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Comparative of influences of light intensity and wind velocity on the evaporation rate of saturated soil surface

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Abstract

The evaporation rate of saturated soil was investigated. The evaporation pan (Class A) was setup in a laboratory-scale experiments. The effects of varying light intensity from 0 to 1,000 W·m^{-2} and wind velocity from 0.53 to 1.82 m·s^{-1} on the evaporation rate were investigated. It was found that light intensity plays an important role in the evaporation rate. The evaporation rate increased from 6.08x10^{-5} to 11.6x10^{-5} m·min^{-1} when the light intensity increased from 0 to 1,000 W·m^{-2} because the convective mass transfer coefficients were increased due to the decrease in vapor pressure difference between the water surface and air, while evaporation increased from 9.93x10^{-5} to 13.20x10^{-5} m·min^{-1} when the wind velocity increased from 0.53 to 1.82 m·s^{-1} because the convective mass transfer coefficients were increased due to the high temperature difference between the air and water surface. On the other hand, when light intensity decreased 0.95% from 1,000 to 990.52 W·m^{-2} caused the evaporation rate to decrease 0.0523x10^{-5} m·min^{-1} from 11.66x10^{-5} to 11.55x10^{-5} m·min^{-1} or 0.45%. While wind velocity decreased 0.25% from 1.82 to 1.81 m·s^{-1}, the evaporation rate decreased 0.0117x10^{-5} m·min^{-1} from 13.20x10^{-5} to 13.19x10^{-5} m·min^{-1} or 0.089%. When compare to the actual data during the years 2008 to 2017, light intensity decreased 0.95% from 423.66 to 419.68 W·m^{-2} caused the evaporation rate to decrease 0.0187 mm from 4.351 to 4.332 mm or 0.432%. While the wind velocity decreased 0.25% from 6.041 to 6.026 m·s^{-1} caused the evaporation rate to decrease 0.001 mm from 4.351 to 4.350 mm or 0.023%. Thus, light intensity has influence on the evaporation rate by accounting for 95.01% of decrease in the evaporation rate and the wind velocity has influence on the evaporation rate by accounting for 4.99% of decrease in the evaporation rate.

Keywords: wind velocity, light intensity, evaporation rate, saturated soils

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1. Introduction

Climate change from global warming causes average temperature of the Earth's air to rise; especially, near the surface of earth and ocean. The model of climate projection shows the world average temperature would increase from 1.1 K to 6.4 K between 2001 to 2100 [1]. In Thailand, the frequency and severity of natural disasters increase substantially as a result from global warming. Average annual temperature in the country is higher than normal level of 1 K (the highest in 56 years) [2]. Thailand Environment Institute (TEI) identifies that the trend of climate change will cause desertification which will reduce the total amount of water by about 5 to 10 percent [3]. These changes will have a direct impact on the hydrological cycle and an indirect impact on the quality of water and the ground. These changes of water content also cause the soil temperature to rise and affects the evaporation of soil water and cultivation. When assessing economic impact, agricultural production decrease by 50% of the average yield in each sector. The financial cost of the impact is 3,829.01 million baht (Northern 2,152.48 million baht, Northeast 890.94 million baht, Eastern 294.28 million baht, Central 253.43 million baht, and Western 237.89 million baht) [3].

Desertification has a potential to be more severe and attracted widespread attention in Thailand [4 - 6]. The evaporation loss is considered to be an important mechanism controlling hydrological cycle which affects water storage efficiency and the amount of water in the arid areas. The water loss to the atmosphere is a combination of evaporation from soil and wet vegetative surfaces, and transpiration from the canopy and understory layer which the estimation of the evaporation rate has received much attention recently but it is difficult to measure directly, so many indirect approaches have been used to estimate evaporation rates. For example, the Penman equation, the evaporation pan, the energy balance methods and mathematical modeling [7 - 14] etc.

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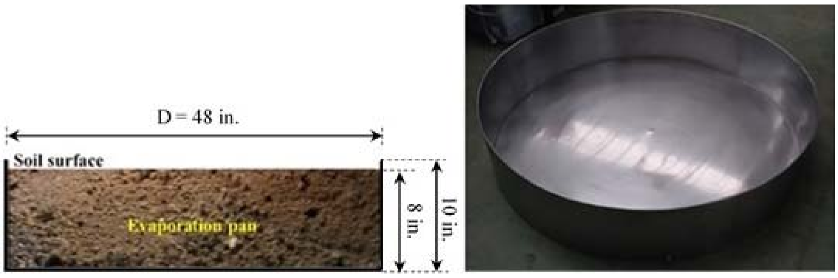

Figure 1 The pan evaporation (Class A pan)

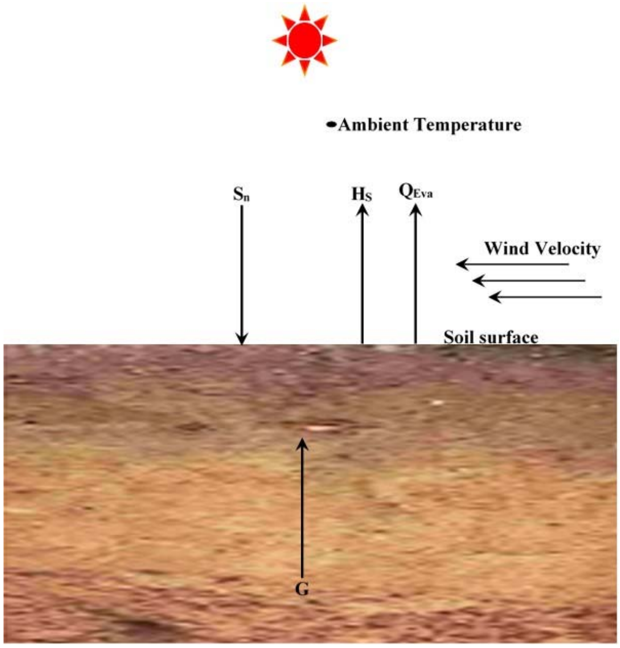

Figure 2 The heat transfer mechanism at the surface of the water resource

Currently, the significantly decreasing trend of evaporation rate from water resources and the land were found in many regions of the world [15]. Since the global observations of the surface air relative humidity are roughly constant from a global observation [16, 17], this implies that the evaporation loss from soil may be enhanced in some parts of the world [18 - 21]. Thus, the discrepancy between the expected and observed trends of pan evaporation has drawn great attention from many scientists trying to identify the answers what meteorological factors have caused the observed decreasing trends [22 - 25].

However, there is an evidence that the vapour pressure difference between the water surface and the surrounding air does not show any significant correlation in a tropical monsoon climate such as Thailand [26]. Decreasing in light intensity from the sun and wind speed may be the important factors affecting the evaporation rate. Since no further study has been made to identify the impact of these two factors on decreasing in the evaporation rate. Understanding heat transfer mechanisms that affect soil temperature and control the evaporation of water are thus important for water management as the reduce in evaporation will affect the hydrological cycle and reduce the draught problem [27 - 31]. Drought may be important phenomena inducing desertification in Thailand.

This article focuses on the comparison of influences of light intensity and wind velocity effecting the evaporation rate of saturated soil surface. Therefore, a laboratory scale pan evaporation experiments were conducted to investigate the changes in soil temperature and changes in the evaporation rate of saturated soil.

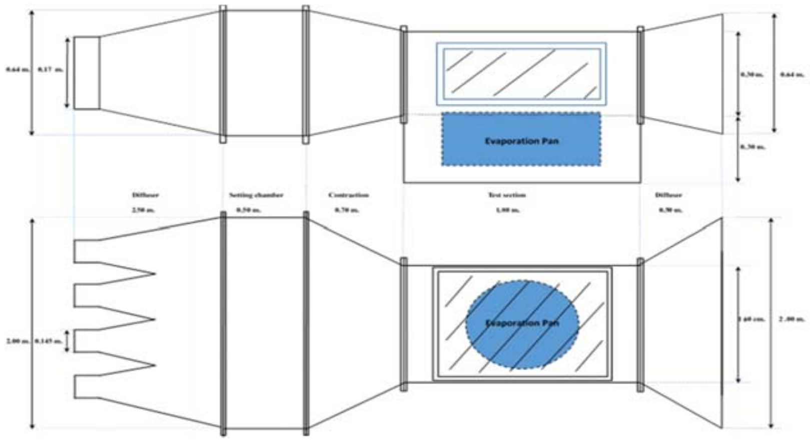

Figure 3 The open circuit low velocity wind tunnel

Figure 4 The centrifugal fan, electric motor, inverter and the setting chamber

2. Materials and methods

In this study, the evaporation rate of water from saturated soil was investigated using the method of water loss determination from evaporation pan directly and calculating evaporation rate from an energy balance equation.

2.1 The direct measurement method of water loss from evaporation pan

The direct measurement of evaporation was done by using a standard equipment the pan evaporation (Class A pan) which is a standard certified by the National Weather Service (NWS), USA. The standard size of an evaporation pan was 48 inches in diameter, 10 inches deep and made of stainless steel. The edge was moulded by stainless sheet to prevent the pan twisted. The bottom tray was welded to prevent water leaking and able to fill water up to 2 inches from the pan top as shown in Figure 1.

2.2 An energy balance method

Evaporation is the process by which water changes from liquid to gas or vapour. It occurs at all temperatures at the saturated soil surface. The evaporation of water occurs when the heat transfer is sufficient to overcome the molecular bonds of water so that the molecules are released. Evaporative or latent heat loss from the saturated soil surface is proportional to the difference between the water vapour pressure at the soil surface and the ambient air. It is the combined effects of the evaporation of water and the diffusion of water through the soil surface and can be expressed as [32]:

$$Q = m_v h_{fg} = h_{mass} A_s (\rho_{v,s} - \rho_{v,\infty}) \quad (1)$$

where Q is the latent heat loss ($kJ \cdot s^{-1}$), m_v is the rate of evaporation ($kg \cdot s^{-1}$), h_{fg} is the latent heat of vaporization of water at the surface temperature ($kJ \cdot kg^{-1}$), h_{mass} is the convective mass transfer coefficient ($m \cdot s^{-1}$), A_s is the surface area (m^2) and $\rho_{v,s}$, $\rho_{v,\infty}$ are the densities of the water vapour and dry air, respectively.

The heat transfer mechanism at the saturated soil surface can be written in terms of equations describing heat and mass based on the energy balance method (Figure 2), where accurately determining the heat flux would enable a better understanding of the evaporation process.

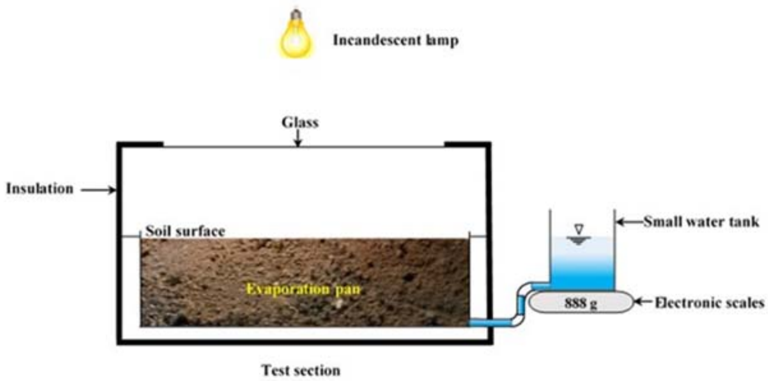

Figure 5 The test section and Class A evaporation pan in the test section.

The thermal energy involved in the evaporation process consists of solar radiation from the sun, the latent heat of evaporation, convection from the difference in temperature between the air and the water surface, and conduction into or out of the ground. Thus, Equation 2 can be rewritten as follows:

$$S_n = Q_{evap} + H_s + G \tag{2}$$

where S_n is the net solar radiation, Q_{evap} is the latent heat flux, H_s is the sensible heat flux to the atmosphere and G is the heat conducted to the ground. The latter two are typically small and difficult to measure.

By assuming that the heat transfers to the atmosphere (H_s) and the ground (G) are very small, the equation can be written as:

$$S_n = Q_{evap} \tag{3}$$

2.3 Experimental apparatus

The experiment was carried out in an open circuit low velocity wind tunnel designed according to fluid dynamics principles for engineering [33 - 36]. The wind tunnel has a size of 2.0 m × 6.5 m × 1.0 m and has 5 main components, namely the drive section (0.5 m length), diffuser (2 m length), settling chamber (0.5 m length), contraction (0.7 m length), and test section (1.8 m length) as shown in Figure 3. The air flow is generated by four centrifugal fans driven by a 5 HP electric motor (three-phase, 380V), as shown in Figure 4. The inverter frequency could be adjusted from 0 to 50 Hz (resolution of 0.1 Hz) to control the fan velocity. The settling chamber section consisted of honeycomb and wire mesh. The honeycomb was 50 mm length and 5 mm diameter; thus, the aspect ratio of the cells was about 10 and the standard wire mesh was 120 wires per inch, in which the height and length of each screen cell was 0.14478 mm. The wire diameter was 0.066 mm with an open area of 47% , with a pressure drop coefficient of 2, was chosen because it could eliminate nearly all variations in the longitudinal mean velocity. The test section was shrouded with insulation by 13 mm thick lightweight elastomeric material (Ethylene rubber or EPDM), with low thermal conductivity of 0.038 $Wm^{-1}\cdot K^{-1}$. The cross-section was 0.30 m high, 1.30 m wide, and a Class A evaporation pan (containing the saturated soil) placed in the centre of the test section as shown in Figure 5. The evaporation pan was connected to a small water tank using syphon tube for water filling. A small water tank was located on an electronic scale (Super-SS /New SU-3K) with an accuracy of 1 gram to measure the weight of evaporated water. The wind velocity averaged over the entire cross-section, was in the range from 0.53 to 1.82 $m\cdot s^{-1}$ at 0.15 m above the water surface. Simulating the radiation intensity of sun was applied using a combination of 20 lamps as shown in Figure 6. The lamp area was ventilated at room temperature to reduce the convective thermal effect of the lamp. The radiation intensity was from 0 to 1,500 $W\cdot m^{-2}$ (the luminous flux was 30,000 lux). The air temperature, soil temperature and relative humidity were recorded in 10 minute time interval by a set of 30 gauge (0.25 mm diameter) type K (chromel-alumel) thermocouples and a humidity probes which were connected to a data logger (Agilent Model 34970A) as shown in Figure 7.

2.4 Experimental procedures

The experiment was conducted by adding soil and water in the evaporation pan with a height of 0.2 m (due to a way to measure the evaporation rate according to international standards which is a standard certified by the National Weather Service (NWS), USA), and keep the soil to be saturated (the soil moisture content was 100%) with water at all times. The experiments were conducted with wind velocities of 0.53, 0.62, 0.71, 0.88, 1.02, 1.17, 1.30, 1.41, 1.54, 1.68 and 1.82 $m\cdot s^{-1}$ and radiation intensity of 0, 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1,000 $W\cdot m^{-2}$. The air was heated before entering the test section to control the temperature

Figure 6 Incandescent lamp.

Figure 7 The electronic scale, thermocouples, and humidity probe connected to the data logger.

and relative humidity within the range of 306.15 K to 308.15 K and 35 to 50%, respectively. The radiation was applied from the top of the test section for 3 hours during the experiment and then it was ceased for 1 hour (ASTM E 715-80) [36] for letting the test section cool down before next repetition. The data (i.e. inlet air temperature, exit air temperature, air temperature, soil temperature and humidity) were recorded every 10 minutes. The experiments were carried out between January 01st 2017 and February 28th 2017. Finally, the evaporation loss from the effects of light intensity and wind velocity was analyzed to study their effects on evaporation.

3. Results and discussion

In the laboratory-scale experiment, it was found that increasing the light intensity from 0 to 1,000 $W \cdot m^{-2}$ (at wind velocity of 0.53 $m \cdot s^{-1}$) increased the evaporation rate by about 0.0000547 $m \cdot min^{-1}$ from 6.08×10^{-5} to $11.60 x 10^{-5}$ $m \cdot min^{-1}$ as shown in Figure 8.

Since the surface of the saturated soil absorbs heat from radiation, increasing light intensity from 0 to 1,000 $W \cdot m^{-2}$ slightly increased the water temperature by 4.98 K from 298.12 to 303.10 K as shown in Figure 9. It is obvious that the evaporation rate should increase with increasing the light intensity because the convective mass transfer coefficients were increased due to the decreased in the vapor pressure difference between the water surface and air, which in turn, increased the evaporation rate. Figure 10 shows that increasing the light intensity from 0 to 1,000 $W \cdot m^{-2}$ increased the convective mass transfer coefficients (h_{mass}) only slightly from 0.00637 to 0.00643 ms^{-1} or 0.94%.

From data of wind velocity, light intensity and evaporation rate in during the years 2008 to 2017 (from the Meteorological Department and the Department of Alternative Energy Development and Efficiency) as shown in Figure 11, it was found that the light intensity decreased from 423.66 to 419.68 $W \cdot m^{-2}$ or 0.95% from 2007 to 2016. When compared to the experimental results, it could be seen that decreasing the light intensity about 0.95% from 1,000 to 990.52 $W \cdot m^{-2}$ caused the evaporation rate to significantly decrease from 11.60×10^{-5} to 11.55×10^{-5} $m \cdot min^{-1}$ or 0.453%.

In terms of the effect of the wind velocity on the evaporation rate, it was found that higher wind velocity increased the evaporation rate. Increasing the wind velocity from 0.53 to 1.82 $m \cdot s^{-1}$ (at light intensity of 100 $W \cdot m^{-2}$) increased the evaporation rate by about 0.0000322 $m \cdot min^{-1}$ from $9.93 x 10^{-5}$ to $13.20 x 10^{-5}$ $m \cdot min^{-1}$ as shown in Figure 12.

Increasing the wind velocity from 0.53 to 1.82 $m \cdot s^{-1}$ slightly decreased the water temperature by about 3.39 K from 301.45 K to 298.06 K as shown in Figure 13. It is obvious that the evaporation rate should increase with increasing wind velocity because the convective mass transfer coefficients were increased due to the high temperature difference between the air and water surface,

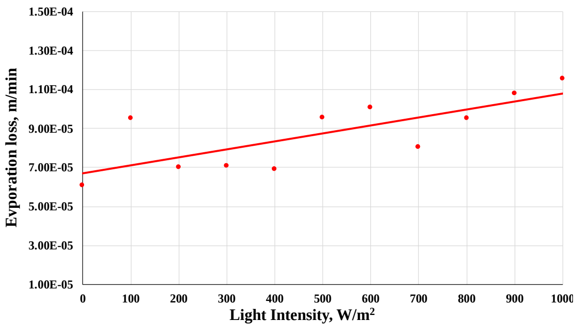

Figure 8 The relationship between evaporation loss in the evaporation pan and the light intensity

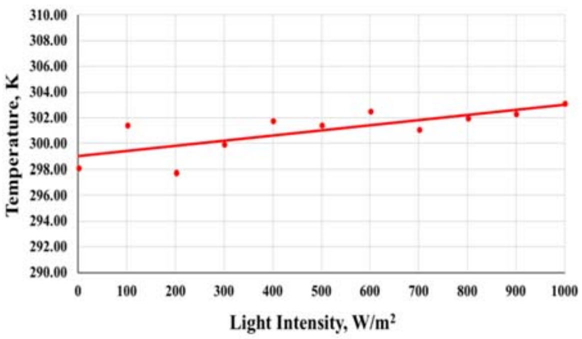

Figure 9 The relationship between the saturated soil temperature in the evaporation pan and the light intensity

which in turn, increased the evaporation rate. Figure 14 shows that increasing the wind velocity from 0.53 to 1.82 m·s^{-1} increased the convective mass transfer coefficients (h_{mass}) from 0.00642 to 0.01182 m·s^{-1} or 83.93%.

From Figure 11, it was found that the wind velocity decreased from 6.041 to 6.026 m·s^{-1} or 0.25% from 2007 to 2016. When compared to the experimental results, it could be seen that decreasing the wind velocity about 0.25% from 1.820 to 1.815 m·s^{-1} caused the evaporation rate to slightly decrease from 13.20×10^{-5} to 13.19×10^{-5} m·min^{-1} or 0.089% as compared to 0.453% in the case of decreasing light intensity.

Therefore, it can be concluded that the light intensity plays an important role in the evaporation rate. It is possible that the decrease in evaporation is mainly due to the decrease of the light intensity by light intensity has an influence on the evaporation rate by accounting for 95.01% of decreasing the evaporation rate and the wind velocity has an influence on the evaporation rate by accounting for 4.99% of decreasing the evaporation rate. From data during the years 2008 to 2017, the light intensity decreased 0.95% from 423.66 to 419.68 W·m^{-2} caused the evaporation rate to decrease 0.0187 mm and

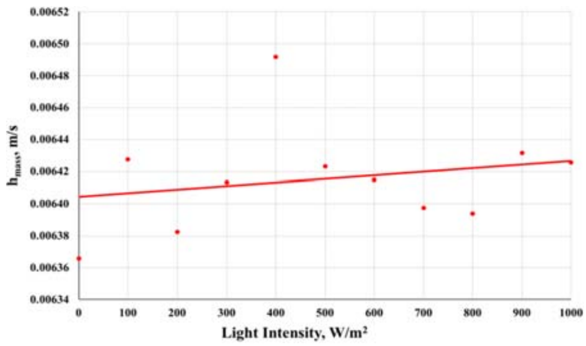

Figure 10 The relationship between the convective mass transfer coefficients and the light intensity

the wind velocity decreased 0.25% from 6.041 to 6.026 m·s^{-1} caused the evaporation rate to decrease 0.001 mm. The sum of decreasing the evaporation rate due to decreasing the light intensity and decreasing the wind velocity about 0.0197 mm caused the evaporation rate to decrease from 4.351 mm to 4.331 mm, which is close to the decrease in the evaporation rate in 2016 of 4.304 mm. The results also show that the trends in evaporation rate influenced by global warming, are consistent with the results of several studies by researchers. The guidelines for reducing evaporation losses need the light intensity may be decreased by find materials or accessories that cover the saturated soil surface, which will reduce the light intensity and evaporation rate of the water. For example, cropping will be used to cover the soil, using of mulching materials and irrigation to wet the soil surface as little as possible etc.

4. Conclusions

1. From experiment data which this experiment was limited under the constraints as follows: a laboratory scale pan evaporation experiments, wind velocities of 0.53 to 1.82 m·s^{-1}, radiation intensity of 0 to 1,000 W·m^{-2}, control the temperature and relative humidity within the range of 306.15 K to 308.15 K and 35 to 50%, and the soil moisture content of 100%,

   1.1 The light intensity decreased 0.95% from 1,000 to 990.518 W·m^{-2} caused the evaporation rate to decrease 0.0523x10^{-5} m·min^{-1} from 11.66×10^{-5} to 11.55×10^{-5} m·min^{-1} or 0.453%.

   1.2 The wind velocity decreased 0.25% from 1.82 to 1.815 m·s^{-1} caused the evaporation rate to decrease 0.0117×10^{-5} m·min^{-1} from 13.20×10^{-5} to 13.19×10^{-5} m·min^{-1} or 0.089%.

   1.3 The light intensity and the wind velocity have an influence on the evaporation rate by accounting for 81.71% and 18.29%; respectively, of decreasing the evaporation rate.

2. From data of wind velocity, light intensity, and evaporation rate in during the years 2008 to 2017 (from

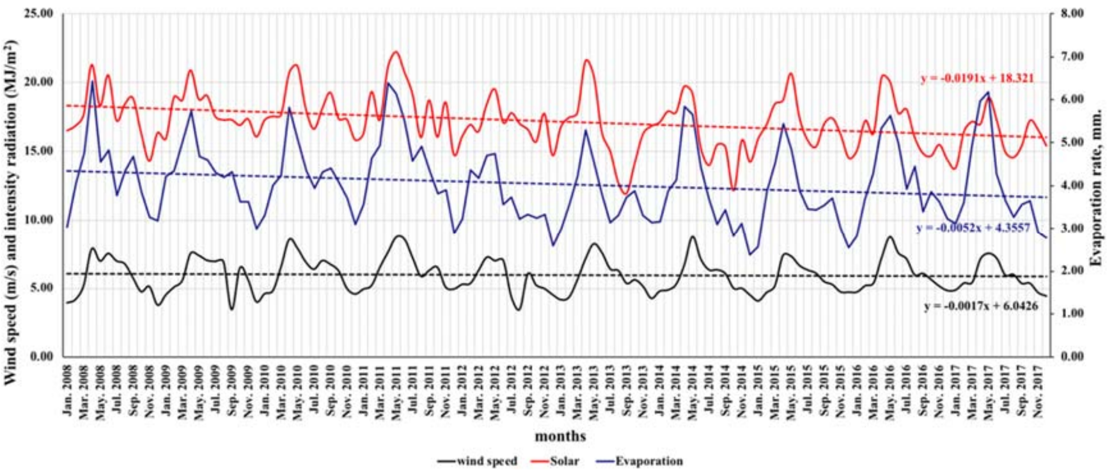

Figure 11 The trends in wind velocity, radiation intensity and evaporation with time for Chiang Mai during the period from 2008 to 2017.

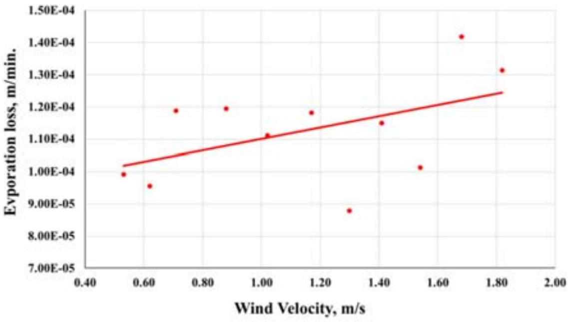

Figure 12 The relationship between the evaporation loss in the evaporation pan and the wind velocity.

the Meteorological Department and the Department of Alternative Energy Development and Efficiency),

2.1 The light intensity decreased 0.95% from 423.66 to 419.68 $W \cdot m^{-2}$ caused the evaporation rate to decrease 0.0187 mm from 4.351 to 4.332 mm or 0.432%.

2.2 The wind velocity decreased 0.25% from 6.041 to 6.026 $m \cdot s^{-1}$ caused the evaporation rate to decrease 0.001 mm from 4.351 to 4.350 mm or 0.023%.

2.3 The light intensity and the wind velocity have an influence on the evaporation rate by accounting for 95.01% and 4.99%; respectively, of decreasing the evaporation rate.

3. The intensity of light has a more significant effect on the evaporation rate compared to the wind velocity.

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