accomplish passive and low-energy usage, there are many strategies using rainwater that can be adopted (Sun et al., 2013). However, the easiest applicable strategy that can be applied involving low cost in terms of installation and maintenance is to create pleasant environment using natural resources like rainwater (Macias, Gaona, Luxan, & Gomez, 2009) . Many scholars agreed that , it is wise to implement various systems for passive cooling strategies in a building which highlight the usage of rainwater as its main source like the usage of roof pond with water collected from rainwater (Spanaki, Tsoutsos, & Kolokotsa, 2011), provide ample space for roof garden that is watered by rainwater harvesting (Saadatian et al., 2013), have water hardscape and softscape obtained from rainwater by integrating it with building structural elements (Daglio, 2014) as well as have cooling wall run by rainwater flow at strategic exterior locations (Castell, Martorell, Medrano, Pérez, & Cabeza, 2010). All of the above will be explained in turn. Following this, the relevance of each systems and their relationship with the building spaces and form making by using example of mock up case study will be discussed in the subsequent section.

2.8 Roof pond

According to scholar, roof structure is the most vital element of building envelope to establish passive measures in architectural design as it is directly exposed to solar radiation and heat load. Since, roof contribute to almost up to 30% to 50% of heat load in building hence, it is wise to shade, insulate , vegetate and have flowing water at the roof to regulate heat gain. Nonetheless, using water is an ideal choice due to its thermal mass which is cheap, non toxic, with large volumetric heat capacity. Historically, the origin of roof pond system was introduced by Harold Hay in the late 1960's but in recent context many variety and comprehensive design of roof pond system was established by designers. In discussing on the subject of roof pond for passive cooling, scholars had outlined that there are 8 typologies of roof pond system involving –open roof pond, roof pond with movable insulation, roof pond with floating insulation, walkable roof pond, roof pond with gunny bags, shaded roof pond, ventilated roof ponds, and closed roof pond (Sharifi & Yamagata, 2015). However, the benefits of using roof ponds lies in its cooling processes which utilizes indirect evaporative cooling and radiant cooling. From the cooling effect of evaporation on the surface and radiation to the air, the roof pond will act as heat exchanging material to the building spaces and structure below it such as roof ceiling. Through this roof ceiling structure, radiation and convection will take place to cool the indoor space when the ceiling is thermally in contact with the roof pond above. From this understanding, the implementation of roof pond is seen much suitable in hot and humid country since it will not increase the humidity in the air. Nonetheless, in the tropical context like Malaysia, closed roof pond type is seen much effective to be adopted. This is because the effective characteristic of roof ponds for hot and humid country should be closed at day time and opened during night time. The free water surface in the pond is exposed starting at 7 P.M. by opening the roof to the sky and closing it during the day starting from 7 A.M. The water in the pond is cooled by radiation during the night and by evaporation all day long. Heat gain in the water is reduced by prevent it from solar radiation and natural ventilation during the day (Krüger, Cruz, & Givoni, 2010).

From the roof pond experiment done by (Krüger et al., 2010) in hot-humid climate of Maracaibo, the indoor temperature of the tested room is 2°C cooler compared to the other tested room without roof pond above it. The use of rainwater for the roof pond is really important as the conventional roof that use evaporative cooling system require large amount of water daily to cool down the roof temperature(Krüger et al., 2010). Other than this method, study done by (Cheikh & Bouchair, 2004) highlighted that closed roof pond covered by an insulation layer known as the "evapo-reflective roof pond" is also suitable. According to (Sharifi & Yamagata 2015; 9),' *this roof pond is supported by a concrete deck over which a water pool, filled with small pieces of rock, is placed. An unventilated air layer separates water pool from the upper roof which is a flat aluminum plate "painted with titanium-based pigment" to enhance its reflective properties. The system reflects incoming solar radiation during daytime hours. At night, temperature of the water pool is higher than that of the aluminum plate. As this is a closed roof pond, the water vapour does not leave the system. The vaporized water condenses and falls back into the water pool. This way, heat is transferred outside the system. Radiation between the two humid internal surfaces of the system enhances heat exchange'*. To supply water to this roof pond, rainwater harvesting system can be used and reuse it for the roof pond as passive cooling purpose.

2.9 Roof garden

Roof garden has many benefits. Besides functioning as decorative elements, roof garden whether in small or larger scale are utilized for temperature control, hydrological values, recreational and ecological opportunities. The implementation of roof garden in a building also gives effect to thermal performance of indoor space. Saadatian (2013) defines roof garden as living roofs, eco-roofs, vegetated roofs, or planted roofs. Plants is used on roof to enhance its performance and also its appearance. Santamouris (2014) explains that plants on roof garden will act as insulation as the plants provide shades to the roof. The substrate layer of the plants that lies on a roof structure will slow down the heat transfer from exterior while taking in heat from interior spaces underneath. This process shows that the plants on top of roof garden will act as a thermal mass. In this case, the building is cooled down by the process of evapotraspiration that takes place (Santamouris 2014). One of the case study on roof garden conducted by Rumana (2009) proves that the green roof can lower the indoor temperature more than uncovered roof. From their experiment done at one of hostel in Universiti Teknologi Malaysia (UTM), 4°C to 5°C reduction in the indoor temperature during day when the green roof is implemented on it. Both indoor and outdoor environment of the building get the thermal benefit from the implementation of green roof on rooftop.Thermal performance of roofing system can be improve through the use of green roof. Roof garden will provide insulation and shading. Besides, the rainwater that collected through rainwater harvesting system can be used to irrigate the plants on the roof garden. This can reduce the water supply for the building hence cools the building as well.

2.10 Water hardscape and softscape features

Fountains, waterfalls, ponds, waterspouts, waterfalls, water gardens are classified as water hardscape and softscape features consist of static or moving water. Since ancient history, the implementation of water features in buildings and monuments had been adapted to provide comfort for humans and to cool its surroundings such as the Hanging Gardens of Babylon and the Chand Baori Stepwell (O'Connor 2000). In recent years, scholars found that the presence of water on top of ground surface material will reduce the surface temperature significantly regardless of its color (Bakar & Malek, 2015). In addition the microclimate of surrounding area will also gains benefits from the use of water features as it will increase the amount of water needed to enhance the evaporation process. This can lower the surrounding temperature easily(Bakar & Malek, 2015). The fall of temperature from hot to cool can also be affected by the building distance from any water feature or water body. This is because, water bodies are noted to be the best absorbers of radiation, which exhibit very little thermal response(Wong, Tan, Nindyani, Jusuf, & Tan, 2012). This is because water comprised of four important properties which susceptible as radiation absorbers and sensible as heat transfer element. According to scholar, water demonstrate little thermal response since it is a good penetration substance that allows short wave radiation transmission to considerable depths; permits easy mixing like the process of convection that allow heat gains or losses to be spread throughout a large volume; helps in the process of evaporative cooling which is efficient as latent heat sink, as well as has a large and exceptional thermal capacity (Coutts, Tapper, Beringer, Loughnan, & Demuzere, 2013). Due to these properties, Jusuf (2009; 1) stated that, "*this make the surface temperature of water bodies cooler than that over the land*". Previous scholars also indicate that the presence of water bodies effect a city air temperature. A study conducted by Murukawa (1991) highlights that there is a big difference of air temperature between the river and the city area in Japan which is about 3 - 5°C. This proves that cooling source of the surrounding microclimate is greatly influenced by water elements like the existence of flowing river. Hence, the choices of building site near the water bodies gives many advantages to the building microclimate and also act as temperature control.

2.11 Water wall and cooling wall

Water wall is also defined as curtain or sheet of falling water and act architectural feature for building and landscape design. In other words, a water wall is the flowing of water over an architectural surface, such as hard or opaque surfaces which allows the material that is beneath the water to show through the flowing water. In most cases, the bottom of the water wall is a reservoir which is located to collect the water as it flows down from the water wall. The water in the reservoir is then pumped back to the top of the water wall to complete the circuit. This water wall is a low energy consumption fountain**, s**ince it needs minimal pressure and flow for proper operation as the water is easily obtained from rainwater harvesting technique. In many cases, the wall is illuminated from the back, or the front, to further enhance the aesthetics of the feature. Water wall may block the heat from entering the building interior space. As a result, this reduce the building indoor temperature to make it more comfortable for the building occupants. Water wall is an effective solution for maintaining indoor or outdoor temperature and reduce energy consumption. In addition to water wall, cooling wall is also important to control increased surface temperatures and create cooler urban environments. Cooling wall is typically made of pipes that allows inlet and outlet of water flow. Referring to study done by scholars, this cooling wall can be made of porous pipe-shaped ceramics known as PECW (Passive evaporative cooling wall). The PECW is capable of absorbing water and allows wind penetration, thus reducing its surface temperature by means of water evaporation (He, 2011). In other words, the cooling wall has the ability of capillary force to absorb the water up using the ceramic pipes. In brief when the air passes the PECW, the air is cooled naturally. Hence the air temperature nearby the cooling wall area is reduced to a minimum value by several degrees namely during hot daytime (He, 2011). The water used for this cooling wall is tapped from rainwater harvesting system.

From all of the above discussed system for passive cooling using rainwater –only the roof pond and roof garden will be discussed in depth and are chosen as the main focus to investigate its suitability in low rise office building. This is because the roof pond and bare soil concrete roof (greenery roof) are seen as the most appropriate for the Malaysian context since its operating cost are minimal, significantly can reduce the roof surface temperature and heat transmission into the building and also utilize rainwater to irrigate and run the system. Moreover, the suitability of the Malaysian humid and hot climate all year round with an average rainfall of 250cm a year and average temperature is 27 °C (80.6 °F) with two monsoon winds seasons, the Southwest Monsoon from April to September, and the Northeast Monsoon from October to March will allow passive cooling to occur when involving these both design strategy- (roof pond and garden), since they utilizes the evaporative and radiant cooling methods to function naturally. Although scholars highlighted that there are drawbacks like -water leakage, water hardness and scaling, mud accumulation at bottom in dusty areas and rusty metallic surfaces nonetheless, proper installation, anticipation and compensation by the building designers and users may overcome this matter.

Nevertheless, the adaptation of roof pond and roof garden utilizing rainwater for passive cooling purposes to increase thermal comfort in buildings are still likely seen to be less adopted in the context of Malaysia as many designers and builders tend to overlook on this matter due to lack of interest and knowledge(Taib, Abdullah, Fadzil, & Yeok, 2010). Although there are offices buildings in Malaysia that applied this green roof and roof pond concept but the numbers are still few and not widely implemented. Moreover, there are lack of efficiency in implementing the roof garden and roof pond in building design which makes it unusable, impractical and un functional to serve the user needs. Furthermore, the application did not compliment to the requirement of microclimatic conditions like thermal comfort but instead merely for aesthetical purposes (Taib et al., 2010). In addition, there is also limited research focusing on the potential of roof garden and ponds particularly in office design in Malaysia's tropical climate (Taib et al., 2010). This study will look this matter in depth by proposing a medium low rise office building to be located in Medini, Iskandar for Suruhanjaya Air Johor Berhad that applies the roof garden and roof pond as design solution for both aesthetics and thermal comfort purposes. Both of these passive cooling strategies that uses rainwater system will be tested for the purpose of developing new framework approach to highlight its importance. To understand this the next section will elaborate on the method used to analyse the significant roof garden and roof pond by using single proposed design as case study. This study used a single case study as the research strategy to provide much in depth empirical enquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and context are not clearly evident or considered likely to provide a good explanation (Yin, 2011).

3. Case study - proposed medium low rise office

To conduct the analysis, the researcher had proposed and designed low medium rise office building for Suruhanjaya Air Johor Berhad on a piece of 1.1 acre land in medina Iskandar beside the emerald lake (Figure 3). The site is surrounded by commercial comprised of Shops, offices and private school and residential homes.The proposed building is divided into three zones which are public zone, education and training zone, staff and researcher zone. Public zone includes water education gallery, multi-purpose gallery space, mini auditorium, café, recreation area and also rooftop garden. The education and training zone are occupied by classrooms and workshops for weekly and monthly water education training for registered members. This zone is considered as semi-public zone and can be assessed by registered members only. The other zone is the staff and researcher zone. This zone is classified as the private zone in this building. Spaces included in this zone is staff/trainer lounge and rooms, researchers' room, laboratory and also the management office. In doing the spaces' massing for this centre, the public zone is designed near and towards the lake to enhance the use of lake as recreational spot and also to

Figure 3 *Proposed Iskandar Water Education Centre*

enhance the effect of passive cooling by the water body into the main public spaces which are the gallery and the auditorium. The other two zone is located on the upper part, far from the public spaces to avoid noise.

4. Design strategies

In implementing the passive cooling technique using rainwater in this proposed building, the rainwater runoff from the roof are collected by series of ramp like water channel. The ramp is ended at the rainwater harvesting tank located at the building basement. The filtration process took place in the basement and the filtrated water is then pumped up to the rooftop to be distributed throughout the building for supplying the roof pond, irrigation purposes for the roof garden and cooling wall. Water wall and water features surrounding the building central area also used filtered water to operate. Integrated roof pond and roof garden is implemented in the design because these two elements greatly contribute for passive cooling effects. The roof garden and roof pond are placed above the two main public spaces which are the gallery and the auditorium so that the interior of the building will be less heated and well insulated to reduce cooling energy consumption for this building. Furthermore, both of this space are covered by huge area of roof which are exposed and received radiance heat loads from the sol-air temperature and direct solar insolation which increases the mean radiant temperature. According to Mintorogo (2015; 26) , '*this is because the roof receives the greatest heat radiant impacted than other parts of the building façade. The sun's ray will produce thermal heat on a surface that is absorbed or reflected by roof materials which increases the outer surface temperature of the roof by 30 to 40 degree Celcius*'. To lessen the radiant heat, the roof pond and garden therefore, are placed above both of these spaces. The closed roof pond type is adopted as it is the most appropriate selection for hot and humid climate to reduce cooling loads from rooftop. Water cooling wall is also applied at the exterior building side which is affected by radiant from the evening sun. The water-cooling wall obtained its flowing water pumped from the roof pond and water harvesting tank. Existence of water features in a building can contribute to the effective evaporative cooling for the surrounding microclimate of the building. Therefore, a large wading pool provided at the ground floor will give additional cooling effect for the exterior and interior building. In fact, the location of the building nearby the natural lake also have a positive effect for achieving passive cooling strategies. Nevertheless, for the benefit of this study, the importance of roof garden and roof pond for medium low-rise office building will be further explained in the methodology section using Ecotech simulation and small field experiment to justify the findings.

5. Methodology

To conduct the analysis on the roof garden and roof pond two method are used which to justify the findings. The first method is simulation analysis and the second is small scale field experiment. Both of these methods will be explained in turn below. The simulation analysis is conducted refereeing to testing technique established by past scholars (Saeid, 2011). Saeid (2011) work is referred as she adopted the usage of computer simulation known as Ecotect to measure the selected parameter which is the solar radiation of the roof as well as the heat transfer from the roof into the building. Her method is suitable for this study, as the aim of this paper is also to measure the radiation value on the proposed building roof area.

5.1 Method 1: Simulation analysis

The aim of the simulation analysis in this study is to identify the efficiency of integrated roof garden and roof pond for building based on the difference in intensity of solar radiation striking on external surfaces of different roof treatment. For that matter, ECOTECT Analysis 2011software is used in this study. Base model for this study is done in Sketch Up Pro 2104. The model is taken from the massing model of the proposed medium low-rise office building established by the researcher. The roof of the auditorium and gallery is used in this study since these two areas has the largest roof area which prone to radiant heat and both of these roof areas are placed the roof garden and the roof pond as passive cooling system strategy for the building. The simplified model of the two main part of the building is shown in Figure 4 and Figure 5.

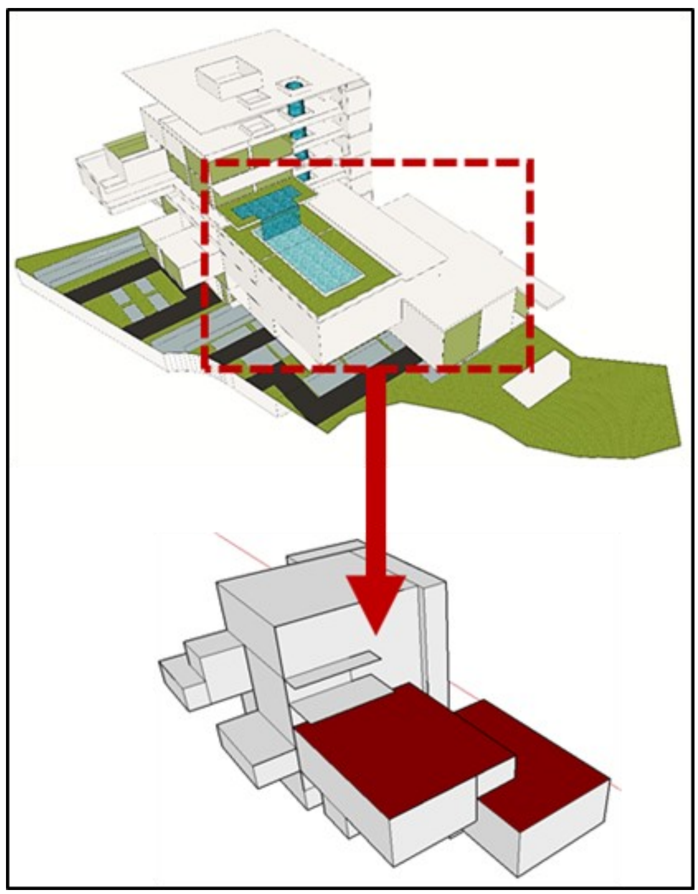

Figure 4 *Massing Model and Base Model of the proposed building*

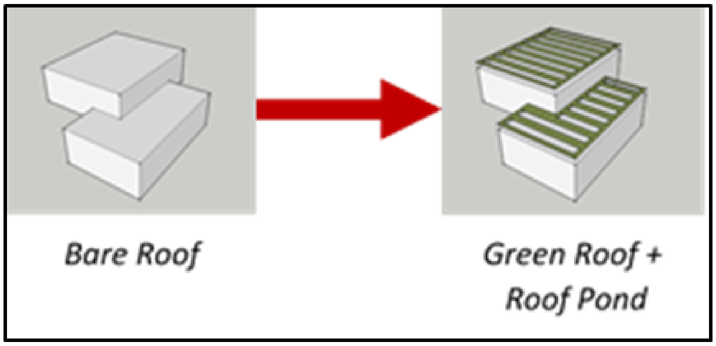

Figure 5 *The Base Model*

To resemble the roof garden and roof pond, the base model is added with shading device and some voids (to ensure solar radiation can pass through). These shading devices will act as green roof and roof pond on the study area. The shading device will take up around 40% to 50% of the roof area. The model is then imported to ECOTECT Analysis software and the radiation value of the proposed roof area is analysed.

5.2 Method 2: Small-scale field experiment

To support the simulation analysis, a small-scale field experiment is conducted to find the condition of thermal performance level and indoor space temperature in the gallery and auditorium when the roof garden and roof pond are placed above these spaces. This experiment is conducted based on past scholar methodology done by Gonzalez & Givoni (2004). Although there are various method introduced by scholars this particular method is referred to as their study much refer to the same tropical climatic context as case study like Malaysia and in defining the role and importance of roof garden and pond in building design. To obtain the findings, three identical testing boxes are needed to compare the indoor temperature changes between testing box with roof pond system and without roof pond system (bare roof), and with roof garden. The testing boxes were made of corrugated box board with the measurement of 210mm x 210mm x 300mm. the roof overhang is measured 50mm for all four edges to protect the wall. The inner parts of the boxes are lined with 6mm polystyrene sheets to protect the absorption of heat via the walls. The roof part is not covered with polystyrene sheets in which the roof pond system and roof garden are located.

Figure 6 *Preparation of Testing Box*

To resemble the roof pond system, two air tight plastic bags with (5 inch x 4 inch in size) are filled with water at room temperature. The plastic bags were then placed at the top of one box (Figure 7). To resemble the roof garden layer of grass on soil is placed at the top of the other box. The other box is without any insulation to resemble bare roof. The three boxes have two small openings measured 150mm x 50mm on top of the North and South side of the walls to mitigate the heat inside the boxes. Data loggers were installed in the boxes. Three set of (4-channel data logger) is used in this experiment to provide RTD based precision temperature recorder in which the retrieved data are then link to windows software to be tabulated in table format.

Data Logger 1
In BOX A : Roof Pond Box. (indoor and surface temperature)

Data Logger 2
In BOX B : Bare Roof Box. (Indoor & surface temperature)

Data Logger 3
In BOX C: Roof garden (with grass) (indoor and surface temperature)

Since temperature condition in Malaysian context do not differ much from month to month, and the daily range of temperature is small, hence the test was done on the hottest day in the month of February, March, April and May at an open field. This is because all these months had shown the highest and warmest temperature recorded for the past three years (2014 to 2017) which is between the maximum of 32 to 33 degree Celsius. The measurement however was taken during the hottest month which is in April (refer to the meteorology Malaysian report) and in three days in a row which no rainfall occurs from sunrise - 6 am until sunset -7 pm. This is important to get the exact reading of the radiant heat absorbed by the roof with pond, roof garden and bare roof. Comparative analysis then is made to indicate which condition are much better whether the roof pond with rain water supply, irrigated roof garden with rain water, or bare roof concrete without any

Figure 7 *Plastic bag filled with water that act as roof pond*

Figure 8 *Preparation of Testing Box at site. Box A (right) and Box B (left)*

insulation. The interior temperature with different roof condition is also recorded, compared and analysed without the disruption by any mechanical ventilation effect.

6. Results

This section focuses on measurement results of the simulation analysis and field experiment done to identify the thermal performance and efficiency of integrated bare roof, roof garden and roof pond.

***Table 1** The results of the experiment*

MONTH	TIME	TEMPERATURE (°C)			
		DATA LOGGER 1 (ROOF POND)	DATA LOGGER 2 (BARE ROOF)	DATA LOGGER 3 (GREEN ROOF)	DATA LOGGER 4 (OUT-SIDE – OPEN FIELD)
April	600	28.120	28.212	28.113	28.713
Day 1	700	28.882	28.923	28.887	28.921
	800	28.716	28.811	28.718	28.812
	900	29.221	29.271	29.229	29.349
	1000	30.149	32.339	30.221	32.376
	1100	29.300	30.697	29.221	30.700
	1200	29.276	29.757	29.271	29.760
	1300	29.471	29.572	29.346	29.543
	1400	29.371	29.466	29.346	29.450
	1500	29.296	29.391	29.346	29.400
	1600	29.296	29.371	29.351	29.383
	1700	29.271	29.371	29.331	29.376
	1800	29.296	29.396	29.315	29.372
Day 2	600	28.148	28.312	28.131	28.413
	700	28.615	28.878	28.712	28.923
	800	28.716	28.822	28.718	28.827
	900	29.321	29.421	29.329	29.439
	1000	30.151	32.527	30.112	32.625
	1100	30.123	30.624	30.221	30.645
	1200	30.276	30.557	30.271	30.660
	1300	30.471	31.447	30.346	32.543
	1400	30.321	30.442	30.256	30.450
	1500	30.216	30.331	30.246	30.412
	1600	29.411	29.821	29.421	29.883
	1700	29.353	29.643	29.441	29.689
	1800	29.334	29.587	29.423	29.669
Day 3	600	29.110	29.121	29.100	29.325
	700	29.210	29.454	29.211	29.543
	800	29.243	29.522	29.232	29.544
	900	30.612	30.772	30.712	30.877
	1000	31.100	31.121	31.009	31.322
	1100	31.522	31.779	31.432	31.855
	1200	31.722	31.701	31.271	31.760
	1300	32.471	32.572	32.346	32.543
	1400	30.371	30.466	30.346	30.450
	1500	31.296	31.391	31.346	31.489
	1600	30.296	30.351	30.371	30.383
	1700	29.612	29.712	29.523	29.779
	1800	29.296	29.315	29.396	29.372

6.*1* *Result 1: Simulation analysis*

By using ECOTECT Analysis software, average daily radiation analysis has been run to calculate the amount of solar radiation that strikes on the external surface of the study roof area. The simulation results are as follows.

Based on the simulation results shown above, it clearly seen that the average radiation drop when the roof area is covered with shading device that act as roof garden and roof pond. The yellowish colour at the bare roof surface in the figure shows that the intensity of solar radiation is higher. While at the shaded roof surface, orange and purple to bluish colour appeared. This explain that the intensity of solar radiation strikes on the surface is lower compare to the bare roof surface. On the external surface of the roof, the simulation result shows that by installing integrated roof garden and roof pond, the radiation absorb by the roof surface is decrease hence will have a potential in lowering the internal temperature of the study area.

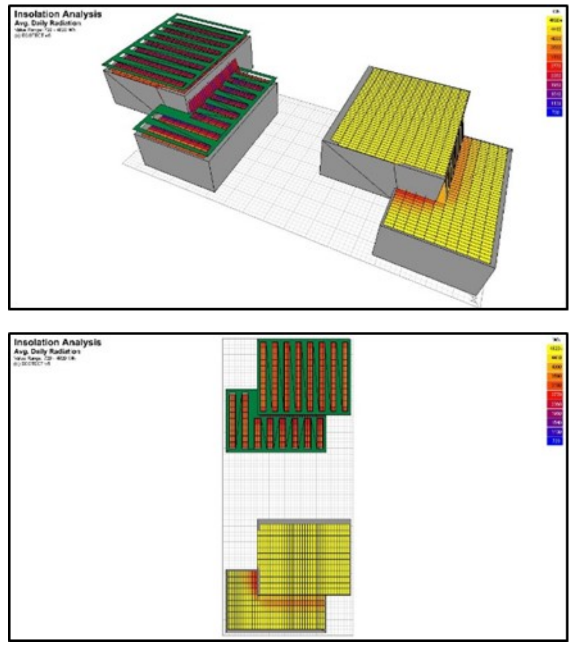

***Figure 8** Figure showing the results of the experiment*

6.*2* *Result 2: Small-scaled field experiment*

By using HOBOware Software, the data from the HOBO data logger is then collected and analyse. Figure 9, 10 and 11 show the results of the experiment.

Based on the graph shown in Figure 9, 10 and 11, during the hot peak hours around 1200 P.M. until 1600 P.M. (critical time for afternoon and evening sun), the difference in indoor temperature between the three boxes can be clearly seen. The temperature inside Box A (roof pond) with Data Logger 1 and Box C (grass roof) with Data Logger 3 are slightly cooler than Box B (bare roof) with Data Logger 2. The presence of roof pond and grass roof on top of the roof affect the indoor temperature. The indoor temperature) drop from maximum 2.0°C to minimum 0.5°C. The significant result is shown at day 2 where Box A with roof pond on top and Box C have indoor temperature at 30°C, while the outdoor temperature is 32°C.

7. Discussions

This section attempts to discuss the study by summarizing major findings of the study. From the two methods; simulation analysis and field experiment, the results shown from both methods can be combined. From the results, it shows that :

- integrated roof garden and roof pond will absorb lower solar radiation and decrease the indoor temperature below it.
- bare roof will absorb higher solar radiation and this affect the indoor temperature of the space below.

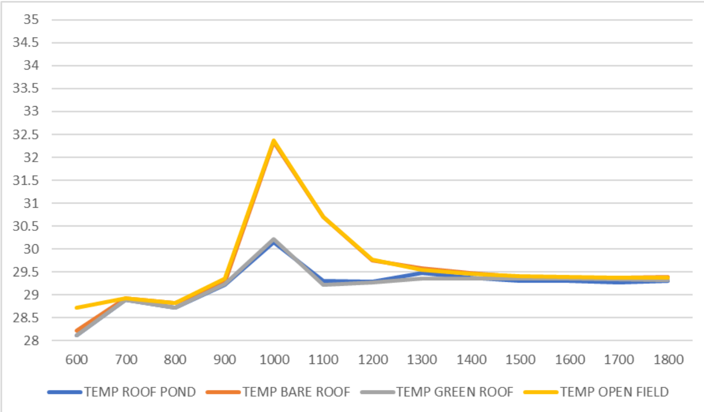

Figure 9 *Graph showing the results of the experiment*

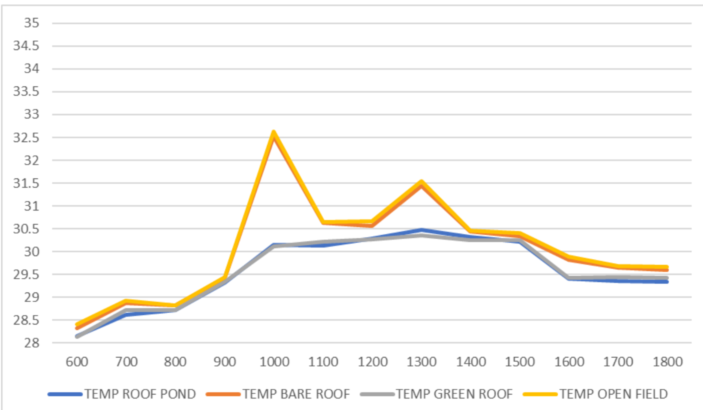

Figure 10 *Graph showing the results of the experiment*

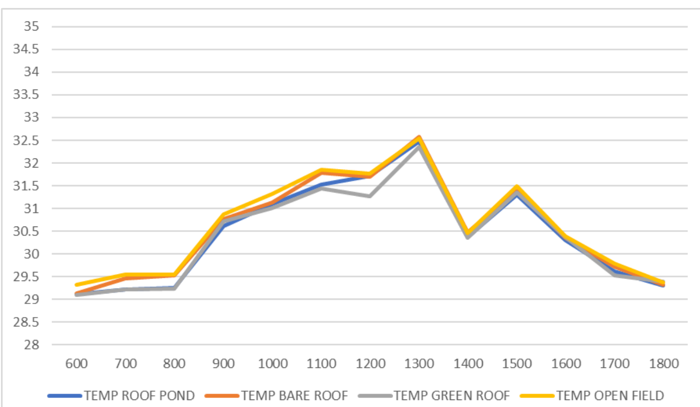

Figure 11 *Graph showing the results of the experiment*

- from the small experiment done, the temperature drop is about 1° C when using roof pond and green roof.

Time and weather's condition are the major limitation for this research. Most of the data collected cannot be used because of bad weather condition due to raining season in the evening. Therefore, it is recommended that future research could look further into this area in order to strengthen and compliment this research.

8. Conclusions

Integrated roof garden and roof pond have potential to improve the thermal performance of a roofing system through shading, insulation, evapotranspiration and thermal mass. Thus reducing a building's energy demand for space conditioning. Thus, harvesting rainwater do helps and improve building performance by using the collected rainwater as part of passive cooling agent to improve the thermal performance while saving water. Others strategies also play important role in boosting up the cooling effect that can gain through passive cooling techniques from rainwater architectural design elements. Rainwater therefore should be utilizes as it is the best measure to produce an environmentally friendly office building notably in the Malaysian context.

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