Environmental Engineers' Passion for Sustainability Research Study

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OIDA International Journal of Sustainable Development, Ontario International Development Agency, Canada

ISSN 1923-6654 (print) ISSN 1923-6662 (online) www.oidaijsd.com

Also available at http://www.ssrn.com/link/OIDA-Intl-Journal-Sustainable-Dev.html

Abstract: This paper demonstrates a no expense barred passion of a geo environmental engineer to pursue fundamental sustainability research studies. At the onset, a prototype " home set up" with wide research potential was installed in their home to analyse the effectiveness of a hybrid system of solar panels and a"vertical axis" wind turbine to generate power for domestic use. Electrical power generation from such systems are solely dependent on the environmental parameters such as wind speed and direction, solar radiation intensity and ambient temperature. Concurrent and continuous nformation of these independent environmental variables (and more) were continuously monitored with a HOBO weather station installed on site and within 10m from the hybrid system. Linked relationships between real environmental parameters and the power generated can thus be ascertained. The feasibility of using such hybrid systems for domestic or mini industrial scale power generation were investigated. This home research set up facilitated the research on two further environmental projects; Urban Heat Island (UHI) effect study was one project where the influence of environmental temperature, solar radiation, wind speed, rain fall and relative humidity on cores of road surface asphalt concrete samples coated with paints of diferent albedo were monitored. Weather induced soil erosion is the other project described in this paper. Soil erosion process is also induced and even enhanced by the moisture absorption character of the soil. The natural elements that affect the soil moisture changes in field include rainfall intensity, relative humidity, sunlight radiation, and ambient temperature. The home research set up collated information in real time and environment frame, contrary to the often reported and practised, controlled laboratory testing conditions. The research outcomes from such studies can be applied to wider scale models and predictive software.

Keywords: Weather station, Solar panels, vertical axis wind turbine, Asphalt concrete pavement; Temperature; Urban Heat Island; Soil moisture content; Soil erosion.

Introduction

Sustainable and alternative sources of energy are topical with global concerns of climate change faced by humanity now and in the future. Such concerns are not exclusive to those living in nations endowed richly with fossil fuels. However, it must be a sustainability prerogative that such countries cannot solely rely on non-renewable energy sources anymore. Burning of fossil fuels is a known contributor to the undesirable emissions of greenhouse gases leading to global warming. Developments of both domestic and commercial appliances are becoming electrical/ petroleum / gas dependent, with escalating fuel bills. Hence, studies on alternative energy sources such as solar radiation and wind energy are being explored and harnessed in many countries. These alternative sources are necessarily dependent on favourable environmental condition, such as wind speed, solar radiation and temperature. Thus one of the aims pursued in this paper was to present a passionate field study on the power generation of a hybrid system (wind turbine and solar panel) . This research monitored in real time the energy output from the hybrid system over the study period.

Home Research Set Up

Figure 1: Hybrid System: - Vertical Axis Wind Turbine & 3 Solar Panels In Yong Peng, Johor

This “home research set up” is located in Yong Peng, Johor, Malaysia. Hybrid of a wind turbine and solar panels, (Figures 1a and 1b) purchased and owned by the authors were installed in the garden of their own private residence, to research and with also a view to power a few garden appliances too. Both the vertical axis wind turbine (VAWT) and the suite of 3 solar panels are connected to the same Hybrid System Control Panel, and the total energy thus generated are stored in the battery bank and used as and when needed.

The energy that the sun beams on the earth every hour is sufficient to meet the global energy needs for an entire year. Solar panel technology is now popularly being used to harness the sun's energy and make it useable. As of today, the technology produces only less than one tenth of one (0.1) percent of global energy demand. Most countries have access to electricity through the grid. As a result, the current application of photovoltaics (PV) power supply is limited only to some special applications such as remote telecommunications (relays), lighthouses or sea buoys. The application of solar PV technology is being developed and used aggressively in some states of east Malaysia namely, the states of Sabah and Sarawak. Altogether, over 2.1 MWp of PV systems have been installed for buoys, beacons, lighthouses, remote villages and repeater stations with the largest proportion, around 320 kWp for rural telecommunications. Malaysia is located at the equatorial region with an average daily solar radiation of 4,500 kWh/m^2, with daily sunshine duration of about 12 hours. Ambient temperature remains uniformly high throughout the year; the average ranging between 27 to 33°C. Most locations have a relative humidity of 80 – 88%, rising to nearly 90% in the highland areas and never falling below 60% [1] .

‘Suria 1000’ programme was a notable initiative to promote usage of solar energy in Malaysia. Since 2007, limited number of grid-connected solar PV systems has been offered annually to the public on a bidding (auction) concept, advertised through local mass media and administered by the project team in order that the public may install and profit from the programme.[2,3]. In contrast, the current utilization of wind energy sources in Malaysia is still limited, primarily due to the low average wind velocity in the whole country. A number of feasibility studies have been carried out by by researchers on the potential of wind energy in Malaysia. A detailed 1989 research study conducted by Universiti Teknologi Malaysia (UTM), reported that Malaysia experiences a significant amount of wind throughout the year, with wind speeds of more than 2.5 m/s over 75% of the year time.

Wind turbines are the technological equipment used to produce electrical energy from wind energy. It may appear simple in appearance but they are mechanically complex equipment. There are two types of of wind turbine designs depending on the axis orientation; The most common being the the Horizontal Axis Wind Turbine (HAWT) (Figure 2).

(a) Pulau Perhentian Kecil, Terengganu, Malaysia
Average Annual wind speed 2.7 m/s

(b) Pulau Layang- Layang, Sabah, Malaysia
Average Annual wind speed > 4 m/s

Figure 2: Horizontal Axis Wind Turbines

The first wind energy facility in Malaysia was located in Pulau Layang-Layang, Sabah (Figure 2b). A Wind Turbine Generator (WTG) hybrid system has been installed and constructed in November 1995 by TNB Research Sdn. Bhd, a TNB subsidiary. In United Kingdom wind power is harnessed successfully that the Guardian reported that in 2016, UK generated more electricity from wind power than from coal.

Figure 3 illustrates the HOBO weather station used in this study. It is a device that is central and of prime importance to this “home research setup”. It monitors and collects measurable parameters related to the environment and the local weather. It is therefore equipped with appropriate and relevant electronic and electro mechanical sensors. The data collected can be used to archive, analyse data, and model for weather forecast and climate data. There are many types of weather stations including weather centers, personal weather stations,

Figure 3: Hobo Weather Station In Yong Peng [4]

professional weather stations, home weather station, weather forecaster and forecasters. The physical size of the weather station can be of a size comparable to a building size and the size and capacity will influence the accuracy of the data recorded. The usual basic measurements taken from a weather station are rainfall (/ precipitation amount), wind speed and direction, barometric pressure, ambient temperature, relative humidity, sunlight radiation, and soil moisture content. Meauring instruments installed in a weather station include rain gauge, anemometer, wind vane, barometer, thermometer, hygrometer, pyranometer, solar panel, and soil moisture sensor. The weather station has an inbuilt a facility of an integral data logger which in turn had a memory chip that will store all the data for the study period. These stored data within the weather station memory unit was retrievable onto a laptop computer using a data cable and the appropriate HOBO software [4]. These data can also be retrieved via the internet, as the weather station data logger is wifi enabled, and can transfer all the data directly to the HOBOlink website when there is an internet connection. The weather station did not depend on external power source as the energy required to operate is was produced through an integral solar panel. The stored data can be transferred from the data logger to a computer using a software called HOBOware which would read the transmitted data and save it in Excel spreadsheet.

Environmental Factors Influence On Energy Generation

The field study was facilitated by the combined resources of the Hybrid system and the weather station and involved monitoring the real time energy output from the hybrid system over a period of study time. The weather station monitored and provided the environmental condition data which was deemed to affect the power generation from the Hybrid System. The data collected were wind speed, gust speed, temperature and relative humidity. The data was logged into the system at an interval of every 15 minutes. However the data collection system from the VAWT and the solar panels were done separately and monitored using different type of systems. Separate data loggers were installed at the site, the solar panels had solar controllers storing information regarding its energy production whereas the wind turbine data logger was not a stand – alone device. It enabled the analysis and correlation of the effects of the environmental conditions such as wind speed, solar radiation and temperature on the energy production .

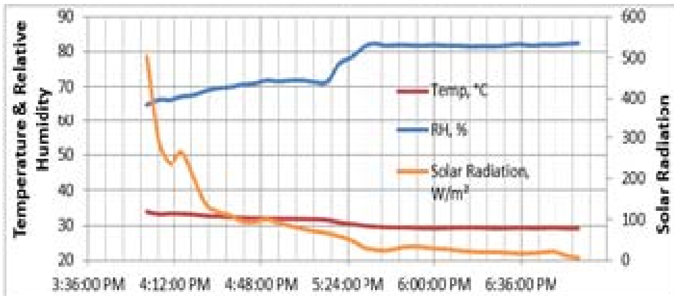

Figure 4: Variations Of Temperature, Relative Humidity And Solar Radiation With Time

Figure 4 is a typical output of observations from the weather station. Near sunset on this day, the relative humidity increased from 65% to 72% while the ambient temperature decreased 2°C. From 5pm onward, solar radiation slowly reduced to zero while the temperature also slightly reduced to around 29 °C then remains constant after 6pm. Relative humidity of the environment increased after 5pm to around 81% and then remained stable during this window of observation.

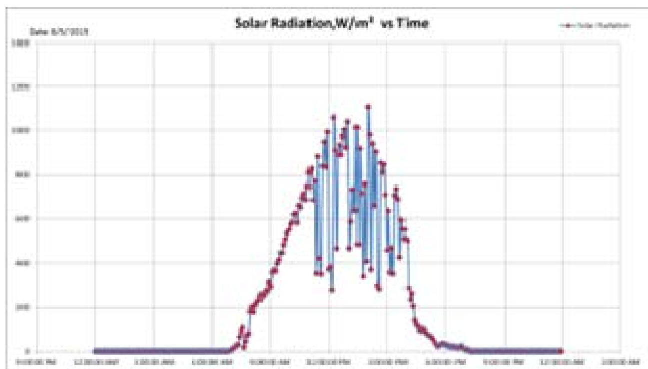

Figure 5: Solar Radiation Variation Observed

Figure 5 is an illustration of the variation of solar radiations on a day with intermittent cloud cover. It was also seen that on average the solar radiation was prevalent and available from 6.35 am – 7.00 pm at most. The highest ever recorded solar radiation during the 7 days period was 1191.9 W/m². There are about 2.75 hours at most over the period of seven day study period where the solar radiation strength exceeded 1000 W/m². Thus meaning that if the solar panel efficiency was 100% , it can produce 1 KW of power from a solar radiations incident on every 1m^2 of panel. Table 1 gives the solar panel efficiency analysis over a seven day period for one of the controllers. The analysis shows that the efficiency is linked to both average temperature and average humility. If these data were data were analysed being singly dependent will yield erroneously misleading interpretations that low panel efficiencies arise with higher temperatures or with lower humidities. Cloud cover , wind speed and rainfall are further contributory factors that need to be considered for a fuller understanding.

Table 1: Efficiency Evaluations For One Solar Controller

Day No.	Efficiency (%)	Average Temperature (ºC)	Average Humidity (%)
1	21.72	28.68	85.28
2	29.28	27.93	88.73
3	25.46	29.57	83.16
4	18.98	30.48	76.54
5	11.44	31.26	75.12
6	19.51	30.08	80.42
7	30.75	30.46	80.27

Figures 6 and 7 show the variations of the gust speed and wind speed respectively at the site (Yong Peng) on the same day. Figure 6 shows maximum gust speed of 4.5 m/s. However, since gust speed is not a consistent speed, there would be only momentary surges of power in the wind turbine power output before it drops again. However from the data, it can be seen there is the potential to have an occasional wind speed of 3.5 m/s to 4.5m/s which can be used to produce electricity. Figure 8 illustrates the instantaneous power generated with the varying gust speed.

Figure 6: Variation Of Gust Speed In Yong Peng

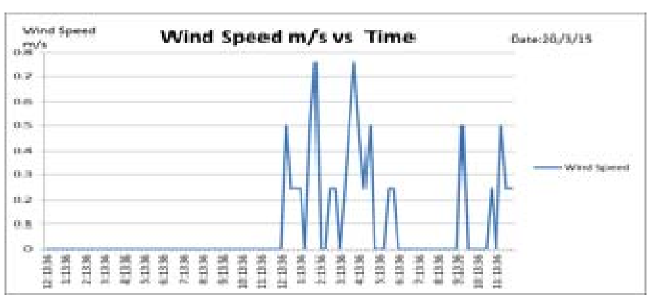

Figure 7: Variation Of Wind Speed In Yong Peng

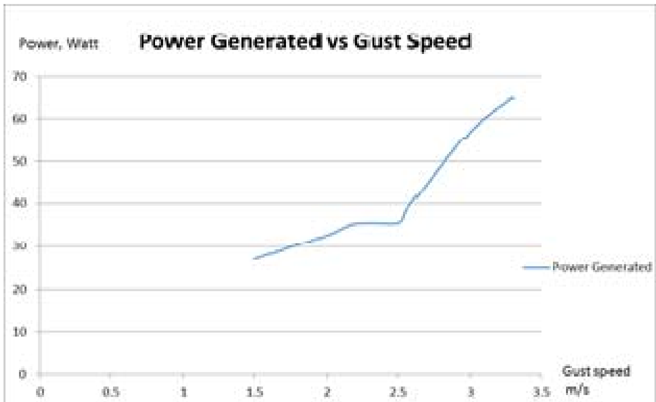

Figure 8: Monitored Power Geration With Gust Speed

Urban Heat Island Related Research

Adverse climatic changes enhance urban heat island effect (UHI), a phenomena where the ambient temperature in urban areas are dominantly higher than in rural area [5, 6]. Urban developments change the morphology and the environmental balance of open-land and vegetation, replacing such with industrial landscapes and residential area as well as infrastructure that include: buildings, skyscrapers, houses, cement sidewalks and paved roads. These structures and infrastructures absorb heat and eventually make the surrounding warmer than in other place and such increases in temperature will necessitate the demand of energy for air- conditioning that further worsen the air quality. Conduction forms a transfer process of energy from the more thermally energised particles of a substance to the adjacent particles of a lower energy level through particle interactions. On the other hand, Convection is the mode of energy transfer between solid surfaces and where the medium between the surfaces comprise of a mobile phase (liquid or gas) that is also affected while in motion and it involves the combined effects of conduction and convection. Radiation is the energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the changes in the electronic configurations of the atoms or molecules. Figure 9 illustrates the utilisation of all of the above three processes of solar energy transfer in the heating of a road pavement.

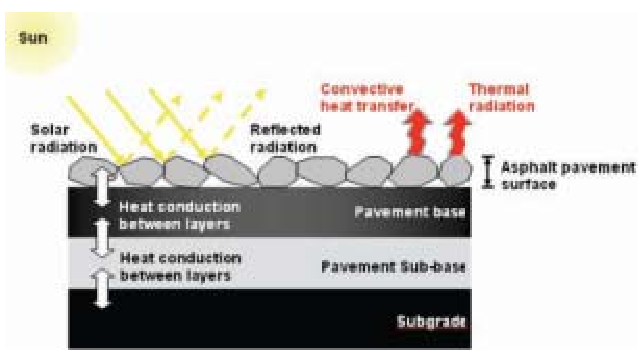

Figure 9: Heat Transfer In Asphalt Road Pavement

Common building natural stone, asphalt, brick and concrete are generally dark in colour with low albedo, and making them absorb solar radiation at a faster rate than vegetation and make their surrounding warmer for a longer period. Albedo, defined as a non-dimensional index that indicates how well a surface reflects solar energy. Albedo varies between 0 and 1. Accordingly, Albedo refers to the "whiteness" of a surface, with 0 meaning black and 1 meaning white. A value of 0 means the surface acts a "perfect absorber" and absorbs all incident solar energy. Absorbed solar energy can be a source of heat the surface or, in the case when sea ice is present, it can melt the surface. A value of 1 means the surface is a "perfect reflector" that reflects all incident energy.

Some additional factors that contribute to the UHI effect are the size and density of population in an area, anthropogenic heat sources. and thermal and radiant properties of the building material. and anthropogenic heat sources. Hot weather impacts widely on the community and its assets. Consequently, human health, human behaviour, infrastructure and the natural environment are all affected by high daily temperatures. UHI effect exacerbates these impacts by increasing not only day-time temperatures within urban areas, but also night-time temperatures, and sequences of days and nights with high temperatures. The impacts of hot weather on health are profound, particularly amongst the more vulnerable members of the community such as the elderly, and the correlation between temperatures and health impacts is strong beyond a threshold temperature [7]. The increased vulnerability among the elderly is attributable to a combination of impaired physiological response to heat, and a higher prevalence of chronic diseases involving cardiovascular, respiratory, renal, and endocrine systems.

Six different samples of asphalt concrete were used, as shown in the Figure 10 to study the different levels of solar energy absorption depending on the albedo of the coating made on the samples. The samples were prepared according to asphalt concrete wearing 14 specification and procedure. Temperature variation within the samples and surface of the samples were recorded by UX 120 data logger. UX 120 Data Logger (Figure 11) was used to record the temperature variation within the samples. Thermocouple type K were connected to the data logger and were used to measure the temperature variation within the samples under changing weather conditions. Samples were place in the outdoor environment near the weather station to absorb solar radiation. Electronic thermocouples (type K chromel – alumel) were used to measure temperature.

Figure 10: Asphalt Concrete Samples With Different Colours (Albedo)

Figure 11: Ux120 Data Logger For Monitoring Thermal Measurements

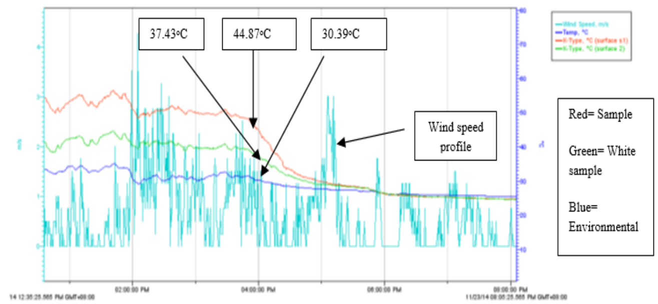

Figure 12: Wind Speed Influence On Temperature Profile In Asphalt

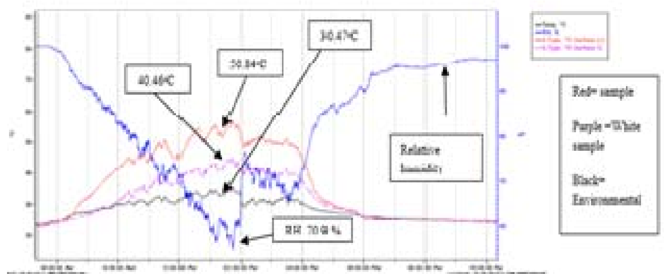

Figure 13: Influence Of Humid Environment On Temperature In The Asphalt Cores

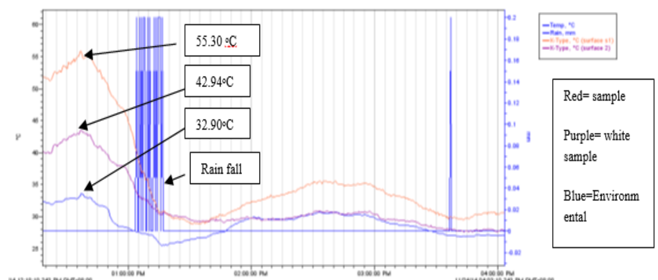

Figure 14: Influence Of Rainfall On The Temperature Of The Asphalt Cores

Wind can cooling down the environmental and samples temperature. The temperature of samples and environmental dropped due to wind effect. Figure 12 shows that there is an inversely proportional relationship between the wind speed and environment temperature. Environment temperature will drop as the wind speed was high, or there was a wind. Same relationship applied to the specimens' temperature.

Relative humidity being the ratio of the partial pressure of water vapor to the equilibrium vapor pressure of water at the same temperature .The Relative humidity increased, the environment temperature will decreased. Figure 13 show that when the relative humidity was high, the specimens temperature will decreased compare to the specimens' temperature where the relative humidity was low.

Figure 14 shows Rain was one of the parameters that will affect the environment temperature and specimens' temperature in the test. The heat trapped in the sample released by the rain drop where the rain fall decreased. There were no rain fall, temperature of sample were started to increase have direct contact with the sample.

Research On Soil Erosion

Water occurr in the atmosphere as water vapour, flows on the earth surface as water runoff, and moves under the ground as groundwater flow. Climate Change has caused major changes in weather patterns and spates heavy rainfall has caused flooding, landslides and taken the toll of many lives, properties and infrastructure. Soil moisture content (/ water content) is the proportion of free water within a soil mass [8]. There are many techniques adopted to measure soil moisture content and the most established method is through the drying test in an oven set at a temperature of 105ºC [9, 10]. This test gives accurate mass of free water in soil sample. However oven drying process in laboratory is time consuming and does not therefore provide real time instant soil moisture content on site. Another method of measuring soil moisture content is using a soil moisture sensor, which is an electrical device that is normally incorporated into a weather station to detect the water content on site instantly and accurate within reason.. Geotechnical and geoenvironmental engineers consider this an important parameter that is used to find out the physical and chemical behavior of a soil through its properties. The consistency of a fine grained soil will depend on its water content. It also governs the phase relationship in the three phased unsaturated soils [11]. Generally, water content also represents a value that shows the relative ratio of water to dry soil, and can be expressed both in gravimetric value, volumetric value. All these values are interrelated to each other and therefore give the same image of the amount of water content for an amount of soil.

The soil moisture content in the field is not consant but depends on time, position and is influenced by the natural environmental elements at that point and time. For example, raining will cause the soil moisture content to increase while a hot sunny day with strong winds will reduce the soil moisture content and the soil's hydraulic conductivity properties will influence the evapo transpiration properties. Hence the rainfall intensity, relative humidity, ambient atmospheric temperature, and solar radiation are primary environmental factors that affect the moisture content of a sub surface soil element with its own characteristic state of compaction and therefore such field observations that substantiate their interrelationships will prove useful in any numerical modelling for predictions.

The soil moisture sensor operation is based on the concept of using the capacitance to observe the water content of soil through the measurement of the dielectric permittivity of the soil. In the measurement, the two pronged soil moisture sensor is inserted into the soil and the volumetric water content of the soil will be reported in percent. Dielectric soil properties such as capacitance and electrical conductivity are governed mainly by the water content of the soil mass [12, 13]. By measuring these parameters between two electrodes, the soil's dielectric permitivitty in between is obtained and the soil moisture can be determined. The capacitance of dry soil is determined by its dielectric constant. For dry soil this constant is of the order of 3 to 6 and for water the constant is 80; in other words, the capacitance between the two electrodes is dominated by the volume fraction of water.

Laterite soil samples with three differing compaction states (Heavy, normal and poor) were used in this soil erosion study. Soil characterization tests carried out on the laterite soil were dry sieve analysis, liquid limit and plastic limit test, specific gravity test, proctor compaction test, pH value, linear shrinkage test and observation in changes of soil colour with moisture content change from light pink (very dry) to dark orange (very wet). Sieve analysis classed the researched laterite soil as a well graded clayey gravelly sand. The effective size (D_{10}) of the laterite soil samples was 0.065mm. The researched laterite soil uniformity coefficient (Cu) was 8.46 and coefficient of gradation (Cc) was 1.12. The liquid limit and the plastic limit were 93.56% and 40.83% respectively. The plasticity index of this laterite soil being 52.73% and referring to AASTHO, this laterite soil was classified as A-2-7(17). Using USCS, the soil is classed as Clayey Sand (SC). This laterite soil had a specific gravity and pH value of 2.71 and 4 respectively. A linear shrinkage value of 12.14% was observed. The notable colour change with changes in moisture content is given in Table 2.

The laterite test samples in three different states of compaction were placed in three separate plastic containers whose bases were pierced with drainage holes to ensure continuous drainage; but a layer of filter paper was placed on top of the perforated base to prevent any loss of soil particles. Besides that, a hole was made at the side of the container to position the moisture sensor to be located within the soil during compaction.

When the three samples and weather station were fully set up, the weather station data logger monitored and stored data from all the smart sensors. The period of study reported here was over a period of 10 days. The data was logged into the system at an interval of every 15 minutes . Figure 14 shows that the rain started around 3:35 pm and ended around 4:15 pm. All 3 test samples showed a response of an increase in moisture content. For different compacted soil, a 40 minutes normal rain will increase the soil moisture content for at least 20%.

Table 2: Data For Colour Of Laterite Soil Samples

Sample Moisture content	Colour Name	Colour Notation (Before Oven dry)	Colour Notation (After Oven Dry)
0%	Light Brown	5YR 7/4	5YR 7/4
10%	Light Brown	7.5YR 7/4	7.5YR 7/4
20%	Light Brown	5YR 6/6	5YR 6/6
30%	Light Brown	5YR 6/8	5YR 6/6
40%	Moderate Brown	7.5YR 5/8	5YR 6/4
50%	Moderate Brown	7.5YR 5/6	5YR 6/4
60%	Moderate Brown	7.5YR 5/6	5YR 6/4
70%	Moderate Brown	5YR 5/8	5YR 6/4
80%	Moderate Brown	5YR 5/6	5YR 6/4
90%	Moderate Brown	5YR 5/6	7.5YR 6/4
100%	Moderate Brown	5YR 5/6	7.5YR 6/4
110%	Moderate Brown	5YR 5/6	7.5YR 6/4

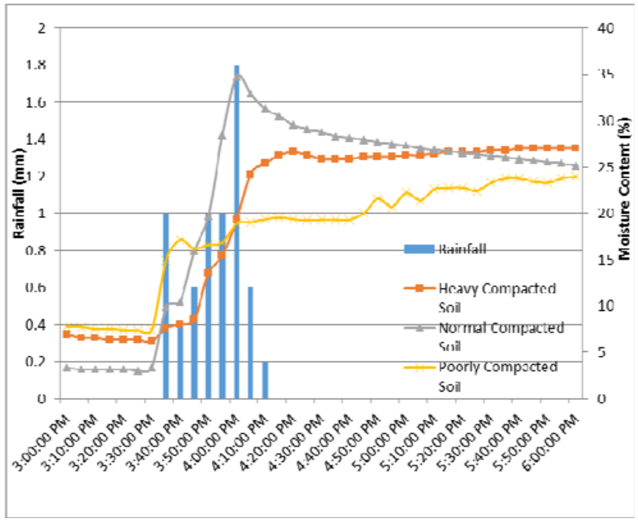

Figure 14: Rainfall Influence On Moisture Content Of Three Laterite Soil Samples

The moisture content of these 3 different level compacted soils reduced although the relative humidity increased. The moisture content reduction observed was relatively small and around 2 to 3 %. The effect of relative humidity on soil moisture was affected by concurrently occurring factors such as solar radiation and temperature (Figure 15).

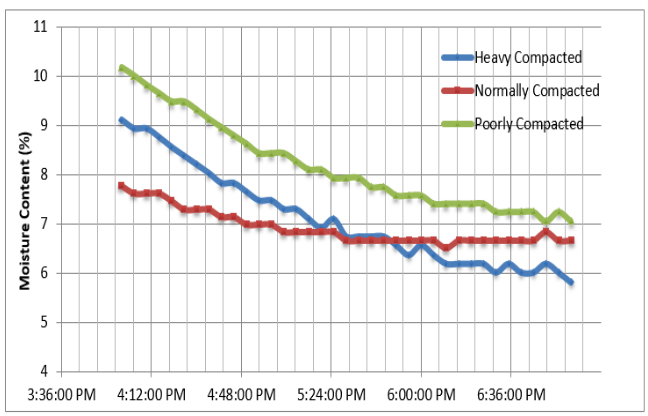

Figure 15: Soil Moisture Content Changes With Ambient Drying.

Concluding Remarks

The provision of a well instrumented "home research set up" to further the understanding of various environmental research projects has been described. Sponsored research collaboration on future sustainability projects will be welcomed.

Research to analyze and correlate the effects of the environmental conditions such as wind speed, solar radiation, temperature and humidity, on the energy generation efficiency of a hybrid system was presented. The current efficiency of the solar panels are still low ranging from 11% - 30%, thus more research needs to be done to increases the energy conversion technology of the solar panels.

From the wind speed, wind gust data and wind power generation data from the wind turbine, the field study in Yong Peng showed the potential of reaching a wind speed of 3.5 m/s to 4.5m/s. The wind turbine is able to reach an energy efficiency level of almost 65% to 72.4 % at certain period of time.

Solar radiation showed a directly proportional influence on the heat trapped in the pavement samples. Wind speed, rain fall and relative humidity were inversely proportional to the heat trapped in the samples pavement.

There is wide scope for further research on UHI related activity to explore viz. how the stored thermal energy in pavements can be used for heating , how coatings with high albedo can be developed and used to reduce the adverse effects of UHI.

The response to changes in soil moisture is a consequence of a combination of environmental parameters where rainfall is most dominant. The optimized levels of compaction required for dirt roads to minimize soil erosion can be further investigated.

Acknowledgments

Author would like to express his heartfelt gratitude and appreciation to staff, research colleagues and students of University Tun Hussein Onn Malaysia and University of East London UK for their research collaborations and inspirations. This research would not have been possible if not for the patient support, tolerance and enduring appreciation by his wife and co author, Anoma, for the joint dedication to the development of the science and sustainability research.

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