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The potential of evaporative cooling window system using labu sayong in tropical Malaysia: A review

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ABSTRACT

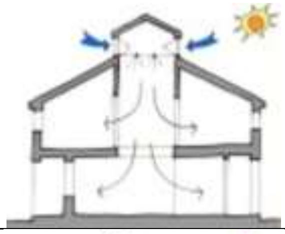
In reducing indoor temperature, evaporative cooling window system using *labu sayong* can be one of the alternative strategies. This system will help to tackle the issue of increasing costs in keeping the home cool by managing the energy consumption and also offers a better indoor environment. In preventing the issue of increasing energy cost, this system not only cools the indoor environment as cool as using air conditioning, but, it also relief from the indoor heat build- up. This review aims to investigate the potential of the evaporative cooling window system using *labu sayong* as an alternative reduction of indoor temperature environment in tropical Malaysia. As commonly known Tropical Malaysia is categorized as a warm and humid climate. Therefore, non-passive direct evaporative cooling system suitable for Malaysia. This system is integrated with mechanical ventilation energy operated by solar electricity as an environmental friendly concoction. The uniqueness of this system is using the *labu sayong* as a medium of porous material to provide a surface to saturate water. Through this combination, it will reduce the temperature in providing a better indoor environment.

INTRODUCTION

Natural cooling is part of passive cooling methods for energy efficient buildings by considering heat dissipation technique. Based on the interpretation from architectural view, natural cooling can be classified as utilize of natural heat sinks for surplus heat dissipation from internal area, including

Ventilation, ground cooling, evaporative cooling and radiative cooling [1]. Refers to [2], cooling is to move energy from one area or from the air to another area to get a temperature decrease compared to the normal environment [2]. The natural cooling strategies can divided into three methods and it briefly clarified in Table 1. Within these three methods, it is potential to reduce the temperature and improve the indoor environment quality.

Table 1: Three methods in natural cooling strategies

Natural Cooling Strategies	Sectional Diagram	Quotes
Evaporative Cooling		*"Evaporative cooling is the exchange of sensible heat in air for the latent heat of vaporisation of water droplets on wetted surfaces. It can be used to cool building air directly by evaporation or indirectly by contact with a surface previously cooled by direct evaporation."* [3]
Ground Cooling		*"The concept of ground cooling is based on heat dissipation from a building to the ground, which during the cooling season has a temperature lower than the outdoor air."* [2]
Radiative Cooling		*"In the case of building radiative cooling, the building envelope (or another appropriate device such as a metallic flat-plate radiative air cooler) is cooled by dissipating infrared radiation to the sky, which acts as a low-temperature environmental heat sink."* [1]

In order to reduce temperature, the most important part is keeping the home cool by managing the indoor heat build-up. Heat build-up gains by absorbing day lighting. Three main starting place of heat build-up are through the roof, walls and windows. Refer to Figure 1, the heat increased from four causes, namely solar heat gain, internal heat gain, air leakage and temperature difference[4].

Currently, in preventing this issue, there are several opportunities to keep the buildings cooling. Bhatia believes that passive cooling works on two principles, namely minimizing or preventing heat gain and avoid unwanted heat [5]. On the other hand, [2] categorize the passive cooling under three divisions. Figure 2 summarized passive cooling was categorized as heat prevention or heat reduction, modifying heat gains and removes internal heat.

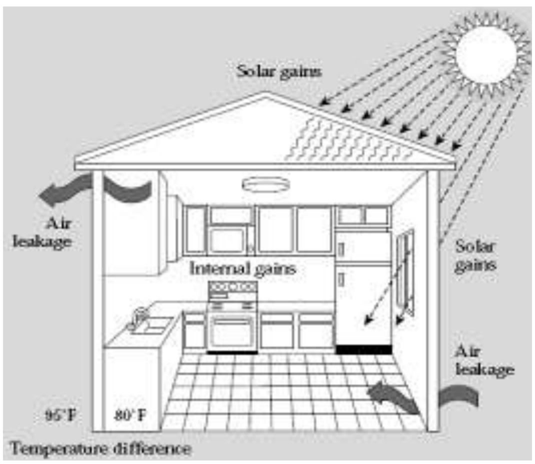


Figure 1: Heat factors affect [4]

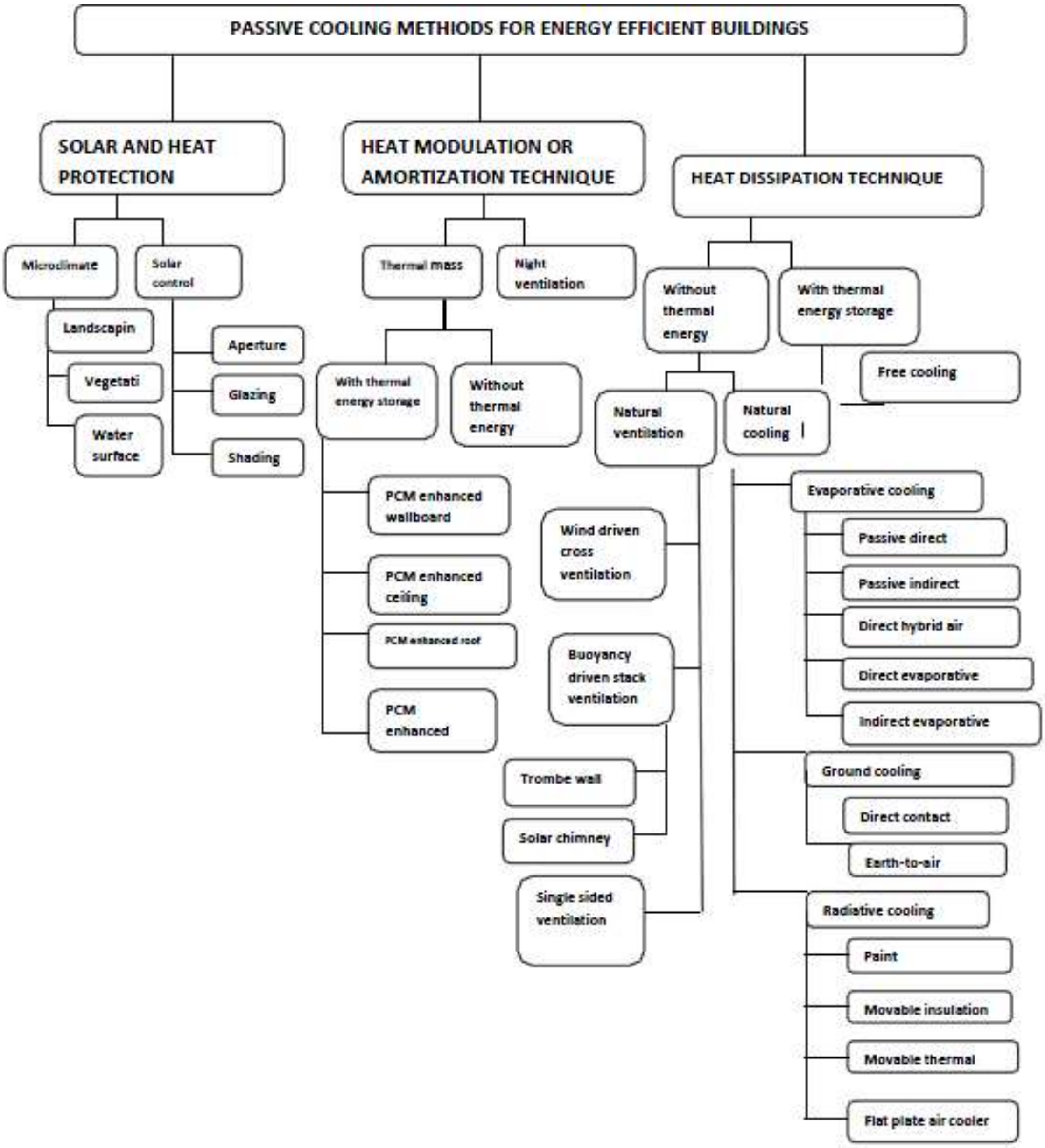


Figure 2: Classification of passive cooling methods in energy efficient buildings [2]

Heat can be reduced with two ways, which is microclimate and solar control. Through microclimate, a building should be designed by considering the building orientation, wind flow, vegetation and water surface. This consideration is the key to reduce the internal heat gain besides to enhance the passive cooling efficiency [2]. Furthermore, the building design also will influence the solar heat gains. In ensuring the building will protected by the solar control, there are some alternatives way must be added in the design such as shading, building finishes, glazing, insulation and aperture [4].

[6] Revealed that modify heat gains can be reached by two techniques, namely, thermal mass and night ventilation. For the first technique, in daytime, heat will be absorbed by thermal mass which available in building's floors and walls. The thermal mass functioned as indoor temperature controller. Then, a part of heat which had been absorbed before this will be transferred back into the building to reduce the maximum cooling during the night. In reaching this technique, there are some methods that can be applied such as phase change materials (PCM) enhanced wallboard, PCM enhanced roof and PCM enhanced glass windows. After that, for the second technique is night ventilation. The night ventilation will be keep night coolness for the next following daytime usage. These two techniques will help to modify the heat gains and simultaneously decrease energy consumption for cooling of buildings.

Besides reduce heat gains and modify heat gains, remove internal heat also can be one of the alternatives in getting cooling of buildings. By using this alternatives, there are two techniques can be applied. First is without thermal energy and the second one is with thermal energy storage. Refers to [2] method under thermal energy storage is free cooling. But this research will only focus on natural cooling which using without thermal energy technique. For natural cooling, there are several methods that can be implemented in the building such as ground cooling, radiative cooling and evaporative cooling. All options have advantages and disadvantages depending on the building place itself. Whatever the way in ensuring the buildings cooling, the most important thing is to fulfil the aim to get the temperature reduction.

THERMAL COMFORT RANGE

Usually, there are five environmental factors in considering Malaysia climate; dry bulb temperature (°C), relative humidity (%), amount of rainfall (mm), wind speed (m/s) and direction (°), and solar radiation (MJ/m^2) [7]. These factors normally affect architects to design buildings that react to the local climate. Therefore, a variety of cooling methods had been implemented into the building to provide thermal comfort to the occupants after the building the does not give enough comfort [8].

Thermal comfort can be explained as the situation of mind to convey pleasure from any thermal environment [9]. Thermal comfort affected by two main factors which are environmental factors and subjective factors [10]. Environmental factors can effect to the cooling device through air temperature, relative humidity and average air velocity [11]. Meanwhile, the subjective factors are the activity level, metabolic rate, clothing, dieting habits, sex, age, health condition, skin colour, human size and acclimatization [12]. This paper will touch in deeply the environmental factors relate to the evaporative cooling in reducing the indoor environmental temperature.

To determine the thermal comfort range, there are several field studies from the hot-humid tropical country. Start with field study held in Singapore was examined the thermal comfort level of 583 subjects from naturally ventilated apartment and 235 subjects from air-conditioned office buildings. The result shows that the neutral temperature in a naturally ventilated building was 28.5°C T_o, while the air-conditioned building was 24.2°C T_a [13].

In Thailand there had a field study of office buildings. The study also the comparison of the thermal comfort between naturally ventilated and air-conditioned. This study contained more than 1100 subjects show that the neutral temperature for naturally ventilated buildings was 27.4°C ET*. Then, for the air-conditioning building was 24.7°C ET* [14]. Next study is the field study of institutional buildings in Shah Alam, Malaysia. This study also involved a thermal comfort study in both, naturally ventilated and air-conditioning. The study revealed the thermal comfort range was 24. 5°C to 28°C with 73%RH. While, the best comfort temperature was 26.3°C [15].

Another field study in Kuala Lumpur, Malaysia was carried out to get the comfort condition in naturally ventilated classroom. The study found that the thermal comfort range was 23.4°C to 31.5°C and the neutral temperature was 27.4°C. Besides, this study also imply that when the average humidity was 65%RH, the mean air movement was 0.27m/s and mean temperature was 29.8°C [16].

In Jakarta, there also had a field study was conducted on 600 office workers from 7 office buildings. The study includes three types of buildings namely, one naturally ventilated, one hybrid and five air-conditioned buildings. The study was found out that the comfort temperature was 26.4°C T_a and 26.7°C T_o [17].

An added field study on the thermal comfort for air-conditioned office workers, situated in Penang, Malaysia. The results showed that the comfort temperature was 24.7°C and the thermal Comfort Range between 20.8°C to 28.6°C [18].

There was also a field study which was relate to the thermal comfort for naturally ventilated but this time was in apartment buildings in Singapore. The study illustrate that comfort temperature was 28.9°C [19].

As conclusion for the thermal comfort studies had been shown in table 2. The outcome of thermal comfort range had done in this zone suggested by [9] and [20] was 23.0 – 26.0 T_o with the upper acceptable comfort value was 24.5 T_o. While, MS 1525:2007 [21] suggested that the thermal comfort range was 23°C - 26°C.

Table 2: Review of indoor thermal comfort studies in South-East Asian region [22]

Study	Year	Country	Comfort Range (°C)	Comfort Value (°C)	Type of Study
De Dear et. al	1991	Singapore	-	28.5 T_o (NV) 24.2 T_o (AC)	Field Study (NV & AC)
Busch	1992	Thailand	22.0 – 30.5	27.4 ET^* (NV) 26.3 ET^* (AC)	Field Study (NV & AC)
Zain-Ahmed et al.	1997	Malaysia	24.5 – 28.0	26.3	Field Study (NV & AC)
Abdul Rahman & Kannan	1997	Malaysia	23.4 – 31.5	27.4	Field Study (NV)
Karyono	2000	Indonesia (Jakarta)	-	26.4 T_a 26.4 T_o	Field Study (NV & AC)
Ismail & Barber	2001	Malaysia	20.3 – 28.9	24.6	Field Study (AC)
Wong et al.	2002	Singapore	-	28.9 T_o (NV)	Field Study (NV)
ASHARE Std 55	1992		23.0 – 26.0 T_o	24.5 T_o	Climate Chamber
ISO 7730	1994		23.0 – 26.0 T_o	24.5 T_o	Climate Chamber
DSM	2007	Malaysia	23.0 – 26.0 with 55 – 70%RH	na	For AC non residential building

T_o=Operative Temperature, ET^* temperature=Effective Temperature, NV=Naturally Ventilated, AC=Air Conditioned

EVAPORATIVE COOLING SYSTEM AND TEMPERATURE REDUCTION

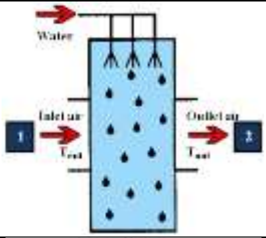
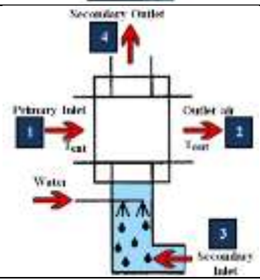
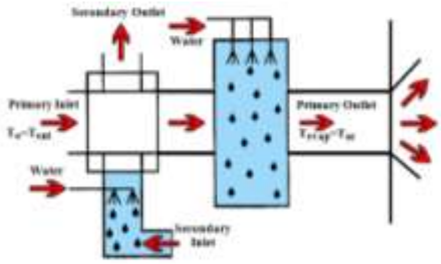
Basically, [23] is saying evaporative cooling can becomes a method of converting hot air into a cool breeze using the process of evaporating water. Evaporative cooling is a technology that can substantially reduce the cooling energy requirement in the building [24]. Referring to the [3], he agrees with [23] but he explained it in detail that in making cooling of buildings, evaporation can be produced either indirectly or directly.

Evaporative cooling techniques can be divided by two basic types namely direct evaporative cooling and indirect evaporative cooling. [5] Acknowledges that in direct evaporative cooling, it will be directly into the airstream and reduce the temperature with humidifying the air. While [25] with [26] believes that there are strong relationship between temperature and humidity in direct evaporative cooling. Through this evaporation, temperature will decrease when humidity increases.

Next, for the second basic type of evaporative cooling techniques is indirect evaporative cooling. [25] with [26] has the same opinion that this basic type will not affect increasing of humidity. Moreover, Mattheos [26] and [5] agree that this system used sensibly cooling where there is no moisture adding up through heat exchanger.

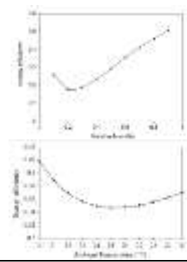
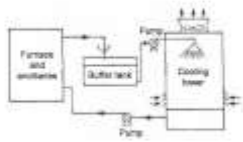
Besides the basic types of evaporative cooling techniques, [27] with [24] believes that evaporative cooling can be divided into three groups (table 3), namely direct evaporative cooling, where moisture is added to the air stream, indirect evaporative cooling, where the moisture content of the air stays constant and another one is a combination of these two methods which is indirect and direct evaporative cooling.

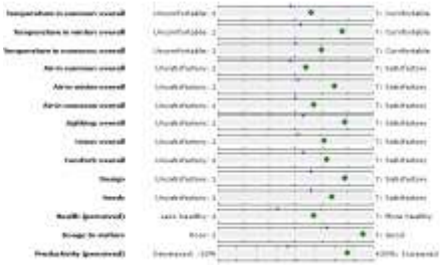
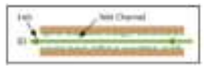
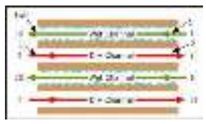
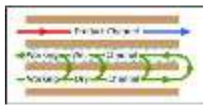
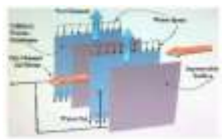
Table 3: Types of evaporative cooling techniques

Evaporative Cooling Strategies	Typical Sectional Diagram [27]	Description [5]
Direct Evaporative Cooling		**Direct evaporative cooling** introduces water directly into the supply airstream (usually with a spray or some sort of wetted media). As the water absorbs heat from the air, it evaporates and cools the air.
Indirect Evaporative Cooling		**Indirect evaporative cooling** lowers the temperature of air via some type of heat exchanger arrangement, in which a secondary airstream is cooled by water and which in turn cools the primary airstream. The cooled air never comes in direct contact with water or environment.
Indirect/Direct Evaporative Cooling		**Indirect/direct evaporative cooling** is accomplished by passing air inside a heat exchanger that is cooled by evaporation on the outside. Then, the pre-cooled air passes through a water-soaked pad and picks up humidity as it cools. Because the air supply to the second stage evaporator is pre-cooled, less humidity is added to the air, whose affinity for moisture is directly related to temperature.

The effectiveness of evaporation is depends on relative humidity, temperatures, air movement and surface area [5]. In warmer climates, natural ventilation cannot circulate enough air through a building to provide sufficient cooling at night to remove the day's heat.

Table 4: Summary of the latest studies conducted on evaporative cooling in South-East Asian region

Studies	Methods	Results	Figures
1. [24]	Use direct evaporative cooling method. *Location: Malaysia	The findings indicate that the function of relative humidity as exergy efficiency of the evaporative cooling process with T_0 = 29.25°C. Then, the function of relative humidity as exergy efficiency of the evaporative cooling process with RH = 70%.	
2. [28]	In theory and practically, the cooling pond system is designed and built for 0.16 ton coreless induction furnace. As option for smelted in foundry shop, it utilize in two induction furnaces. Location: Myanmar	The advantages of this system are simplicity, low capital cost and cooling water with the ambient wet-bulb temperature. This system also had disadvantages like, water is lost by evaporation, if the water level hard to rise, it will cause reduction of heat transfer. Another disadvantage are effect of corrosion and fouling trouble from flying dust and impurities which are drawn into the tower. The cooling towers also had disadvantage, because it dependent to temperature and humidity, when temperature and humidity high, the efficiency will be decline.	 Open-Circuit System with Evaporative Cooling Tower

3.	[29]	The Torrent Research Centre consists of six laboratory and office blocks. Four of it integrates with passive downdraft evaporative cooling system. *Location: India		 Plan and section of a PDEC Building  Torrent Research Centre (drawings and photo courtesy: Abhikram)
4.	[30]	This research use of various cooling pad materials. The systems use the Maisotsenko Cycle is to discover a multiclimate application such dry and humid. *Location: India	Maisotsenko Cycle (M-cycle) has a high possibility to save energy in variety approach. The greatest example is Coolerado Cooler. This method gets the benefit of the thermodynamic properties of air. Both, direct and indirect cooling technologies applied in this cooling system. It was cooler than indirect evaporative cooling and drier than direct cooling.	 Cross section of direct evaporative cooling  Cross section of indirect evaporative cooling  Working of M-cycle  Cellulose porous stack heat exchanger configuration of a DPEC
5.	[31]	When air is not too humid passed through a wet surface, evaporative cooling happened. The quicker evaporation rate will give the better cooling. The efficiency of an evaporative cooling structure relies on the humidity of the environment air. Location: Nigeria	Evaporative cooling principle can be utilized in two methods which are passive-direct evaporative cooling and non-passive direct evaporative cooling. Passive-direct evaporative cooling system depends on the natural wind velocity. While, non-passive direct evaporative cooling system used fan to give air movement.	

The review of table 4 shows the latest studies conducted on evaporative cooling in South-East Asian region. From the table 4, non- passive direct evaporative cooling system to be possible for increasing cooling when wind speed is limited. As commonly known Tropical Malaysia is categorized as a hot and humid climate. This system need to be integrated with mechanical ventilation energy operated by solar electricity as an environmental friendly concoction.

Consequently, mechanical ventilation can provide continuous moving air that will keep the indoor environment cooled in the day and night through circulating fans with evaporative coolers. Window fans are best used in windows facing the prevailing wind or away from it to provide cross-ventilation. Window fans will augment any breeze or create a breeze when the air is still. The purpose is for the windows fan support the evaporative cooling which is installed in windows. As a result, the indoor environment or section of building will be cooled [32].

EVAPORATIVE COOLING WINDOW SYSTEM USING *LABU SAYONG*

[8] Showed that in making rational building design which are pleasurable, relaxing and secure environment must have cooperation between engineers and architects. Indoor spaces can achieve an accurate cooling with this ideal combination. In order to achieve it, this strong relationship was presented as an evaporative cooling using porous material. It was controlled and promoted by means of some mechanical device. This integration created one of innovation for cooling.

Technology has been changed together with the times. Since centuries ago, evaporative cooling has been existed in several different forms by using different materials. The usage of porous water pot for evaporative cooling has been well known and it is still relevant till now. Porous water pot, porous water jar, porous ceramic and porous clay pots are made from the same material which is clay [3]. *Labu sayong* also made from clay and it has been chosen for this reason.

The porosity of *labu sayong* absorbs the moisture by capillary action. Even though, the minor water drops on *labu sayong* surface which caused by capillary action could not be noticed. The capillary action had happened when pours the water in the *labu sayong*. When the water saturated at the surface of *labu sayong*, evaporation occurred. Therefore, theoretically, the cooling of water in *labu sayong* occurs because of two processes. First, the increased of water on the surface of *labu sayong* and the second one was evaporation.

After the water cooled, the outside heat transfer to the *labu sayong* until the system reached thermal equivalence. Then, the porosity of the *labu sayong* surface was completely saturated with water and later, only evaporation process happened in the cooling process. Consequently, the cooling effect depends on the water evaporation on the *labu sayong* surface.

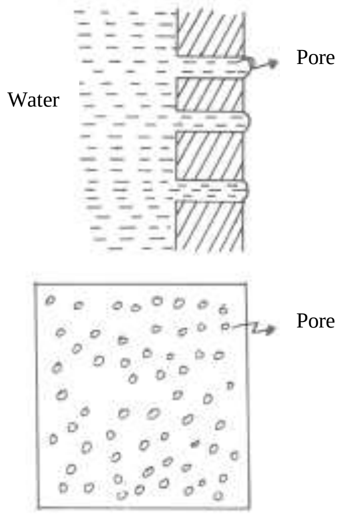


Figure 3: Estimation of porous clay radius was same with a radius of clay soil pore [33]

Referring to [33] if water evaporation happens, surely water temperature is lower than air temperature. The result will show that the water in *labu sayong* is cooler than room temperature. From this theory, it can be concluded that *labu sayong* can make the water inside it always cool. This characteristic was support why *labu sayong* had been chosen in this review.

By using the *labu sayong* in the evaporative cooling window system, this system is expected can promote tourist to come visit Malaysia.

CONCLUSION

In conclusion, for reduce air temperature, evaporative cooling window system using *labu sayong* have potential to implement in tropical Malaysia. This review investigates the various types of evaporative cooling strategies. Based on the result, non-passive direct evaporative cooling window system is anticipated giving promising in reaching the target. Nevertheless, more researches are necessary in order to verify the design of evaporative cooling window system using *labu sayong*.

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