Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Design and Study of Domestic Cooling System through Roof Ventilation Assisted by Evaporative Cooling

Shean Ti Teen[1], Keng Wai Chan[1,*]

[1] School of Mechanical Engineering, Universiti Sains Malaysia Engineering Campus, 14300 Nibong Tebal, Pulau Pinang, Malaysia

ARTICLE INFO

Article history:
Received 5 March 2022
Received in revised form 19 June 2022
Accepted 30 June 2022
Available online 25 July 2022

Keywords:
Roof ventilation; evaporative cooling; rooftop sprinkler system; modelling; performance evaluation

ABSTRACT

This study shows the evaluation of the indirect evaporative cooling system beneath the roof that aims to reduce the cooling load in buildings. As the energy demand for space cooling increases over the years, the evaporative cooler that has lower energy consumption can be a green technology for space cooling compared with air-conditioning systems. An example of an evaporative roof cooling method that is commonly used is a rooftop sprinkler system. This study emphasizes the evaluation of the performances of an indirect evaporative cooler and rooftop sprinkler system in terms of temperature reduction and cooling capacity. The modelling is done by using the sol-air temperature to estimate the solar heat gain. Then, the cooling power of each system is calculated, and finally, the indoor temperature for the respective system can be determined. The finding shows that the temperature drop for the indirect evaporative cooler is 9.2°C, whereas for the rooftop sprinkler system, it is only about 4.4°C. The simulated cooling load of the indirect evaporative cooler for this test house can go up to 49.2W.

1. Introduction

In Malaysia, an air-cooling system is often used to achieve a more comfortable interior environment. There are a few methods to cool an interior space, such as using an air-conditioning system or an evaporative cooling system. However, the air-conditioning is not favourable as it consumes a large amount of electricity. Not to mention, the refrigerant used may potentially pollute the environment. According to "The Future of Cooling" report, 20% of total electrical energy is used for air-conditioning and electric fans to stay cool in buildings around the world today. The demand for air conditioning is still increasing. It is predicted that by the year 2050, two-thirds of the world's households could have air conditioners [1]. Thus, there is no doubt that the global demand for space cooling systems and the energy needed to support them will continue to grow over the next decades.

An evaporative cooling system uses relatively lower electricity, is more practical, and is more environmentally friendly as the refrigerant used is water [2]. During the evaporation process, it is

* *Corresponding author.*
E-mail address: kengwai.chan@usm.my

https://doi.org/10.37934/arfmts.98.1.8291

required to absorb the large quantity of latent heat of vaporization, about 2260 kJ/kg for the phase change of water from liquid to vapor. This eventually reduces the surrounding air temperature and chills the interior space [3]. Most research pointed out that the application of an indirect evaporative cooler could reduce the total electric energy consumption in buildings with air-conditioning systems, which ranges from 20% to 70% depending on the design of the cooling system [4]. There are two types of evaporative air coolers, which are direct evaporative coolers and indirect evaporative coolers (IEC) [5]. In direct evaporative cooling, the ambient air is passed through an evaporative cooler to reach a wet-bulb temperature. The water in the system evaporates to increase the humidity ratio of the air, causing the air temperature to decrease and ideally reach the wet-bulb temperature according to the psychometric chart. In the IEC, there are primary and secondary airstreams, where the primary airstream will go through the evaporative cooling system, and the secondary airstream is air from interior space. Then, the heat exchanger will be applied to cool the secondary air with the primary airstream that has a lower temperature. The major advantage of the IEC system is that it does not increase the humidity in the secondary airstream, which may affect human comfort [6]. However, the IEC system is highly dependent on the parameters of ambient air. It can lower the air temperature until it reaches its maximum air humidity [7].

There are three methods to reduce the heat flux from the roof, which are reflective roof tiles, roof ventilation, and evaporative cooling. Firstly, a covered roof with reflective roof tiles can help in cooling the interior space as reflective tiles have lower emissivity. Reflective roof tiles can reflect the majority of solar radiation and achieve a cooler interior environment [8]. Secondly, forced ventilation is done by using a pump or blower over the ventilation duct to circulate the air. The interior is chilled by circulating cool air consistently. Thirdly, the conventional method of evaporative cooling on a roof is by installing a water spraying nozzle on the roof. The water is spread on the roof tiles and aims to decrease the roof temperature. According to studies [9,10], this method could only cool the roof tiles up to 4°C but not the indoor temperature.

In short, the air-conditioning system has its drawbacks as it has high electrical consumption and its refrigerant use could lead to environmental pollution, whereas the usage of the rooftop sprinkler system is limited by its low cooling capacity. Hence, this project aims to propose a new method for domestic cooling systems through roof ventilation assisted by evaporative cooling. This method also strives to overcome the adverse effect of a rooftop sprinkler system that has a low capability to reduce indoor temperature. A test house with three chambers, which are a chamber with a proposed cooling system, a condition-controlled chamber, and a chamber installed with a rooftop sprinkler system, will be built to estimate their cooling performance. Before that, mathematical modelling will be carried out with Python programming to simulate the temperature profile in each chamber according to the average ambient condition in Malaysia.

2. Methodology

2.1 Design of Test House

A test house was constructed with an average height of 0.75m, 0.5m of width, and 0.7m of length. This test house was built with wood and the walls were made up of Styrofoam materials to eliminate heat gain or loss between the walls. The test house was covered with 12mm thick clay roof tiles. Referring to Figure 1, each chamber was set up for its respective purposes. For the proposed cooling system that is used in the first chamber, a cooling duct made of aluminum will be installed beneath the roof tiles as aluminum has better convective heat transfer performance than other proposed materials such as stainless steel and cast iron in the project by Ibrahim [11]. Cool water will be sprayed into the cooling duct via a nozzle. Then, an air blower will be equipped at the exit of the cooling duct to enhance the rate of the evaporation process, aiming to decrease the duct temperature to the wet-bulb temperature as stated in the review [12]. The second chamber is the condition-controlled chamber where no cooling equipment will be used. Lastly, the third chamber is equipped with a rooftop sprinkler system where a water spray nozzle was installed at the top edge of the roof tiles.

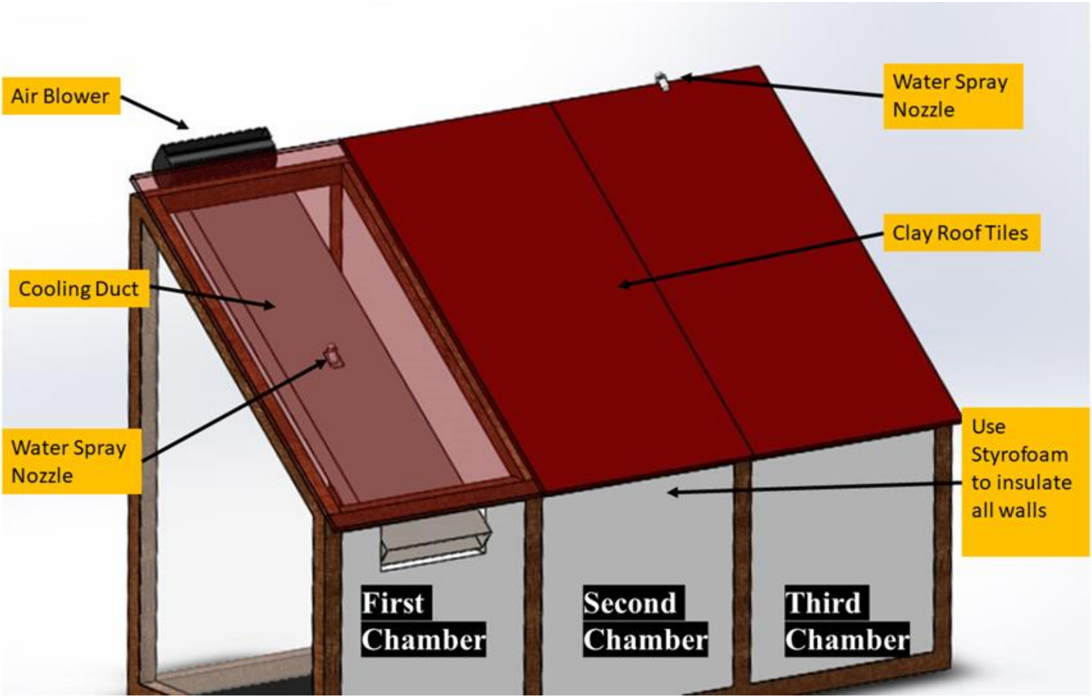

Fig. 1. CAD of Test House

2.2 Solar Heat Gain Power

The performance of an evaporative cooling system highly depends on the ambient conditions. Thus, the ambient condition parameters used in this modelling will affect the accuracy of the results. This experiment will be carried out in Pulau Pinang, Malaysia, which has a tropical rainforest climate with a longitude of 100.33°E and a latitude of 5.41°N. Based on the project "Energy Simulations for Buildings in Malaysia" carried out by Universiti Teknologi Malaysia (UiTM), the Test Reference Year (TRY) was developed that shows the hourly weather data of Kuala Lumpur, Malaysia [13]. As TRY is currently the only known set of weather data for energy simulation and it is used in many energy simulations in Malaysia [14]. This data set provides the parameters used in our simulation, which include dry-bulb temperature, wet-bulb temperature, and global radiation (the sum of direct and diffuse radiation).

To calculate the solar heat through the roof, $Q_{solar\ heat\ gain}$, the Sol-air temperature equation commonly used is used, as can be shown in Eq. (1). This method is a simplified calculation of accounting for the combined effects of conductive, convective, and radiative heat exchange in structures [15].

$$Q_{solar\ heat\ gain} = U_{roof} A[\ (T_{DB} - T_i) + \frac{\alpha I}{h_T}\ ] \tag{1}$$

where U_{roof} is the overall heat transfer coefficient, A is the area of roof tiles, T_{DB} is the dry-bulb temperature, T_i is the indoor temperature, α is the emissivity of roof tiles taken as 0.8, I is the global radiation in Malaysia, h_T is total heat transfer coefficient.

The total heat transfer coefficient, which can also be represented as Eq. (2)

$$h_T = h_{conv,roof} + h_{rad} \tag{2}$$

where h_{conv} is the convective heat transfer coefficient of the roof and h_{rad} is the radiative heat transfer coefficient.

To calculate the radiative heat transfer coefficient, the rate of radiant interchange between the roof tile surface and the ambient can be represented as Eq. (3) Then the radiative heat transfer coefficient can be obtained in Eq. (4) [16]. If the ambient temperature is equal to the roof tile surface temperature, such as during the nighttime, the derived Eq. (5) will be used.

$$Q_{roof-ambient(rad)} = \alpha\ \sigma\ A\ ({T_{roof}}^4 - {T_{DB}}^4) = h_{rad}\ A\ (T_{roof} - T_{DB}) \tag{3}$$

$$h_{rad} = \frac{\alpha\ \sigma({T_{roof}}^4 - {T_{DB}}^4)}{T_{roof} - T_{DB}} \tag{4}$$

$$h_{rad} = 4\ \alpha\ \sigma\ {T_{DB}}^3 \tag{5}$$

where σ is the Stefan-Boltzmann constant equal 5.670Wm^{-2}K^{-4}; T_{roof} is the roof tiles surface temperature in K.

To determine the surface temperature of roof tiles, the Stefan Boltzmann law is applied as Eq. (6) by using the maximum global radiation in Malaysia. Therefore, the roof tiles' surface temperature can be expressed in Eq. (7).

$$Q_{solar\ radiation} = \alpha\ \sigma\ A\ {T_{roof}}^4 \tag{6}$$

$$T_{roof} = \sqrt[4]{\left(\frac{q_{solar\ radiation}}{\alpha\ \sigma}\right)} \tag{7}$$

where $q_{solar\ radiation}$ is the solar radiation heat flux.

Lastly, the overall heat transfer coefficient of the roof tiles can be expressed in Eq. (8)

$$U_{roof} = \frac{1}{\frac{1}{h_{conv,i}} + \frac{L}{k_{clay}} + \frac{1}{h_{conv,roof}}} \tag{8}$$

where $h_{conv,i}$ is the convective heat transfer coefficient of indoor air to roof, $h_{conv,roof}$ is the convective heat transfer coefficient of the roof to ambient, *L*= 12mm is the thickness of roof tiles, and k_{clay} is the conductivity of clay tiles which is equal to 0.7106 Wm^{-1}K^{-1} [17].

With these calculations, the maximum heat gain through the roof using the Sol-air temperature Eq. (1) can be determined. Then, the heat gain is used as the required cooling load for each chamber. The cooling capacity and final room temperature of each chamber will be calculated, followed by the hourly weather conditions in Malaysia based on [14]. Generally, in the condition-controlled chamber, the cooling is only by natural convection through the roof tiles. The indirect evaporative cooling system is cooled by natural convection through the roof tiles, convection through the cooling duct, and conduction through the water inside the cooling duct. Lastly, the rooftop sprinkler system is only cooled by conduction through the water being sprayed on the surface of the roof tiles.

2.3 Cooling Power in Condition-Controlled Chamber

For in condition-controlled chamber, the only cooling is by convection through roof tiles that can be represented by Eq. (9).

$$Q_{conv} = U_{roof}A[\,(T_i - T_{DB})\,] \tag{9}$$

where A is the area of roof tiles that are exposed to ambient.

2.4 Cooling Power in Indirect Evaporative Cooling System Chamber

For the indirect evaporative cooling system, the first cooling is by convection through the roof tiles, which is Eq. (9). For the convective cooling by the running airstream inside the duct, it can be expressed in Eq. (10). As water evaporation happens, the air temperature will ideally drop to the wet-bulb temperature, but the actual wet-bulb temperature is always higher than the ideal wet-bulb temperature. The extent to which the temperature drops and approaches the wet-bulb temperature can be defined as the wet-bulb efficiency. It describes the ratio of the difference between the inlet and outlet airflow dry bulb temperatures to the difference between the inlet airflow dry bulb temperature and its dew point temperature as expressed in Eq. (12) [18]. Based on [6], the maximum efficiency for an indirect evaporative cooler that can be achieved is about 80%. Hence, the convective cooling by the duct can be expressed as Eq. (11).

$$Q_{conv,duct} = U_{conv,duct}\, A\,[\,(T_i - T_{WB'})\,] \tag{10}$$

$$Q_{conv,duct} = U_{conv,duct}\, A\,[\,(T_i - (T_{DB} - 0.8(T_{DB} - T_{WB}))\,] \tag{11}$$

$$\eta_{WB} = \frac{T_{DB} - T_{WB'}}{T_{DB} - T_{WB}} \tag{12}$$

where A is the area of cooling duct, T_{WB} is the ideal wet bulb temperature, $T_{WB'}$ is the actual wet-bulb temperature, $U_{conv,duct}$ is calculated with Eq. (8) and replace thickness *L* to 2mm, *k* to aluminum conductivity of 239 $Wm^{-1}K^{-1}$, and $h_{conv,roof}$ replaced with calculated air convective heat transfer coefficient at $4ms^{-1}$ [19].

Next, as water is sprayed continuously inside the cooling duct, the cooling by water conduction through the cooling duct can be represented by Eq. (13). In this instance, the calculated Reynolds number shows the laminar flow inside the duct, and therefore the convective heat transfer coefficient can be calculated from the Nusselt Number for laminar flow over an isothermal flat plate that can be represented by Eq. (14) [20].

$$Q_{cond,duct} = U_{cond,duct}\, A\,[\,(T_i - T_{water})\,] \tag{13}$$

$$Nu_L = \frac{h\,L}{k} = 0.664\, {Re_L}^{0.5} Pr^{\frac{1}{3}} \tag{14}$$

where k is fluid conductivity, Pr is Prandtl number which can be retrieved from source [21], A is the area of the cooling duct that is exposed to flowing water, L is the length of the flat plat, Re is Reynolds Number, $U_{cond,duct}$ is the overall heat transfer coefficient of the cooling duct due to conduction and calculated based on Eq. (8) by replacing thickness L to 2 mm, k to aluminum conductivity of 239 $Wm^{-1}K^{-1}$, and $h_{conv,roof}$ replaced with calculated water convective heat transfer coefficient.

2.5 Cooling Power in Rooftop Sprinkler System Chamber

For the third chamber that was installed with a rooftop sprinkler system, the cooling is done by the conduction of water on the roof tiles, and it can be expressed as Eq. (15). Similarly, the convective heat transfer coefficient by water is calculated by the Nusselt Number for laminar flow over the isothermal flat plate as Eq. (14). In the equation, $U_{cond,duct}$ is the overall heat transfer coefficient of the cooling duct due to conduction and is calculated based on Eq. (8) by replacing $h_{conv,roof}$ with the calculated water convective heat transfer coefficient. The roof tiles' surface temperature is the actual wet-bulb temperature with 80% wet-bulb efficiency and can be calculated from Eq. (12). However, the study by Jefrey [10] shows that when roof tiles' surface temperature goes above 31°C, the rooftop sprinkler system can only reduce the roof tile temperature to a minimum of 30°C. This parameter will also be included in the modelling.

$$Q_{cond,roof} = U_{cond,roof}\, A\, [\, (T_i - T_{roof})\,] \tag{15}$$

where A is the area of roof tiles for respective to that chamber.

2.6 Final Temperature in Respective Chamber

To simulate the final temperature of each chamber, net heat is calculated by subtracting the solar heat gain with the cooling capacity of each element, as shown in Eq. (16). The net heat gain into the chamber causes the temperature to rise proportionally to the mass of air and the specific heat capacity of air at a given time. By restructuring the equation, Eq. (17) is expressed and is used for simulation by iterating to calculate the final room temperature.

$$Q_{nett} = Q_{solar\ heat\ gain} - \Sigma Q_{cooling} = m_{air} c_p \frac{T_{t2} - T_{t1}}{t_2 - t_1} \tag{16}$$

$$T_{i+1} = T_i + \frac{Q_{nett,i} * (t_{i+1} - t_i)}{m_{air}\, c_p} \tag{17}$$

where c_p is the specific heat capacity of that air could be retrieved from the source [21].

3. Results

3.1 Temperature Profile of Respective Chamber

The result in Figure 2 shows that the heat radiation starts to increase at 7 am and achieves its peak of radiation of 1076.5 Wm^{-1} at 2 pm. After that, as the sun goes down, the radiation starts to decrease and reaches zero at 9 pm. Besides, from Table 1, it is noticed that the resulting temperature of the condition-controlled chamber has the greatest increase in temperature, and it reaches the maximum temperature of 49.6°C at 2 pm. For the rooftop sprinkler system, the maximum temperature is 45.3°C, whereas for the indirect evaporative cooling system is 40.4°C. Table 2 also indicates that the temperature reduction by the rooftop sprinkler system is about 4.3°C and by the indirect evaporative cooling system is about 9.2°C. Based on the research done about rooftop sprinkler system [9], this system do not much affect a reduction in indoor temperature. Moreover, a study [22] that used an indirect evaporative cooler stated that the temperature reduction across the cooling duct could be 8.56°C with mist and water shower used and under the ambient condition of 38°C and 55%RH. This temperature drop of 8.56°C demonstrates that a temperature drop of 9.2°C is possible in this modelling. In contrast, the proposed indirect evaporative cooling system can decrease by up to 9.2°C which could be an alternative way to reduce the cooling load of interior space.

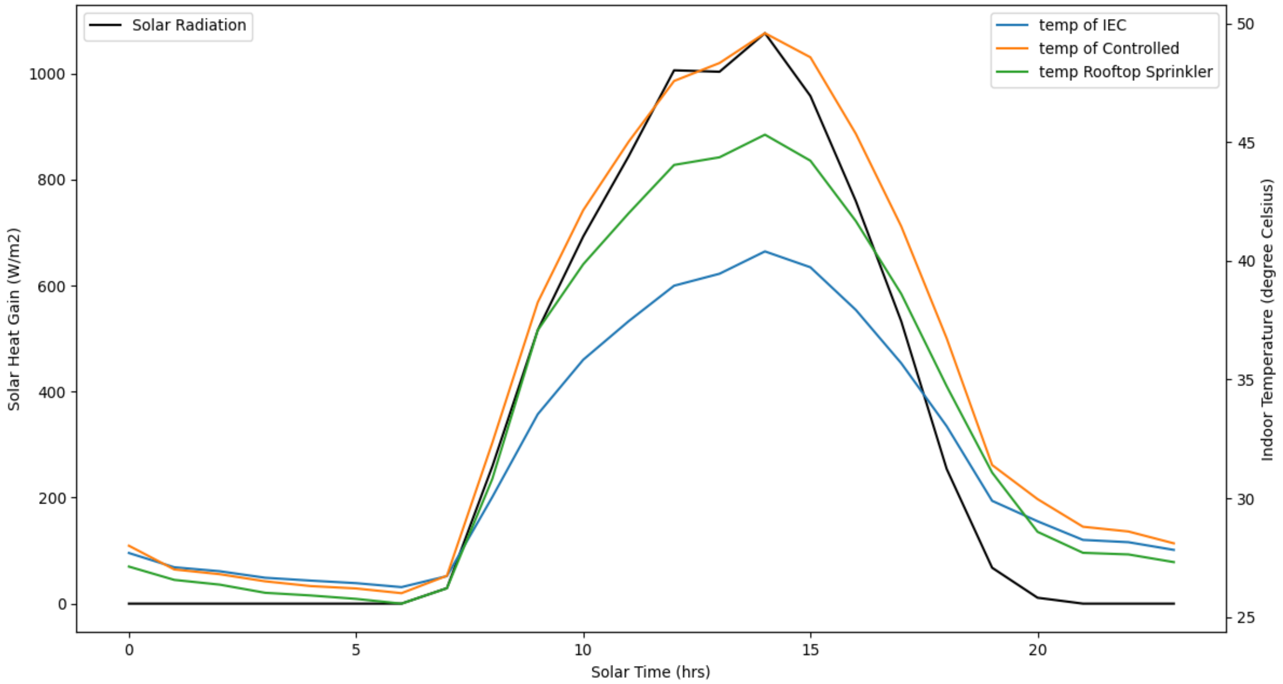

Fig. 1. Solar radiation and temperature profile of respective chamber versus time

Table 1
The temperature profile in degree Celsius in each chamber versus the hourly weather

Time(h)	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100
Cham 1	27.7	27.1	26.9	26.7	26.5	26.4	26.3	26.7	30.0	33.5	35.8	37.5
Cham 2	28.0	27.0	26.8	26.5	26.3	26.2	26.0	26.7	32.3	38.3	42.1	45.0
Cham 3	27.1	26.6	26.4	26.0	25.9	25.8	25.6	26.2	30.8	37.1	39.9	42.0
Time(h)	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300
Cham 1	39.0	39.5	40.4	39.7	37.9	35.7	33.0	29.9	29.0	28.2	28.1	27.8
Cham 2	47.6	48.3	49.6	48.6	45.4	41.4	36.7	31.4	30.0	28.8	28.6	28.1
Cham 3	44.0	44.4	45.3	44.2	41.7	38.6	34.7	31.1	28.6	27.7	27.6	27.3

Table 2
The temperature difference profile in degree Celsius respective to chamber 2 versus the hourly weather

Time(h)	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100
Cham 1	0.3	-0.1	-0.1	-0.2	-0.2	-0.2	-0.3	0	2.3	4.8	6.3	7.5
Cham 3	0.9	0.4	0.4	0.5	0.6	0.4	0.4	0.5	1.5	1.2	2.2	3.0
Time(h)	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300
Cham 1	8.6	8.8	9.2	8.9	7.5	5.7	3.7	1.5	1.0	0.6	0.5	0.3
Cham 3	3.6	3.9	4.3	4.4	3.7	2.8	2.0	0.3	1.4	1.1	1.0	0.8

3.2 Cooling Load Profile of Respective Chamber

By assuming that there is no heat storage effect in this simulation, the space heat gain is equal to the space cooling load. By retrieving the solar heat gain, we can obtain the cooling load in each chamber, as plotted in Figure 3. From this figure and Table 3, the cooling load in the respective chamber can be estimated. The indirect evaporative cooling system has the highest cooling load with 49.2W, especially during the hours of high solar radiation. The higher cooling load represents the greater capability of the cooling system to remove heat from a designated space and results in a lower indoor temperature.

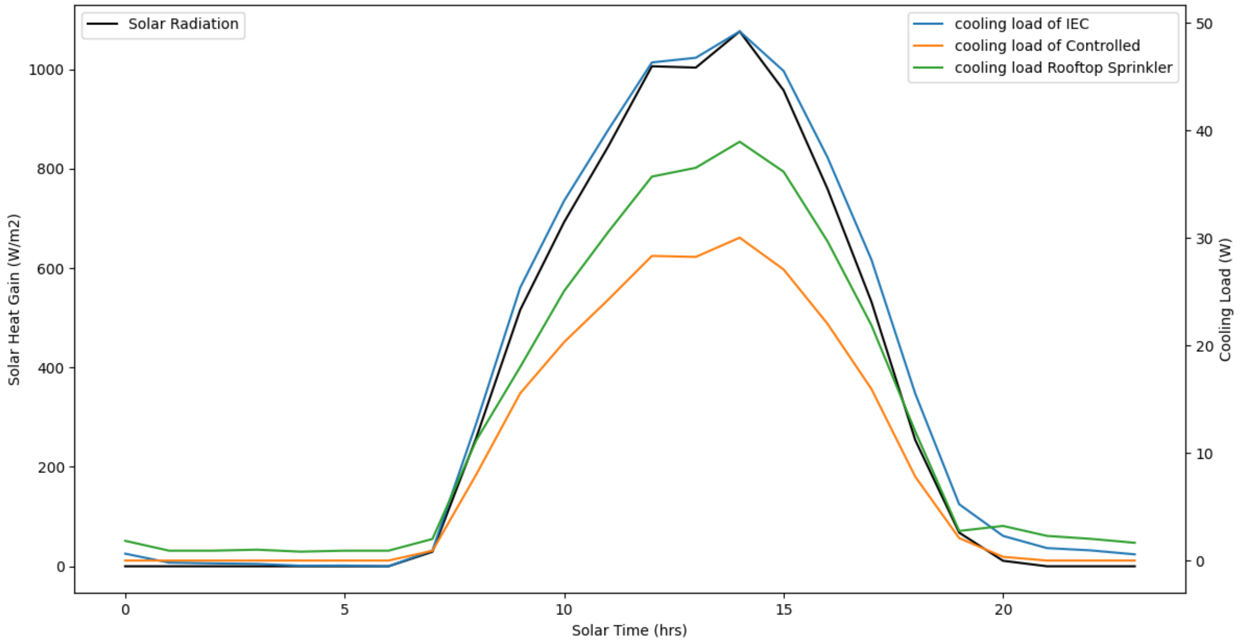

Fig. 2. Solar Radiation and Cooling Load Profile of Respective Chamber

Table 3
The cooling load profile in Watt versus the hourly weather

Time(h)	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100
Cham 1	0.6	-0.2	-0.3	-0.3	-0.5	-0.5	-0.5	0.9	12.8	25.4	33.5	40.0
Cham 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	8.0	15.6	20.3	24.3
Cham 3	1.8	0.9	0.9	1.0	0.8	0.9	0.9	2.0	11.2	18.0	25.1	30.5
Time(h)	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300
Cham 1	46.3	46.8	49.2	45.5	37.5	28.0	15.5	5.2	2.3	1.2	0.9	0.6
Cham 2	28.3	28.2	30.0	27.1	22.0	16.0	7.8	2.1	0.3	0.0	0.0	0.0
Cham 3	35.7	36.5	39.0	36.2	29.7	21.9	12.0	2.8	3.2	2.3	2.0	1.7

4. Conclusions

This study aimed to propose a new method of domestic cooling through roof ventilation assisted by evaporative cooling to overcome the drawbacks of air-conditioning systems and rooftop sprinkler systems. This modelling of this test house shows that the potential temperature drops of an indirect evaporative cooling system could reach up to 9.2°C when compared to a rooftop sprinkler system that could only reduce 4.4°C. Besides, the cooling load of the indirect evaporative cooling system in this test house has a potential maximum cooling capacity of 49.2W. This modelling shows there is a potential application of the indirect evaporative cooling system that aims to reduce the cooling load in some buildings. Moreover, the cooling capacity can be increased by upsizing the system to meet the required space cooling.

Future research can be done by validating the simulated room temperature and cooling capacity. After constructing the test house, the outdoor performance test will be carried out, indoor temperature will be recorded, and cooling capacity can be calculated based on various parameters such as temperature and humidity ratio that can be collected during the experiment phase.

References

[1] Birol, F. "The future of cooling: opportunities for energy-efficient air conditioning." *International Energy Agency* (2018).

[2] Osama Khayal. "Uses , Advantages and Limitations of Evaporative Coolers," (2019).

[3] Bora, Y. R., S. D. Bhosale, K. N. Ghandi, and T. S. Ghandi. "Performance improvement techniques for evaporative air cooler–a review." *International Journal of Engineering Research & Technology* 6, no. 3 (2017): 379-382. https://doi.org/10.17577/IJERTV6IS030367

[4] Winaya, I. Nyoman Suprapta, Hendra Wijaksana, Made Sucipta, and Ainul Ghurri. "An Overview of Different Indirect and Semi-Indirect Evaporative Cooling System for Study Potency of Nanopore Skinless Bamboo as An Evaporative Cooling New Porous Material." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 79, no. 2 (2021): 123-130. https://doi.org/10.37934/arfmts.79.2.123130

[5] HANUMANT, KAVALE GANESH, JADHAV VISHAL MANOHAR, and KADAM AKASH SUNIL. "Review Paper On Evaporative Cooling System." *International Journal of Innovations in Engineering Research and Technology* 4, no. 4 (2017): 1-6..

[6] Bindu, R. S. and N. Kumar, "Design of Indirect Evaporative Cooler Flat Plate-Counter Flow Type," *Int. J. Eng. Res. Technol* 6, (2017): 253-260. https://doi.org/10.17577/IJERTV6IS060118

[7] Kowalski, Piotr, and Dariusz Kwiecień. "Evaluation of simple evaporative cooling systems in an industrial building in Poland." *Journal of Building Engineering* 32 (2020): 101555. https://doi.org/10.1016/j.jobe.2020.101555

[8] Farhan, Syed Ahmad, Fouad Ismail Ismail, Osamah Kiwan, Nasir Shafiq, Azni Zain-Ahmed, Nadzhratul Husna, and Afif Izwan Abd Hamid. "Effect of roof tile colour on heat conduction transfer, roof-top surface temperature and cooling load in modern residential buildings under the tropical climate of Malaysia." *Sustainability* 13, no. 9 (2021): 4665. https://doi.org/10.3390/su13094665

[9] Kindangen, Jefrey I., H. Luntungan, and Arie SM Lumenta. "Indirect Evaporative Cooling for Thermal Comfort in Buildings in a Humid Tropical Climate." (2015).

[10] Kindangen, Jefrey I., and Markus K. Umboh. "Design of evaporative-cooling roof for decreasing air temperatures in buildings in the humid tropics." In *AIP Conference Proceedings*, vol. 1818, no. 1, p. 020023. AIP Publishing LLC, 2017. https://doi.org/10.1063/1.4976887

[11] Ibrahim, Abdulwehab, Perk Lin Chong, Vicnesvaran Rajasekharan, Mohamed Muzuhin Ali, Omar Suliman Zaroong, and Nurye Oumer Ahmed. "Investigation of the effect of different materials on convective heat transfer." *Journal of Mechanical Engineering and Sciences* 14, no. 2 (2020): 6642-6651. https://doi.org/10.15282/jmes.14.2.2020.08.0520

[12] A. Dorwat and S. Savant, "A Review on Investigation of Evaporative cooling," *Int. J. Res. Aeronaut. Mech. Eng* 8, no. 3, (2020): 16-22.

[13] Reimann, Gregers Peter, M. P. Davis, and A. Zain-Ahmed. "Malaysian weather data (TRY) for energy simulations in buildings." In *World Renewable Energy Congress VI*, (2000): 571-574. https://doi.org/10.1016/B978-008043865-8/50110-0

[14] Tang, K., and N. Chin. "Building Energy Efficiency Technical Guideline for Passive Design Public Works." *Department Malaysia: Kuala Lumpur, Malaysia* (2013).

[15] Chesser, Gary Daniel, Joseph L. Purswell, Jeremiah D. Davis, Jason K. Ward, and Thomas Tabler. "Comparison of Outside Air and Sol-air Design Temperatures for Estimating Insulation Needs." In *10th International Livestock Environment Symposium (ILES X)*, p. 1. American Society of Agricultural and Biological Engineers, 2018. https://doi.org/10.13031/iles.18-138

[16] Howell, John R., M. Pinar Menguc, and Robert Siegel. "5Chapter Radiation Exchange in Enclosures Composed of Black and/or Diffuse-Gray Surfaces." In *Thermal Radiation Heat Transfer*, pp. 235-298. CRC Press, 2010. https://doi.org/10.1201/9781439894552

[17] Ariyadasa, G. L. M., S. S. K. Muthurathne, and S. U. Adikary. "Investigating the physical, mechanical and thermal properties of common roofing materials in Sri Lanka." In *Proceedings of 6th annual national building research symposium, Sri Lanka*. 2015.

[18] Putra, Nandy, Evi Sofia, and B. Ali Gunawan. "Evaluation of Indirect Evaporative Cooling Performance Integrated with Finned Heat Pipe and Luffa Cylindrica Fiber as Cooling/Wet Media." *Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer* 3, no. 1 (2021): 16-25.
[19] Engineering ToolBox. "Convective Heat Transfer." (2003).
[20] Stetsyuk, Viacheslav, Krzysztof J. Kubiak, Lande Liu, and John C. Chai. "An alternative approach to evaluate the average Nusselt number for mixed boundary layer conditions in parallel flow over an isothermal flat plate." *International Journal of Mechanical Engineering Education* 46, no. 3 (2018): 241-251. https://doi.org/10.1177/0306419017743214
[21] Cengel, Yunus, and John Cimbala. "Fluid Mechanics Fundamentals and Applications." *McGraw Hill,* (2013).
[22] Al Horr, Yousef, Bourhan Tashtoush, Nelson Chilengwe, and Mohamed Musthafa. "Operational mode optimization of indirect evaporative cooling in hot climates." *Case Studies in Thermal Engineering* 18 (2020): 100574. https://doi.org/10.1016/j.csite.2019.100574