Indirect evaporative cooling for a high school classroom in humid subtropical climate, China

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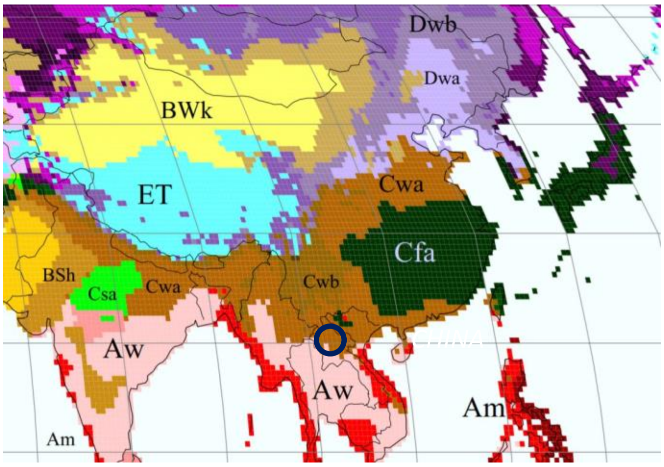
Abstract

Evaporative cooling to a building is aimed to achieve building temperature reduction by undertaking the water evaporation process from building envelope. That is, the surface liquid changes its state to a vapor by receiving heat. During this latent heat transfer process, water absorbed relatively amount of heat would be moved away via evaporates and result in colder conditions. (E. Latif, 2019) This paper is focusing a high school indirect evaporative cooing process via testing local evaporation heat loss.

Introduction

1. Climate & Local temperature

In my hometown Yunnan province, China. The climatic conditions are different among cities. The objective area in this paper is Mengla city where it is located the most southwest of China and surrounded by Vietnam, Laos, and Burma. The city has its latitude and longitude 21.48° north and 101.57° East respectively, and it is classified *Cwa* in Köppen climate classification (2006): a dry-winter humid subtropical climate (*Figure 1*)



: Mengla city, Yunnan province, China

Cwa: C - warm temperate, *w* – winter dry, *a* - hot summer.

[*Figure 1. (Source: http://koeppen-geiger.vu-wien.ac.at/shifts.htm)*]

Weather data in this paper mainly adopted from

a. 'Weather Spark' as its data result by the nearest weather station where it is 200km away from Mengla city and combine with NASA's MERRA-2 satellite-era reanalysis. Also, it provides specific environmental parameters like Clouds, Precipitation, and Rainfall, which is reliable to use.
b. 'EnergyPlus – weather data (Climate Consult stimulation)' provides specific data in Mengla which help with calculation and further analysis.

- *Dry-bulb temperature variation*

In Mengla, the hot season lasts for 3 months, from March to June, with an average daily high temperature above 31°C. The hottest day of the year is in the middle of the April, with an average high of 31.3°C and low of 18.1°C. Contrustly, the cool season only lasts for 2.3 months, from November to January, with an average daily high temperature below 26°C. The coldest day of the year is in January, with an average low of 11.4°C and high of 24.8°C. (*Figure 2.1, 2.2*)

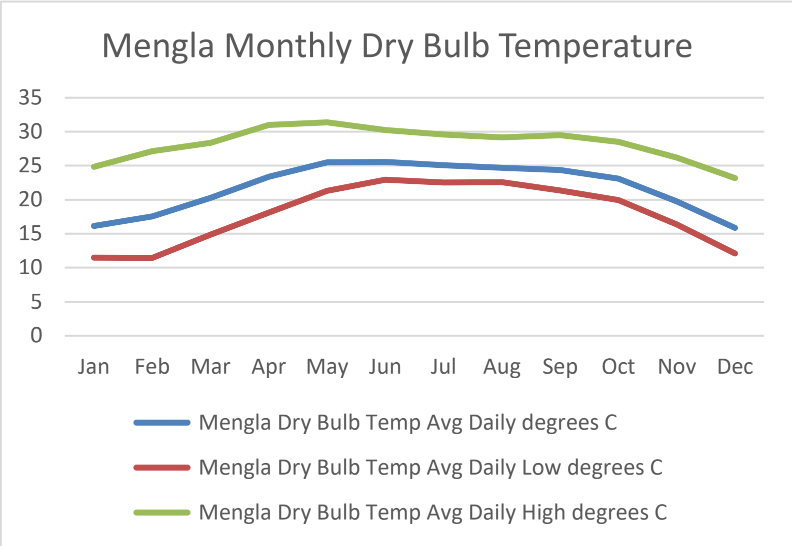


Figure 2.1 [Source: EnergyPlus Weather Data Download - Yunnan Mengla 569690 (CSWD)]

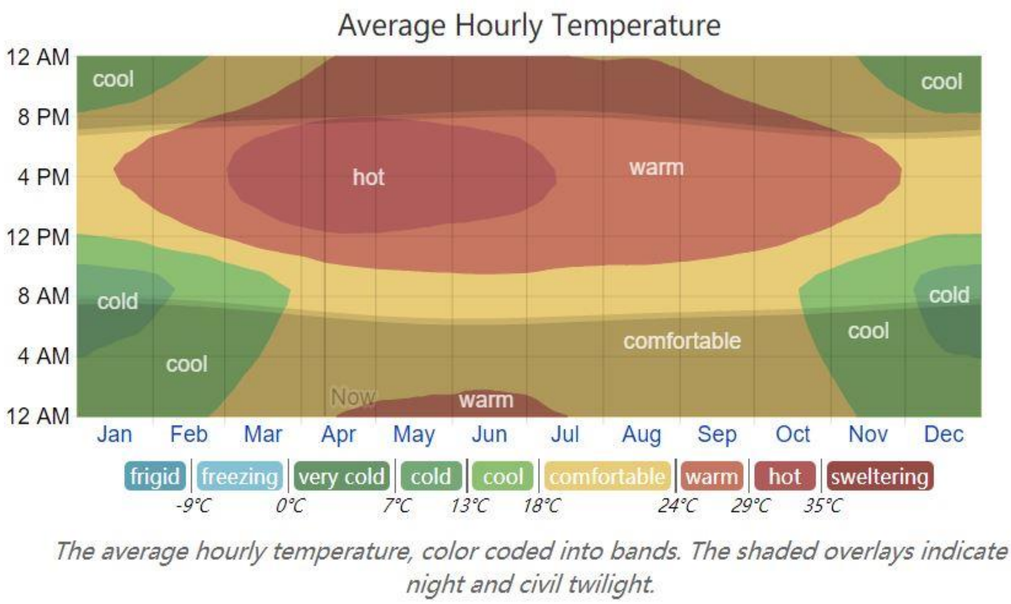


Figure 2.2 [Source: Weather Spark - https://weatherspark.com/y/113967/Average-Weather-in-Mengla-China-Year-Round]

As figure 2.2 demonstrated above, daily temperature from 11 am to 11 pm during the period between February and November revealed high temperature which out of the comfortable range. Specifically, from 1 pm to 7 pm in March and April, Mengla local experiences hot conditions. Therefore, passive evaporation strategy in this paper would mainly focus on the midday until evening in Mengla.

- *Precipitation and Relative Humidity (RH)*

As figure 3.1 below illustrates that the wetter season lasts 4.5 months, from May to September with a greater than 34% chance of a given day being a wet day. The chance of a wet day peaks at 64% on July 18. The drier season lasts 7.5 months, from September 21 to May 6. The red geometry represents the hot season duration in Mengla.

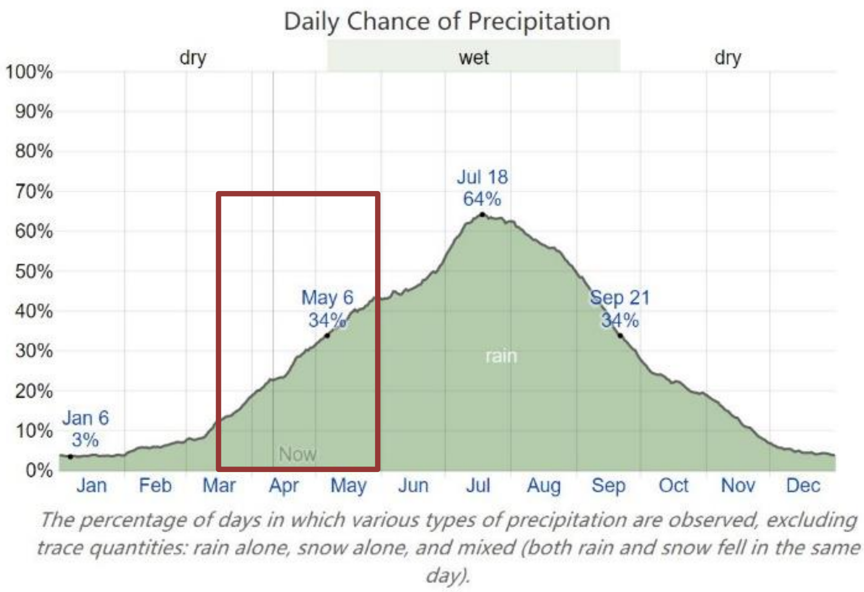


Figure 3.1

[Source: Weather Spark - https://weatherspark.com/y/113967/Average-Weather-in-Mengla-China-Year-Round]

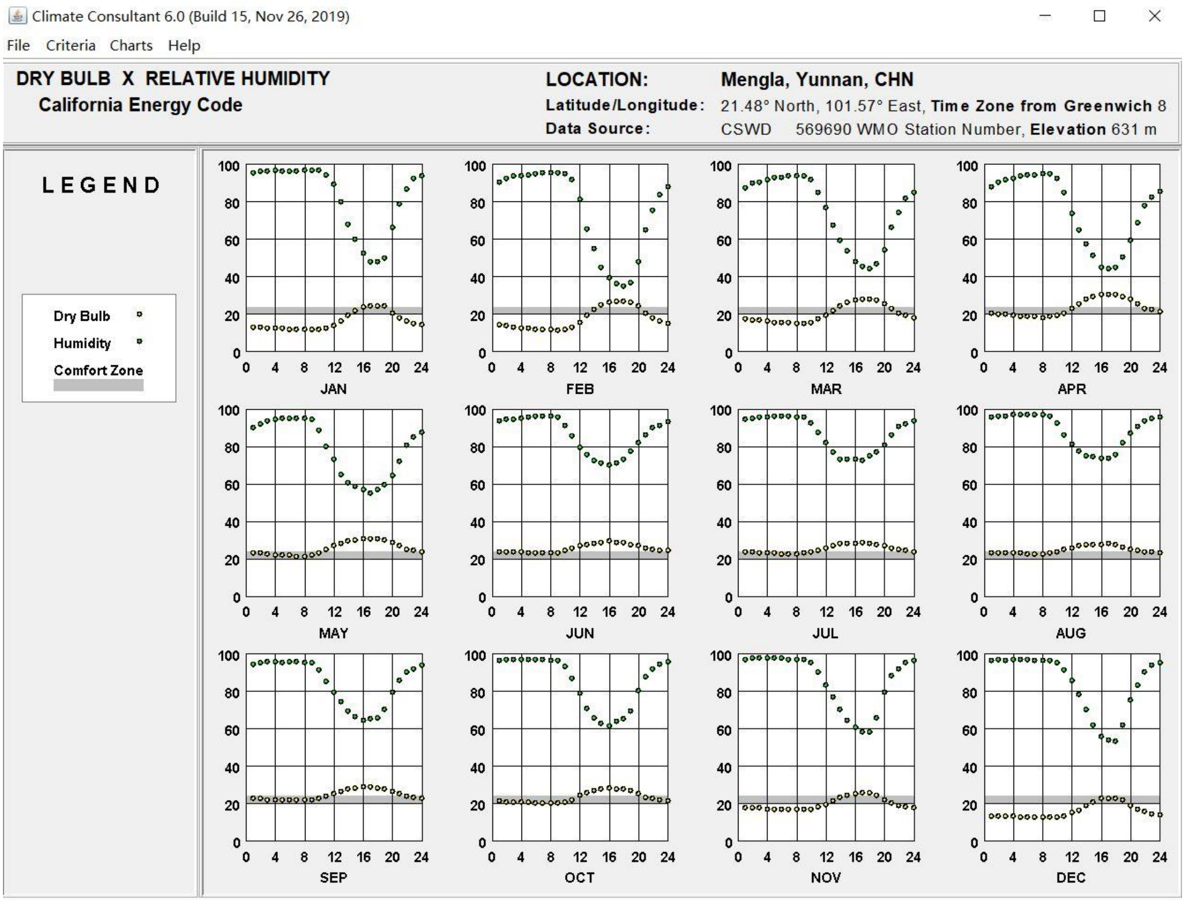


Figure 3.2 Relationship between Dry bulb temperature and Relative Humidity

[Source: EnergyPlus Weather Data Download - Yunnan Mengla 569690 (CSWD)]

Figure 3.2 shows a typical 24-hour period (day) for each month (24 hours) where during typical 8 hours of each day, every month, Relative humidity (RH)remains low. Within these 8 hours, students experiencing high temperatures, which shows out of comfort zone each month in the chart above. Therefore, the evaporative cooling strategy suggests applying in a month that in this 8 hours have a high temperature, and RH reduction, such as the period between March to May. In contrast, the period between July and August is less suggested as it has less RH reduction, the air has more water content, to begin with, and therefore can hold less evaporating water. (A. Bhatia, B.E., 2012) As an underdeveloped city, most buildings in Mengla have poor thermal insulation performance and causing interior hot. Thus, a passive cooling strategy is going to apply on these low RH and high-temperature days in summer.

2. Adopted Passive Strategy – Indirect evaporative cooling

Passive evaporative cooling technology of building surface is a kind of low cost, high efficiency, harmless and energy-saving technology (JP. Liu…, 2016). The general vision for proposing strategy is to focus on building outer skin temperature reduction via the evaporation system. Previous climate parameter research demonstrated Mengla located in a subtropical area. Thus, by utilizing the local Rh and evaporation to cool the building envelope so to achieve building temperature reduction without allowing external and internal airstreams to mix directly. By analyzing the heat loss during IDC to suggest a parameter of cooling pond regarding efficient IDC system.

3. Subjective building occupants

Previous parameters stated the hottest duration happens from midday until 11 pm. Regarding space utilization, the subjective building is focused on a high school in Mengla, where students aged from 16 – 18, and have most daytime in the classroom as well as evening revision purposes. Improving indoor passive cooling is necessary.

Mengla high schools mainly occupied by 595 – 580 students in three incrementally grades. Each grade has 11-unit classes, which result in one classroom containing approximately 53 students. There is 1 class teacher allocated for each class, so the result in total people within a classroom is 54 people. During summer, each student has 0.5 clo (light summer clothing) (E. Latif, 2019), whereas 1.0 clo (typical business suit) in winter.

The main activity while students occupying the classroom study [metabolic heat gains 70 W/m2 (Seated work)], and short breaks and dinning breaks [metabolic heat gains 93 W/m2 (Mobile work)]. (E. Latif, 2019) Therefore, during the break time, more metabolic heat gain produced in hot summer might reveal the importance of applying the passive cooling strategy.

4. Building and room

Objective building chose Nanla High School in Mengla City and select one classroom within a teaching building to proceed the analysis. (*Figure 4.1, 4.2*)

Figure 4.1 (Nanla High school, google satellite picture) *Figure 4.2 (Teaching building perspective,* https://www.ynml.gov.cn/*)*

The classroom located on the ground floor and its basic parameter as follow (*Figure 5*):

a. Leghth - 9m,
b. Width – 6.6m,
c. Window length - 2.75m,
d. Room height - 3m,
e. Window height - 1.75m. (MOHURD, 2011).
The floor & roof area - 59.4m^2
Volume of the room - 178.2m^3.

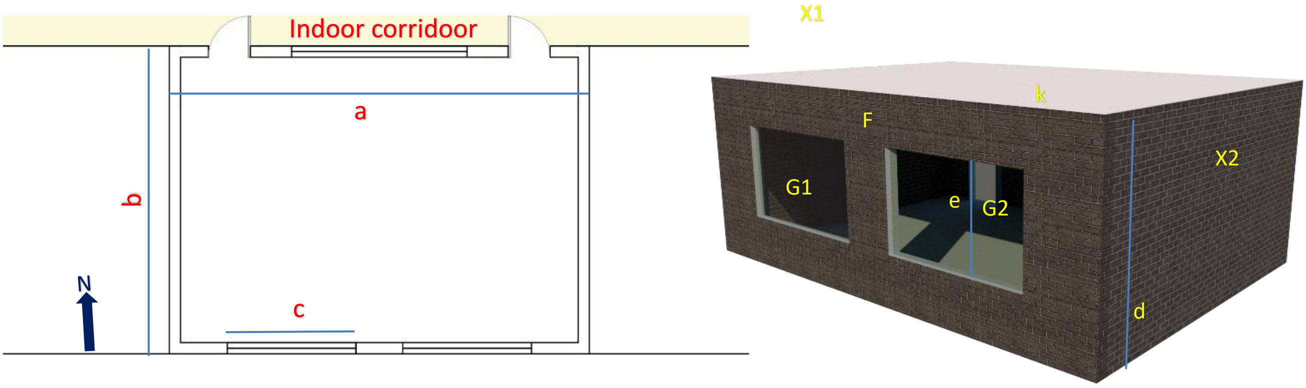


Figure 5 Classroom spatial model stimulation and parameters

The study is mainly focused on energy performance regarding passive measures to improve the building envelope. Side walls X1 and X2 are connected with other class room. Wall F (27m^2) surface area with window G1 and G2 (surface area$_{each}$ is 4.81m^2)and roof K are mainly focused regarding the proposed strategy as they are directly contact with the outdoor. The relative external wall parameters as following:
Total window area to the external wall ratio: 35.6%
Insulated wall: Brick outer leaf, 50mm clear cavity, 100mm block inner leaf using 10mm conventional mortar, plasterboard dot & dab internal finish. $U_{brick\ wall}$ = 0.28W/m^{2}k

Literature review – Evaporative Passive Cooling Strategy

- *Determine adopt stratagy*

The Evaporative cooling system is classified as direct (DEC) and indirect (IEC), in which direct cooling is water directly evaporates into the airstream, thus reducing the air's dry-bulb temperature while humidifying the air. It often applied in a hot – arid region by storing the water and supply into a water-soaked pad or use a wetted pad. Thus, hot air pass through the wetted pad is filtered cold and humidified. (A. Bhatia, B.E., 2012) Alternatively, indirect cooling is suitable for hot humid climate regarding high wet bulb temperature of the ambient, as humidified cooling air is unnecessary. (*Figure 6*)

Passive IEC system is based on use the direct evaporative cooling of air (secondary air) and water, through the heat exchanger (i.e. roof, wall) and ambient air to make heat exchange, then to achieve fresh air (primary air) cooling. Since the indoor air does not directly contact with water, its moisture content remains unchanged. (O. Amer, R. Boukhanouf, and H. Ibrahim, 2015) (*Figure 7*)

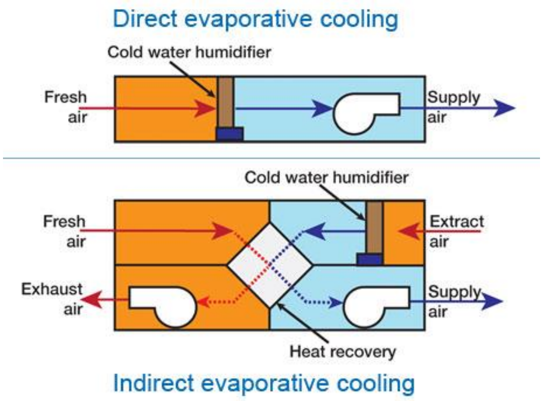


Figure 6 ,7DEC & IEC working principle

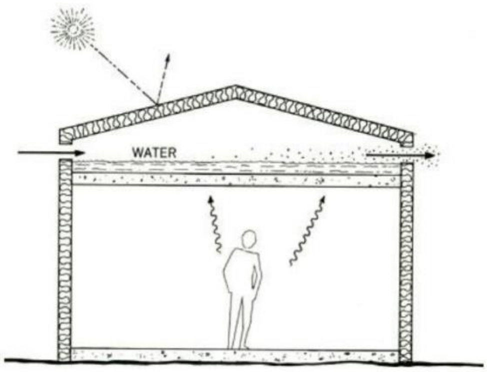
(Source: https://www.condairgroup.com/Energy-optimization/cool-humidification-evaporative-cooling-humidifier)

To summerize, Mengla city is hot and humid, indrect passive cooling can be applied in hot season as humidified air is not required during the cooling process.

- *Case study of IEC system*

Roofpond – Heat sink

Roofpond is one of the IEC strategies in which a sink/pool is storing the water above the roof building layer. As the figure shows below, a water layer is allocated between the roof structure and indoor ceiling structure. Two openings are designed on two sides where allow ambient airflow through. Ambient inlet hot air causes the water temperature to decrease via evaporation, so the indoor ceiling is cooled down.(Lechner, 2015) Implement this strategy to the objective classroom in Mengla can use local precipitation to collect and storing rainwater to the pond.



(*Figure 8*)

Beside the IEC definition, this method can be seen as by applying evaporation and decrease the temperature on structure external surface without import cold and humid air to the interior. (*Figure 8*)

Methodology – calculation of heat loss during evaporation

Preparation:

1. Evaporation heat loss –

1g of water evaporated extracts ~0.6 Whr heat from ambient air (V. Stevenson, 2019)

2. Water content need to evaporates:

Assume flat roof have a parapet wall height 600mm (HM GOV, 2010), no drainage so the roof is treated as a pool with its volume of:

$$0.6\text{m} \times 59.4\text{m}^2 = 35.64\text{m}^3$$

Note: $59.4\text{m}^2 = 639.38\ \text{ft}^2$ is roof area also use as evaporative surface area in this case

Rain falls with its monthly average local precipitation can used as parameter of a different water storage capacity on the roof in each month as following:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average precipitation (m) (Weather Spark)	0.009	0.017	0.028	0.06	0.102	0.155	0.201	0.188	0.116	0.061	0.034	0.016
Roof pond water storage (Gallon)	117.6	222.12	365.85	783.97	799.59	2025.26	2626.21	2456.40	1515.59	796.95	444.34	208.97

3. Average monthly wind speed (mph), average daily high dry bulb temperature (° F) and water's vapor pressure (mmHG) at Ambient Temperature

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W	2.42	2.61	2.73	2.49	2.3	2.11	2.0	1.8	1.93	2.11	2.18	2.3
T	76.7	80.8	83.1	87.8	88.5	86.5	85.2	84.5	85.04	83.3	79.1	73.7
P	18.773	26.168	26.168	26.168	26.168	26.168	26.168	26.168	26.168	26.168	18.773	18.773

water's vapor pressure is referring the chart below:

Temperature	Density	Specific Weight	Dynamic Viscosity	Kinematic Viscosity	Vapor Pressure	Vapor Pressure
°F	slugs/ft^3	lbf/ft^3	lbf-s/ft^2	ft^2/s	psia	mmHG
40	1.94	62.43	3.23E-05	1.66E-05	0.122	6.309
50	1.94	62.40	2.73E-05	1.41E-05	0.178	9.205
60	1.94	62.37	2.36E-05	1.22E-05	0.256	13.239
70	1.94	62.30	2.05E-05	1.06E-05	0.363	18.773
80	1.93	62.22	1.80E-05	9.30E-06	0.506	26.168
100	1.93	62.00	1.42E-05	7.39E-06	0.949	49.077
120	1.92	61.72	1.17E-05	6.09E-06	1.69	87.398
140	1.91	61.38	9.81E-06	5.14E-06	2.89	149.456
160	1.90	61.00	8.38E-06	4.42E-06	4.74	245.129
180	1.88	60.58	7.26E-06	3.85E-06	7.51	388.379
200	1.87	60.12	6.37E-06	3.41E-06	11.53	596.273
212	1.86	59.83	5.93E-06	3.19E-06	14.70	760.209

(*Figure 9*)

Calculating heat loss during evaporation:

$$E = [7.4PA\,(0.447W)^{0.78}]/(T + 459.67) \qquad (1)$$

(US EPA Evaporation Equation) [9]

E = Evaporation Rate (Gallons/Day) – 1 Gallon/day = 0.12kg/hr = 120g/hr

A = Pool Surface Area (ft^2)

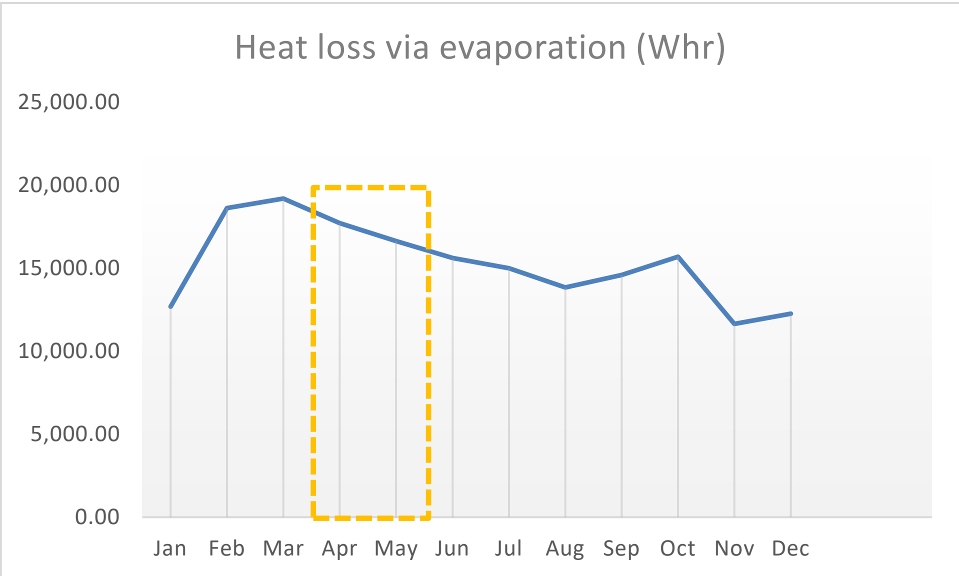
W = Wind Speed Above Pool (mph)

P = Water's Vapor Pressure (mmHG) at Ambient Temperature

T = Temperature (°F)

Result:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
E	176.1	258.4	266.4	245.9	230.8	216.6	208.2	192.0	202.6	217.9	161.6	170.2
E (g/hr)	21,132	31,008	31,968	29,508	27,696	25,992	24,984	23,040	24,312	26,148	19,392	20,424
Heat loss (Whr)	12,679.2	18,604.8	19,180.8	17,704.8	16,617.6	15,595.2	14,990.4	13,824	14,587.2	15,688.8	11,635.2	12,254.4



(*table 9*)

Discussion:

Table 9 above has shown the performance of evaporative cooling （EPC）regarding heat loss by evaporation. It can see from Feb to Mar the heat loss is better than another period within a year. Dry bulb temperature (DBT) in the RH x DBT diagram before demonstrated there is no cooling need from Nov to Jan as it DBT remains close to the comfort zone. In contrast, other month’s temperature remains high during the specific 8 hours in each day. The graph above shows the heat loss reduction during April and Aug. As previously stated, June, July, and Aug have a lower cut of RH, evaporative cooling might not work well significantly. Therefore, the strategy considering the improvement between April and May (see yellow geometry). I noticed during the calculation above; evaporative water surface area has a tremendous value, which relates to evaporating performance. I suggest enlarging the surface area of the cooling pond, perhaps would promote EPC performance. However, as the study focused on the typical afternoon cooling for the classroom, the strategy might consider saving water to prevent evaporation in the morning by storing water from natural precipitation and spray on roof or wall in the afternoon. Wind speed is also the factor that slows down the EPC in April and May; design to accelerating the natural wind speed can be useful. Roof storing water can spray on the building façade to allow liquid to contact the air on the wall surface best possible to accelerate the cooling.

Conclusion

During this study, I have studied indirect cooling via various methods from building façade and rooms. I am trying to seek all the possible evaporative cooling process from building facade to avoid humidified air import to the interior. The methodology of testing is limited but gives the vision, as the goal is to calculate the classroom afternoon 8 hours' desired heat loss in April and May. So, to realize the size of the cooling pond it needs. However, wetted material is a further study where its water adorability, and the surface texture can maximize the EPC. To achieve passive evaporative cooling by widely applying wall watering technology.

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