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A Case Study on the Use of Harvested Rainwater to Operate Passive Cooling Water Wall (PCWW) for SEGi University Tower

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Abstract

This study investigates numerically the effect of passive cooling water wall on power consumption for air-conditioning. A case study was developed to determine the daily energy consumption of the air-conditioning on a particular day in order to estimate the monthly electricity consumption in the whole building. In conjunction with green technologies, a passive cooling system was developed named Passive Cooling Water Wall (PCWW) to cool the glass façade of the building and reduce heat from entering the interior of the building. The system was basically a running water wall located between two layers of glass façade. Its primary function is to take away the heat built up at the glass without blocking the light penetration. The case study was done in a classroom on the 14th floor in SEGi University Tower, as it has seven floors of glass façade which it suitable for the application of PCWW. This case study proves that the PCWW is able to reduce the total heat gain by as much as 7.84kWh (8 hours of working) in a classroom. By incorporating the PCWW system into the building, a total of 658.972kWh could be saved per month, which would translate into in Ringgit Malaysia (RM) 3352.26/ month. The system was seen to produce a drop of almost 1°C in indoor temperature compared to building setup without the PCWW and 24.6% in terms of power and cost savings. The PCWW is a simple and cost effective method to reduce building interior temperature and save energy. The study does not take into account the radiation heat due to the complexity of the simulation involved.

Keywords: Glass façade, Passive Cooling Water Wall (PCWW), numerical simulation, energy saving ;

1. Introduction

In a tropical country like Malaysia, the typical energy consumption pattern [1] is as given in Figure 1. The major part of the energy is used for air conditioning, hence there is need to look into passive

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Nomenclature	
A	Classroom indoor area, m^2
H	Convection heat transfer coefficient, $W/m^2\cdot K$
k	Thermal conductivity, $W/m^2\cdot K$
q	Heat flow, kW
R	Thermal resistance, K/W
E	Electrical energy, kWh
Subscripts	
Cond	Conduction
Conv	Convection
T	Total

cooling of buildings as a technique to reduce its cooling load such as solar control and reducing building interior heat gain [2]. By using this method of passive cooling, the equipment size and energy consumption in air-conditioned buildings can be minimised [3]. Passive cooling of buildings will use renewable sources to impede heat gain of buildings, which in this case being a water wall. Furthermore, glass panels are among the most important parts in a building that allow use of sunlight. However, it also leads to an increase in heat load entering the area. The case study is based in one of the classroom in the 14th floor at SEGi University Tower Building, Selangor, Malaysia. The location is suitable because the building utilised a great amount of glass panels to improve sunlight penetration into the building. SEGi University Tower Building consists of seven floors with glass façade from level 9th to level 15th. Each floor consists of 4 classrooms that have glass façade as one the walls. This setup is proved to be beneficial when electrical lightings during the day can be reduced significantly but however this setup also allow more heat to travel into the building through conduction and convection (radiation is accounted). As a result, the heat load in the building increases significantly causing the air-conditioner unit to perform at overload to maintain the interior temperature, thus increasing the overall electrical cost. As the solution to reduce heat entering the interior space of the classroom, the water wall is designed in such a way that water will flow constantly between two glass panels thus forming a water walls [4]. The function of the water walls is to carry away the heat built up on the glass panel [5, 6]. The water is drawn from a tank, which collects harvested rain water at the roof of the building. This setup will still definitely enable natural light penetration and reduce the amount of heat load in the building. This system is found to be capable of producing a drop of almost 1°C in the indoor temperature of the building compared to building setup without the water walls.

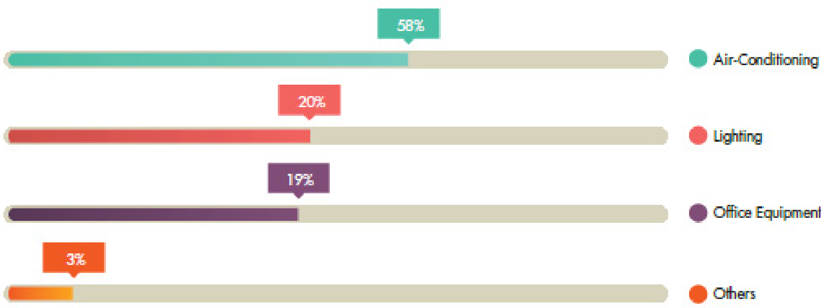


Figure 1: Typical electricity usage in office buildings in Malaysia [1]

2. Methodology

This work involves numerical simulation using a commercial CFD software ANSYS FLUENT and the methodology followed is illustrated below.

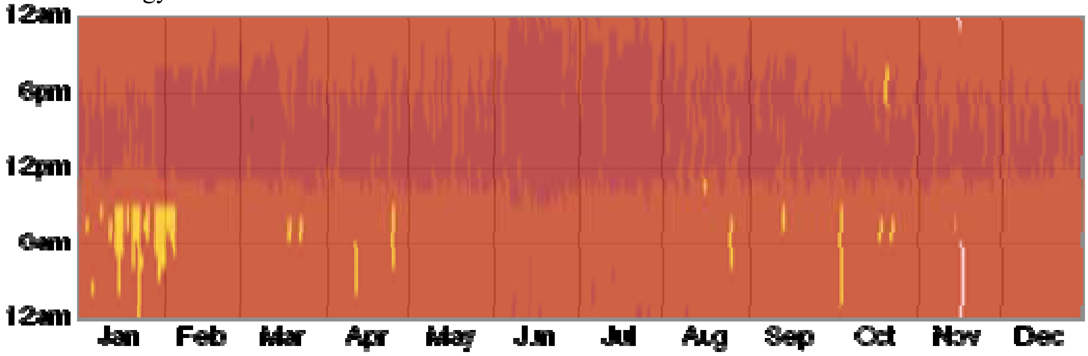


Figure 2: Hourly atmospheric Temperature Bands in Selangor plotted over every month of the year

2.1. Numerical Parameters and Procedures

To run the numerical simulations for both geometric configurations, a commercial software ANSYS FLUENT was used. Based on temperature variation data as in Figure.2 [7], a uniform temperature of 300K (27°C) which was the temperature at 8am was applied to the outer most layer of the glass façade to simulate the ambient temperature of the surrounding. The simulation is repeated with different input of average outdoor temperature such as 302K (9am), 304K (10am), 306K (11am), 308K (12pm), 311K (1pm), 310K (2pm) and 308K (3pm) based on hourly variation trend as shown in Figure.2 [7]. The outdoor temperature is recorded from 8am to 4pm is used for the calculations [8]. The average outdoor temperature was taken as the arithmetic mean of the temperature recorded over every hour. The four air-conditioning inlets were set to have air of velocity 0.1m/s at 286K (13°C) which is the set point temperature of the air-conditioner. The same setup and computational input values apply to both geometric conditions except for the input of water into the water cooling walls. Water temperature is set to room temperature at 300K (27°C). The result of the temperature contours in the interior are compared to illustrate the heat flow. The indoor temperature was obtained by averaging the temperature profile obtained from the simulation, which is then used in the calculation to determine the energy consumption of the air-conditioning.

Table 1: The material properties of the solid and fluid used in the simulation and calculations are listed below.

Material	Properties	Value
Concrete	Density, ρ	2300 kg/m^3
	Specific Heat, Cp	780 J/kg·K
	Thermal Conductivity, k	0.78 W/m·K
Glass	Density, ρ	2500 kg/m^3
	Specific Heat, Cp	750 J/kg·K
	Thermal Conductivity, k	1.4 W/m·K
Water	Density, ρ	998.2 kg/m^3
	Specific Heat, Cp	4182 J/kg·K
	Thermal Conductivity, k	0.556 W/m·K
	Convection Heat Transfer Coefficient, h	50W/m^2·K
Air	Density, ρ	1.225 kg/m^3
	Specific Heat, Cp	1006.43 J/kg·K
	Thermal Conductivity, k	0.0242 W/m·K
	Convection Heat Transfer Coefficient, h	5W/m^2·K

2.2. Geometric Parameters

Two classrooms were setup for this case study. The shape of both the classroom is in a shape of a quadrant with a floor area of 51.501m^2 and with a wall height of 4 m, the total volume of the classroom being 206m^3. The thickness of the wall of the classroom is at 95mm. The curved section of the classroom was covered by glass area with thickness of 60mm for the classroom without the water walls installed in between. As for the classroom setup with the water walls in between the glass, the thickness of the glass for the setup with water walls is 20mm each. The water wall is located in between the two 20mm glass façade. There are 4 cold air inlets located on the ceiling of the classroom. The size of the air-conditioning ducts are 600mm ×600mm.The dimensions for both the classroom are identical except for the design of the glass façade. In fact, the overall glass thickness of both the classrooms was kept identical at 60mm. Both setups will also have a door with size of 860mm × 2110mm as the outlet for air to escape from the room as shown in Figure 3.

2.3. Governing Equations

In this study, the focus is to compare the amount of solar heat irradiation entering the room between glass façade with or without water wall. The following assumptions were made for the calculations:

1. The heat transfer is in steady state and three-dimensional.
2. The other heat load such as Internal Load, Transmission load, and Infiltration Load are assumed to be constant thus not being included into calculation.
3. The properties of the fluid are independent of temperature.
4. The external concrete walls to the surroundings were assumed to be insulated except the glass facade where a constant heat flux is applied simulating heat generation.

With the above assumptions, we can use the following governing equations for the heat transfer calculation [9]:

Convection Resistance:

$$R_{Conv} = \frac{1}{hA} \ldots\ldots\ldots\ldots (1)$$

Conduction Resistance:

$$R_{Cond} = \frac{\Delta x}{kA} \ldots\ldots\ldots\ldots (2)$$

Total Thermal Resistance:

$$R_T = R_1 + R_2 + R_3 \ \ldots\ldots (3)$$

Heat Gain:

$$q = \frac{1}{R_T}(T_1 - T_2) \ldots\ldots\ldots (4)$$

Tonnage Refrigerant: (1 TR= 3.517 kW)

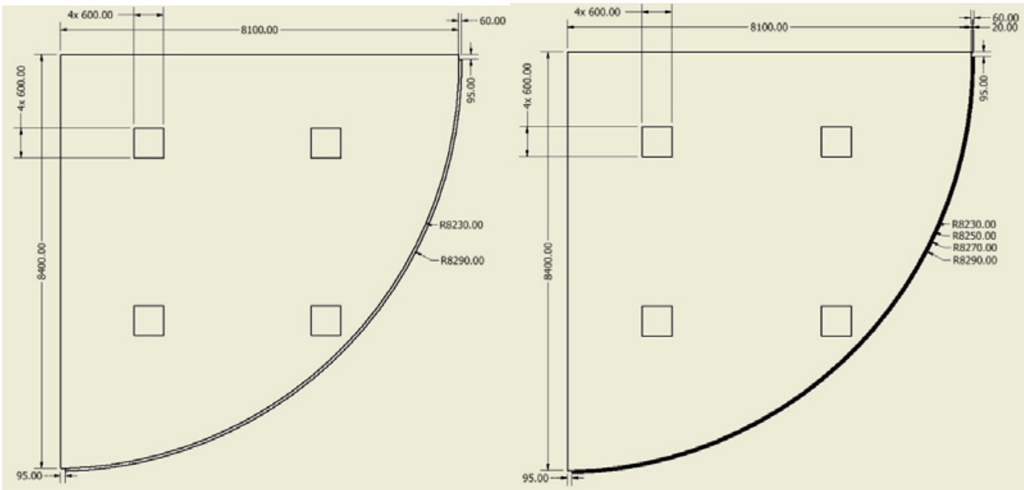
$$TR = \frac{\text{Heat Loss, } q}{3.517} \ldots\ldots\ldots\ldots (5)$$

Total Energy consumption:

E=Tonnage Refrigeration, TR× Operating Duration, h…….(6)

Electricity Cost:

Cost in RM=Total Monthly Energy Consumption, kWh × Current Electricity Tariff, RM/kWh…(7)



(a) (b)

Figure 3: View from the top showing the air-conditioning inlet and the thickness of the (a) glass without PCWW and (b) glass with PCWW.

3. Results And Discussion

3.1. Numerical Results Comparison

The airflow from the air-conditioning is set as a constant, the cold air flows in at 13°C to cool the both classroom in the simulation setup. The outdoor temperature for both classrooms was same in the simulation setup. The outdoor temperature obtained is the average temperature for the particular hour of measurement [10]. A straight line projected on to the temperature contour diagram from the simulation as shown in Figure 4, was used to obtain the average temperature of the interior. Total thermal resistance was calculated by adding the conduction and convection resistances of the elements such as glass, water, and air. The higher the thermal resistance value the better the heat insulation. The total heat energy removed is the ratio of the temperature difference to total thermal resistance, usually represent in Tonnage Refrigeration (TR) [11]. The total energy consumed was obtained by multiplying the Tonnage Refrigerant with the operating duration of the air-conditioning system. In order to obtain the overall electrical energy of the whole building, the energy consumed by one classroom is multiplied 28 as there were four classrooms in each level and overall seven levels. The current commercial electricity tariff in Malaysia imposed by Tenaga Nasional Berhad (Main service provider in Malaysia) is 0.435 RM/kWh for the first 200kWh and 0.509 RM /kWh for 201kWh onwards [12]. The total monthly cost was calculated by multiplying the total electricity consumption of the whole building with the monthly electrical tariff.

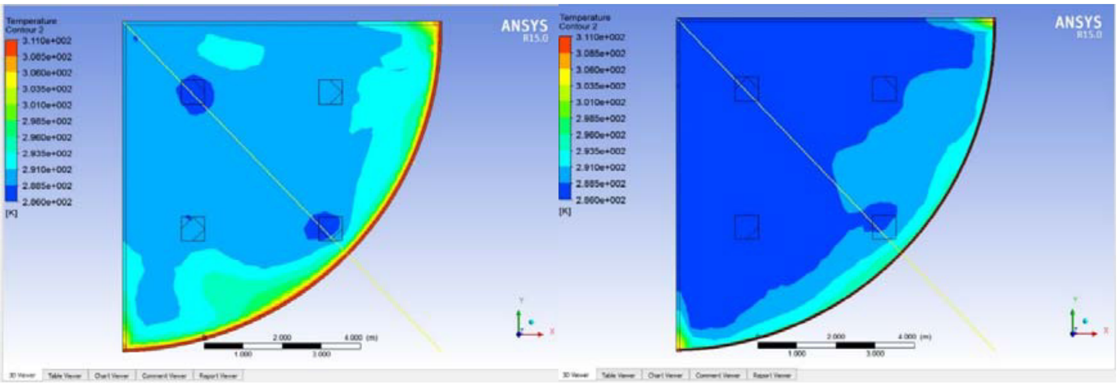
The table 2, appendix A, shows that the overall electrical energy consumption of the air-conditioner without PCWW setup operating for 8 hours. The energy consumption will be greater when the difference between the outdoor and indoor temperature is greater [8]. This is because the amount of heat enter into the indoor is equal to the cooling load of the air-conditioning system. The highest indoor temperature of 289.5K (16°C) is at estimated at 1pm while the lowest indoor temperature of 287.8K (14.8°C) is at 8 am. The classroom without PCWW has a lower total thermal resistance because it has less thermal insulation compare to the setup with PCWW. The calculation of the thermal resistance for the setup without PCWW is [8] is as given below:

$$R_T = R_{Glass} + R_{air} = \frac{\Delta x}{kA} + \frac{1}{hA} \ldots\ldots (8)$$

The table 3, appendix A, shows that the overall electrical energy consumption of the air-conditioner in the class room with PCWW setup operating for 8 hours. The highest indoor temperature is during 1pm at 288.7K (15.7°C) while the lowest indoor temperature is during 8am at 287.5K (14.5°C). The classroom with PCWW has a higher total amount of thermal resistance because it has more thermal insulation compare to the setup with PCWW. The calculation of the thermal resistance for the setup with PCWW is [8] is as given below:

$$R_T = R_{Glass} + R_{Water} + R_{Water,convec} + R_{Glass} + R_{air} \ldots\ldots (9)$$

$$R_T = \frac{\Delta x}{kA} + \frac{\Delta x}{kA} + \frac{1}{hA} + \frac{\Delta x}{kA} + \frac{1}{hA} \ldots (10)$$



(a) (b)

Figure 4: (a) Temperature Distribution without PCWW; (b) Figure 4: Temperature Distribution with PCWW

The average room temperature is 289.5K along the projected line in room without PCWW. The obtained average temperature was used to calculate the heat entering the room. The temperature distribution of the classroom without PCWW, Figure 4(a), shows that the cool air from the air-conditioning system is unable to cool the efficiently, especially near the glass wall shown in light blue and greenish shades. The average room temperature is 288.7K along the projected line in room with PCWW. The temperature distributions of the classroom with PCWW shows that the cooling was efficient with most of the contour in dark blue, Figure 4(b).

The test for the passive cooling system is only a simulation studies with test cells with similar dimensions of the real classrooms. The test cells were without glazed windows and no internal heat source. Thus, in a fully occupied building performance as a passive cooling system yet to predicted. Still, the performance of the system demonstrates its potential under the climatic conditions adopted during the work.

4. Conclusions

As a passive cooling method to reduce the surface temperature of the glass façade and to reduce heat load penetrating into the interior of SEGi Tower Building, Passive Cooling Water Wall (PCWW) was tested by simulation. The amount of heat load entering the interior of the classroom in SEGi Tower was seen to reduce significantly based on the comparison of results achieved in the simulations with and without PCWW. The energy savings on using PCWW was confirmed by a comparison case study between classrooms with and without PCWW system installed. The cooling load is equal to the heat gained and this case study proves that the PCWW was able to reduce the total heat gain as much as 7.84kW daily in a classroom. Thus, improving cooling by the air-conditioning system and reduce electricity consumption. Furthermore, the simulation results can be visualised better by colour image of the temperature contour diagram to understand variation of cooling level at the targeted location of the classroom. The PCWW was able to reduce on an average 1872.611 kWh monthly, which would translate to RM 953.16 of monthly savings. The energy savings on using PCWW further enhance its appeal and potential in green buildings where energy savings is the main priority.

In conclusion, the simulation model of Passive Cooling Water Wall (PCWW) presented in this paper is capable of providing quantitative prediction of the average temperature of the building interior with different insulation and outdoor temperature. The PCWW system is an effective and cost saving method to improve thermal comfort and energy savings.

Acknowledgements

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Biography

Vinod Kumar Venkiteswaran was born in Kochi, India on 1st November 1979 .He obtained his Bachelor's degree in Mechanical Engineering from Calicut University in 20011, Master's Degree in Energy systems engineering from Visvesvaraya Technological University in 2007 and PhD from Universiti Teknologi PETRONAS in 2104 .

He has done research works in the area of Alternative energy especially in Biodiesel and solar energy. He has publications in journals such as IJSE(2009) JAS (2012), IJENS (2013) etc. and has presented more than 20 papers in various international conferences.

Presently working as Assistant Professor in Heriot Watt University Malaysia Campus, he is a Certified Energy Manager and has research interests in Alternate fuels in IC engines, Biofuels, Renewable & Alternative energy, Energy management & Conservation, Green Buildings and Swirling Fluidized Bed.

Appendix.A

Table 2: Results of classroom without Passive Cooling Water Wall (PCWW) selective

WITH PASSIVE COOLING WATER WALL (PCWW)								
Time	8am to 9am	9am to 10am	10am to 11am	11am to 12pm	12pm to 1pm	1pm to 2pm	2pm to 3pm	3pm to 4pm
Outdoor Temperature,T1 (K)	300.00	302.00	304.00	306.00	308.00	311.00	310.00	308.00
Indoor Temperature, T2 (K)	287.5	287.7	288	288.2	288.4	288.7	288.6	288.4
Difference, T1 - T2 (K)	12.5	14.3	16	17.8	19.6	22.3	21.4	19.6
R Total Resistance, K/W	0.005962	0.005962	0.005962	0.005962	0.005962	0.005962	0.005962	0.005962
Heat Gain without PCWW, W	2096.61188	2398.52399	2683.6632	2985.57531	3287.48742	3740.35559	3589.39953	3287.48742
Heat Gain with PCWW, kW	2.097	2.399	2.684	2.986	3.287	3.740	3.589	3.287
1 TR = 3.517 kW	3.517	3.517	3.517	3.517	3.517	3.517	3.517	3.517
Tonnage Refrigerant, TR	0.596	0.682	0.763	0.849	0.935	1.064	1.021	0.935
Duration, hr	1	1	1	1	1	1	1	1
Hourly Energy Consumed with PCWW, kWh	2.097	2.399	2.684	2.986	3.287	3.740	3.589	3.287
Daily Energy Consumed, kWh	24.069							
Daily Each Floor Energy Consumed, kWh	96.276							
Daily Whole Building Energy Consumed, kWh	673.935							
Monthly Whole Building Energy Consumed, kWh	20218.048							
Electricity Cost per Unit, RM	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.509
Hourly Electricity Cost with PCWW, RM	1.07	1.22	1.37	1.52	1.67	1.90	1.83	1.67
Daily Electricity Cost, RM	12.25							
Daily Each Floor Electricity Cost, RM	49.005							
Daily Whole Building Electricity Cost, RM	343.033							
Monthly Electricity bill of Whole Building, RM	10290.99							

Table 3: Results of classroom with Passive Cooling Water Wall (PCWW)

WITHOUT PASSIVE COOLING WATER WALL (PCWW)								
Time	8am to 9am	9am to 10am	10am to 11am	11am to 12pm	12pm to 1pm	1pm to 2pm	2pm to 3pm	3pm to 4pm
Outdoor Temperature, T1 (K)	300.0	302.0	304.0	306.0	308.0	311.0	310.0	308.0
Indoor Temperature, T2 (K)	287.8	288.1	288.4	288.6	288.9	289.5	289.1	288.9
Difference, T1 - T2 (K)	12.2	13.9	15.6	17.4	19.1	21.5	20.9	19.1
R Total Resistance, K/W	0.004378	0.004378	0.004378	0.004378	0.004378	0.004378	0.004378	0.004378
Heat Gain without PCWW, W	2786.66058	3174.96574	3563.2709	3974.41754	4362.7227	4910.91823	4773.86935	4362.7227
Heat Gain without PCWW, kW	2.787	3.175	3.563	3.974	4.363	4.911	4.774	4.363
1 TR = 3.517 kW	3.517	3.517	3.517	3.517	3.517	3.517	3.517	3.517
Tonnage Refrigerant, TR	0.792	0.903	1.013	1.130	1.240	1.396	1.357	1.240
Duration, hr	1	1	1	1	1	1	1	1
Hourly Energy Consumed without PCWW, kWh	2.787	3.175	3.563	3.974	4.363	4.911	4.774	4.363
Daily Energy Consumed, kWh	31.910							
Daily Each Floor Energy Consumed, kWh	127.638							
Daily Whole Building Energy Consumed, kWh	893.467							
Monthly Whole Building Energy Consumed, kWh	26804.020							
Electricity Cost per Unit, RM	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.509
Hourly Electricity Cost without PCWW, RM	1.42	1.62	1.81	2.02	2.22	2.50	2.43	2.22
Daily Electricity Cost, RM	16.24							
Daily Each Floor Electricity Cost, RM	64.97							
Daily Whole Building Electricity Cost, RM	454.77							
Monthly Whole Building Electricity Cost, RM	13643.25							