Chapter 6 : Results

6.1 Global radiation and net radiation

Global radiation is short-wave radiation received from a direct solar radiation plus the diffuse radiation from the skies, whilst net radiation is an energy balance between the incoming radiation and the outgoing radiation. Usually, the values of both hourly average global and net radiation are positive during daytime and negative or less than zero during nighttime. In the equatorial region, there was not much variation of the values from one day to another, unless if there is cloud cover on the site at a particular time of that day. This effect can be seen in the curve (fig. 6.1a-6.1e) for cloudy days with no rain, especially at the middle of the day where there was more fluctuation.

Figure 6.1 to figure 6.1i show the variation of both global and net radiation during the eleven days of observation. According to Kizer et. al (1990), daytime data were defined as readings taken during hourly periods, when solar radiation was 1 Wm^{-2} or greater in the morning; whereas the evening data starts when solar radiation was 1 Wm^{-2} or less. In other words 1Wm^{-2} of solar radiation was used as the dividing point for both morning and evening. So, it means that from the observation the daytime started at 0700 LT or 0800 LT in the morning and ended at 1900 LT or 2000 LT in the evening.

Based on table 6.1(a), the highest maximum values obtained for global and net radiation were 826.11 Wm^{-2} and 579.4 Wm^{-2} on 9.8.95 at 1300 LT respectively. This is a cloudy day with rain. It was observed that the maximum global and net radiation tend to occur between 1200 LT-1400 LT , depending on the weather on that day. Period of cloudy skies tend to reduce solar radiation from reaching the earth's surface, so that the absorption of heat is less at the ground surface than for days with clear sky. The lowest value of the maximum global radiation and net radiation were 430.35 Wm^{-2} and 301.34 Wm^{-2} was recorded on the 5.7.95 during a cloudy period.

The days observed for global radiation and net radiation can be described into three categories; clear day, cloudy days no rain, cloudy days with rain. All the time mentioned is in local time (LT).

Date	Maximum values (Wm^{-2})		Weather condition
	Glob. Rad.	Net rad.	
30.6.95	692.87	497.93	Cloudy day with no rain
1.7.95	492.42	356.74	Cloudy day with no rain
4.7.95	695.95	480.69	Clear day
5.7.95	430.35	301.34	Cloudy day with no rain
6.7.95	673.66	484.72	Cloudy day with no rain
7.7.95	755.85	537.71	Cloudy day with no rain
27.7.95	630.1	447.53	Cloudy day with no rain
7.8.95	660.61	474.43	Cloudy day with rain
9.8.95	826.11	579.4	Cloudy day with rain
10.8.95	549.18	382.25	Cloudy day with rain
11.8.95	580.20	415.06	Cloudy day with rain

Table 6.1(a): Maximum values of global radiation (I_R) and net radiation(R_n)

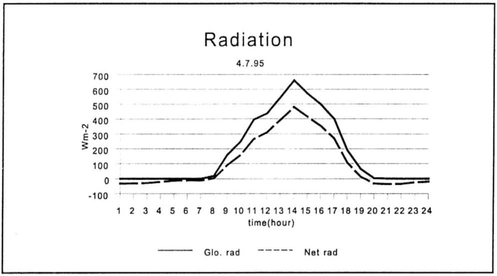


Figure 6.1: Values of global radiation(I_R) and net radiation(R_n) for a day with clear sky

1. The only day that can be considered as a day with clear sky in this period of study was on 4.7.95 which is shown in figure 6.1 above. The global radiation and net radiation was observed to increase at an average constant rate of 80 Wm^{-2} / hr gradually until it reached a maximum at hour 1400 LT. Then radiation decreased at an average constant rate of 90 Wm^{-2} / hr until 2000 LT when it begins to be uniform with time. From the observations, the global radiation begin at about 0700 LT or so in the morning and cease after 2000 LT or so in the evening. The net radiation indicated a negative sign during the nighttime. This is because the incoming radiation is zero, whereas at the same time the earth surface release the infrared radiation into the atmosphere.

2. The cloudy days with no rain occurred on 30.6.95(fig.6.1a), 5.7.95(fig.6.1b), 6.7.95(fig. 6.1c), 7.7.95(fig.6.1d), and 27.7.95(fig.6.1e) . All the results are presented on the graphs below :

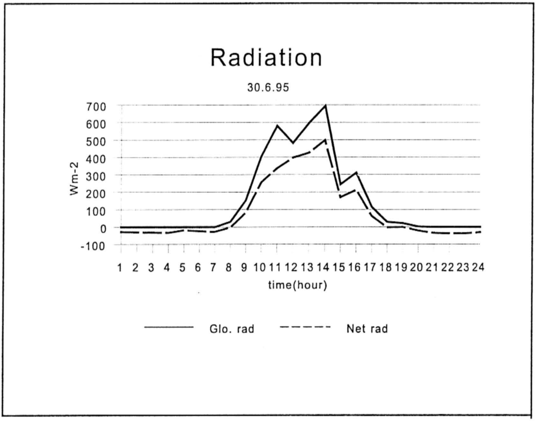


Figure 6.1a: Cloudy day with no rain on 30.6.95

Figure 6.1a shows both net radiation and incoming curves increase steadily with time until 1100 LT, when cloudy skies begin to develop over the site between1100 LT to 1200 LT and 1400 LT to 1500 LT as shown by the days in the results. The radiation values then decrease steadily until sunset.

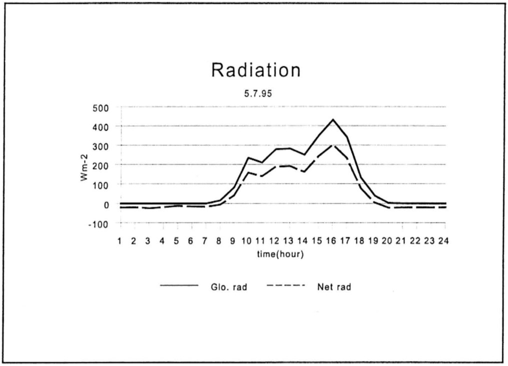


Figure 6.1b: Cloudy day with no rain on 5.7.95

A strong cloud effects on the radiation was shown in figure 6.1(b). It can be seen that it started at 1000 LT in the morning and continued until 1600 LT in the afternoon.

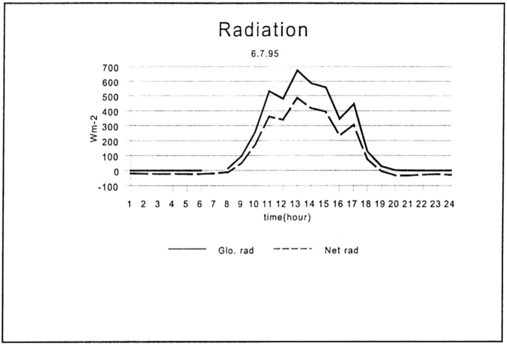


Figure 6.1c: Cloudy day with no rain on 6.7.95

Figure 6.1(c) shows the cloudy skies begin at 1000 LT in the morning and was maintained until 1600 LT in the afternoon. So during these period the global radiation and net radiation values fluctuated in respond to the passage cloud over the site.

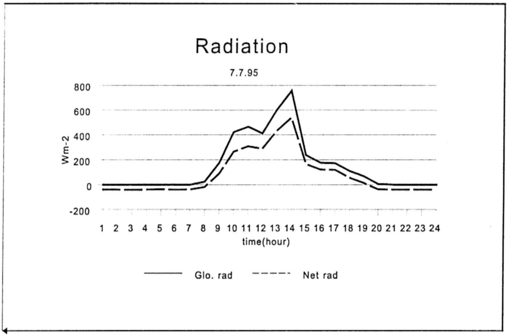


Figure 6.1d: Cloudy day with no rain on 7.7.95

Figure 6.1(d) shows a strong cloud effects on the radiation. It happened between 1000 LT - 1200 LT in the morning and again between 1400 LT to 1700 LT in the afternoon.

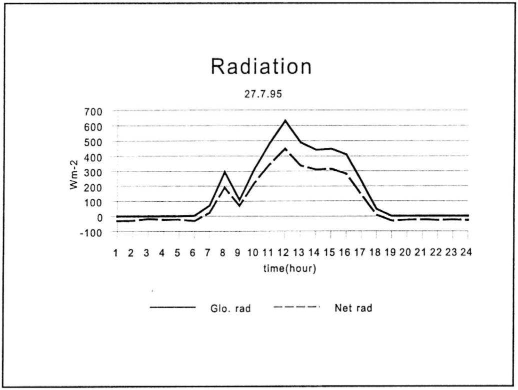


Figure 6.1e: Cloudy day with no rain on 27.7.95

Figure 6.1e shows the cloudy skies only occurred at 0800 LT to 0900 LT in the morning and slightly cloudy at 1200 LT to 1500 LT in the afternoon.

Figure 6.1a to 6.1e indicated that the cloud cover occurred between 1100 LT to 1600 LT. The albedo from the cloud cover reduced the value of global radiation to as low as 400 Wm^{-2}(5.7.95) in comparison to the normal maximum of about 700 Wm^{-2} (e.g on 30.6.95). The amount of cloud cover strongly modulate the amount of radiation that can reach the surface.

From the observation when there were considerably thick cover of clouds the values of global radiation can dropped more than 100 Wm^{-2} in an hour. According to table 6.1(b), on 30.6.95, 6.7.95 and 27.7.95 the global radiation was reduced as much as 100 Wm^{-2}, while on 7.7.95 the amount reduced about 500 Wm^{-2} which represent a very significant reduction due to thick cloud cover over the site.

Date	Changing global radiation/Wm^{-2} at different times	The amount reduced/Wm^{-2}
30.6.95	radiation(time) radiation(time) 580(1100) ⇒ 480.78(1200)	99.22
6.7.95	1) 529.75(1100) ⇒ 478.25(1200) 2) 557.54(1500) ⇒ 344.23(1 600)	51.5 213.31
7.7.95	755.85 ⇒ 237.00(1500)	518.85
27.7.95	1) 292.32(0800) ⇒ 107.92(0900) 2) 630.1(1200) ⇒ 488.4(1300)	184.4 141.7

Table 6.1(b): Values of global radiation reduced by thick cloud cover

3. Cloudy days with rain occurred on 1.7.95(fig.6.1f), 7.8.95(fig.6.1g), 9.8.95(fig.6.1h), 10.8.95(fig.6.1i) and 11.8.95(fig.6.1j). Generally, the types of rain can be divided into either heavy rain and light rain. Heavy rain episode is usually accompanied by an increase turbulence and strong wind.

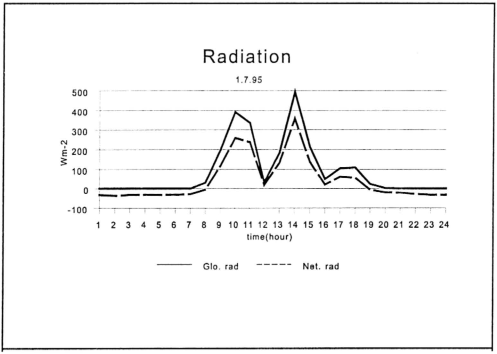


Figure 6.1f: Cloudy day with rain on 1.7.95

In figure 6.1f, heavy rain occurred in the middle of the day (1100 LT) where the amount of rain recorded was 24.4 mm. It can be seen that the amount of radiation dropped significantly at 1200 LT .

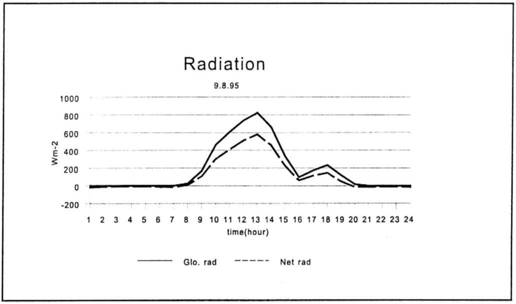


Figure 6.1g: Cloudy day with rain on 9.8.95

In figure 6.1g, the intensity of global radiation and net radiation increased gradually until midday. But it rained at hour 1500 LT and the amount of rain was only 1.5 mm and it rained again at hour 2000 LT to 2100 LT (9.8mm). The rain was considered not heavy and there was a rapid change of global radiation from 1400 LT to 1600 LT; from the value of 660.62 Wm^{-2} to 98.38 Wm^{-2}.

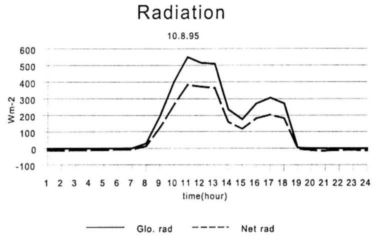


Figure 6.1h: Cloudy day with rain on 10.8.95

In figure 6.1h, clouds cover started to develop at about 1100 LT accompanied by a rapid decrease of global radiation (273.38 Wm^{-2}) followed by heavy rain at 1800 LT. The heavy rain period last for about one hour in which the total rainfall recorded was 38.4 mm. The maximum global radiation and net radiation varied from 600 Wm^{-2} and 400 Wm^{-2} respectively over this period. This heavy rain which usually occur in a short period in the afternoon is a normal phenomenon during end of the South-West monsoon period of the year.

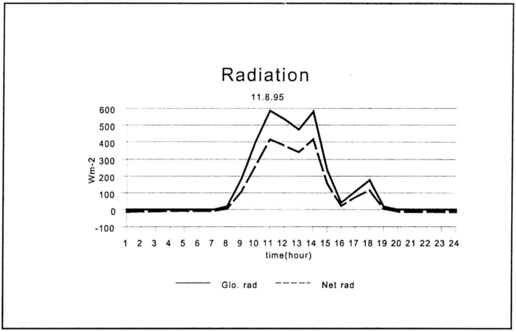


Figure 6.1i: Cloudy day with rain on 11.8.95

In figure 6.1i above, the cloudy skies started at the middle of the day (1100 LT to 1300 LT) and heavy rain fall was recorded for half an hour at about 1500LT (18.4 mm). The rain continued until late in the afternoon but the amount of rainfall was small (1.8 mm).

Figure 6.1(f) to 6.1(j) showed the variation of global and net radiation for the cloudy skies followed by rain. The rain tend to occur in the afternoon and the values of incoming radiation and net radiation was observed to drop more than 200 Wm^{-2} in the daytime. In case of nocturnal rainfall, the radiation values during the preceding afternoon period was also decrease due to the presence of cloud cover.

These observations showed that typically the rain tend to occur late in the afternoon. This normally happens in the humid tropical climate due to the strong convection associated with solar insolation at the surface.

According to the observation, generally there are two types of cloud cover during the overcast periods. The first is the heavy cloud cover which reduced the amount of global radiation by more than 100 Wm^{-2} and the other is a thin or patchy of cloud cover which reduce the global radiation by less than 100 Wm^{-2} .

		Net radiation (Wm^{-2})/nighttime	
Date	Weather condition	Minimum	Maximum
30.6.95	no rain	-38.181	-0.393
1.7.95	rain	-36.831	-5.402
4.7.95	no rain(clear sky)	-35.296	-12.067
5.7.95	no rain	-24.291	-5.784
6.7.95	no rain	-33.50	-5.223
7.7.95	no rain	-40.017	-17.18
27.7.95	no rain	-31.478	-16.818
7.8.95	rain	-14.693	-7.112
9.8.95	rain	-18.16	-6.323
10.8.95	rain	-15.455	-2.075
11.8.95	rain	-14.186	-7.352

Table 6.1(c): The nighttime maximum and minimum values of net radiation

Table 6.1(c) shows minimum and maximum values of the nocturnal net radiation. The range for the maximum was -14.186 Wm^{-2} to -40.017 Wm^{-2} which the range of the minimum was between -0.39322 Wm^{-2} to -17.18 Wm^{-2}. At nighttime, the values of net radiation, R_n is often negative showing the net upward longwave radiative cooling to space. For the cloudy days with no rain, there were more longwave radiation emitted to the air layer above the ground compared with the days with rain. This is due to the fact that rain can reduce surface temperature rapidly and hence decrease the flux of longwave radiated.

According to the hourly cloud cover data recorded at the meteorological station in Subang, it was observed that during nighttime the cloud cover was as much as that during the daytime. Subang meteorological station is about 20 km from University Malaya. The hourly average was 7 oktas for both day and night which means that the skies was almost fully covered with cloud (see appendix 3). The data showed that not only during daytime the cloud cover can be seen from the global radiation data but there was an existence of cloud during nighttime which can influnce the energy balance equation. There was not much difference between cloudy days with rain and cloudy days with no rain except when it rained, the values of global radiation and net radiation dropped to small values. Whereas, in the cloudy days with no rain the phenomena is only temporary when site is under the shadow of the cloud. So, the values of global radiation and net radiation fluctuate in response to it. The perfectly clear day is difficult to obtain since clouds in the humid tropical region is dominant and tend to occur almost all the times.

6.2 Surface temperature (T_o), soil temperature (T_d) and ground heat flux, G.

The calculation of ground heat flux using equation in 5.6, is based on the differences between the surface temperature, T_o and the soil temperature, T_d at depth, d(cm).

The daily variation of T_d were smaller than that of T_o. This is because the soil is a weak conductor so that the flow of heat into the soil is slow during the day. Because of this characteristic also, it takes time to release the heat back into the atmosphere during nighttime. The graphs shows that the values of T_d exceeded T_o at night while T_d is less than T_o during daytime. It means that the air layer at the surface is warmer than the soil a few centimeters underground during daytime but the soil in turn is warmer then the air at the surface during nighttime. This can be seen in table 6.2(a) and also in figure 6.2(a)-figure 6.2(e), with the highest and lowest values of T_o and T_d that can be obtained at the site . The average daytime maximum and nighttime minimum for T_o were 35^{o}C and 25^{o}C respectively; whereas for T_d it was 30^{o}C and 27^{o}C respectively.

The temperature range at the depth of 7 cm in the soil during the period of observation was between 26°C to 31°C in comparison with the surface temperature which was between 24°C to 37°C. It can be seen that the air at the surface lost its heat at a much faster rate than the soil. Max T_o is more than Max T_d and min T_o is less than min T_d for all days.

	T_o(°C)		T_d(°C)	
Date	Max	Min	Max	Min
27.7.95	34.52	25.99	29.42	28.24
7.8.95	35.02	25.70	30.58	26.62
9.8.95	37.48	24.51	31.09	26.66
10.8.95	34.14	25.48	30.13	27.32
11.8.95	35.43	25.34	30.25	27.04

Table 6.2(a): Maximum and minimum values for grass surface temperature(T_o) and soil temperature(T_d) at 7 cm depth

Figure 6.2(a) - 6.2(e) present a variation of T_o and T_d together with the values of ground heat flux, G respectively. From the figure, it can be seen that the time when T_o exceeded the T_d was at about 0900 LT or so in the morning. The variation of T_d was smaller than of T_o. So, the differences between these two temperatures resulted in the values of ground heat flux, G with its curve more likely to follow the curve of T_0 . The highest value of G observed was 27.532 Wm^{-2}(table 6.2(b)). This usually occurred at the same time when the net radiation was also maximum. The time to reach the peak value was at 1300 LT or so.

Date	G (Max)/Wm^{-2}
27.7.95	20.946
7.8.95	18.504
9.8.95	27.532
10.8.95	22.389
11.8.95	19.664

Table 6.2(b): Maximum values of ground heat flux, G for 5 days of observations

The results showed that the values of ground heat flux were very small, approximately 5% compared to the values of net radiation during the daytime. However, in the nighttime the ground heat flux was almost 50% the values of net radiation (Appendix 2). This indicate the greater values of ground heat flux in an upward transfer of heat during nighttime. Ground heat flux is positive during the day and negative at night.

Regarding to Kizer et. Al, 1990, the daytime ground heat flux were also approximately 5% of the net radiation. Whereas nighttime values showed the rapid increment of ground heat flux after sunset when compare with net radiation G exceeded from 21% up to 100%. However , the difference between the two values is extremely high an hour before the sunrise where the values of R_n is relatively small compare with G. This also happen at the hour of the sunset with the difference is lesser than during the sunrise.

The detail explanation in the fluctuation of the hourly values of T_o, T_d and G are described as follow:

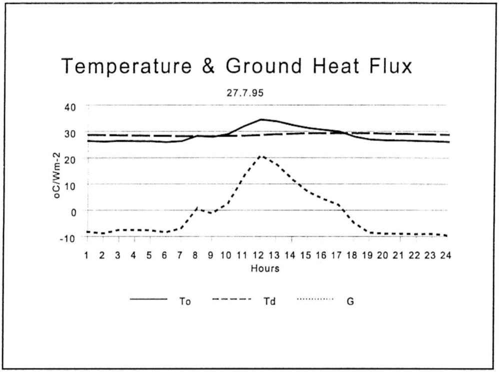


Figure 6.2(a):Temperature and ground heat flux on 27.7.95

Figure 6.2(a) shows the variation of temperatures and ground heat fluxes. Basically, the intensity of G depends on the values of T_o and T_d. Even though there was no rain on this day (figure 6.2(a)) but there was some cloud effects in the morning at 0700 LT to 0900 LT and also during period 1200 LT-1500 LT. So, the curve was distorted due to the situation. The result also showed that the variation of G was similar to that of global radiation and net radiation.

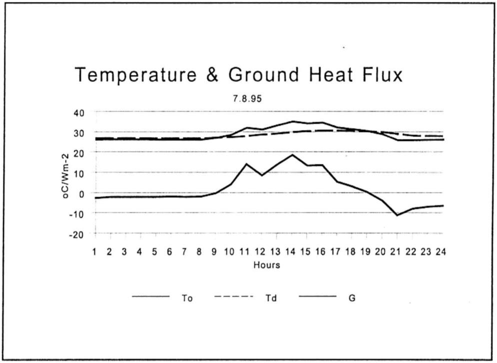


Figure 6.2(b): Temperature and ground heat flux on 7.8.95

In figure 6.2(b), the values of G were almost zero in the early morning but late in the afternoon the values were close to -10 Wm^{-2}. This is because the temperature were relatively high in the early morning since there was no rain the night before but when the rain occurred at 2000 until 2100 LT then the values of G dropped. The rain had a significant effect on the value of G.

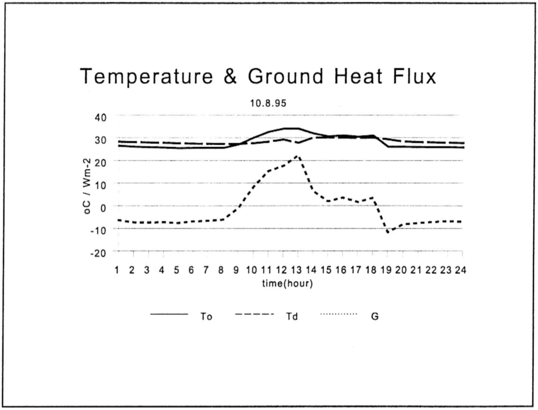


Figure 6.2(d): Temperature and ground heat flux on 10.8.95

Figure 6.2(d) showed that the values of G dropped suddenly after 1300 LT due heavy cloud cover and when rain occurred between 1700 LT until hour 1900 LT with the values further decreased below -10 Wm^{-2}. G recovered after the rain stopped.

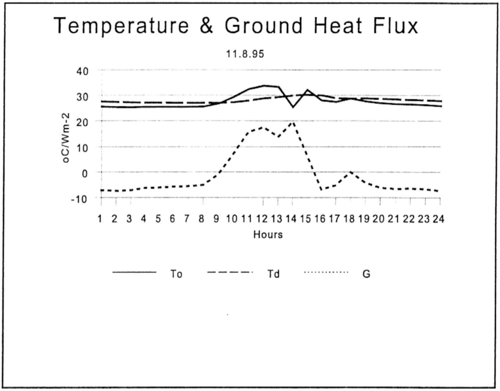


Figure 6.2(e): Temperature and ground heat flux on 11.8.95

Figure 6.2(e) shows G increased steadily from the early morning until 1100 LT then it decreased because of the cloud cover (1100 LT-1300 LT) and G dropped significantly (12 Wm^{-2}) when rain occurred at 1500 LT.

Generally, the ground heat flux is closely related to the surface temperature. The amount of net radiation determined the rate of temperature available at the ground surface and also the occurrence of rain reduced the ground heat flux rapidly. As can be seen from each of the figures, if surface temperature increases, G also increases but if surface temperature decreases due to the cloud cover or rain, the values of G also decreases.

Clouds decrease not only the values of global radiation but also ground heat flux. If cloudy in the morning, an upward transfer of heat showed by the negative value of G instead of positive during early morning. For instance, on 27.7.95 with -1.186 Wm^{-2} at 0900 LT . Ground surface still released G to the adjacent air after sunrise at 0800 LT.

If there was heavy rain, followed by G released to the atmosphere and also the values of global radiation was also negative. This can be seen on 7.8.95 at 2000 LT and 10.8.95 at 1900 LT. These days were rainy in the early evening.

In a case of rain occurred in the afternoon especially with the small amount of rain or moderate, also followed by the an upward transfer of G. Even though there was a small global radiation after that (+ values) but it did not have enough energy to heat the ground surface and hence there is no absorption by the ground as the sunset occurred soon after that. This phenomena can be seen on 9.8.95 (1500LT) and 11.8.95 (1500LT). So, rain has a great influence on both global radiation and ground heat flux.

6.3 Surface wind

The wind condition in all the eleven days of observation were calm during the nighttime and the wind velocity were small or low during the daytime. The maximum wind velocity was no more than 2 m/s. Normally, it was around 1 m/s. For instance, on 30.6.95 the highest wind velocity recorded was only 0.3366 m/s. Table 6.3(a) shows the maximum values for selected days.

Date	Maximum velocity (m/s)
30.6.95	0.3366
1.7.95	1.7744
4.7.95	1.186
5.7.95	0.39708
6.7.95	0.52271
7.7.95	0.57125
27.7.95	0.97979
7.8.95	0.59562
9.8.95	0.55437
10.8.95	0.53979
11.8.95	0.89521

Table 6.3(a): The maximum horizontal wind velocity

The wind speed tend to increase with rainy period, for instance on 1.7.95 (figure 6.3(c)), at 1100 LT - 1400 LT, the wind velocity was 1.7744 m/s. Figure 6.3(a) - 6.3(c) shows a variation of surface wind velocity during selected period of observations.

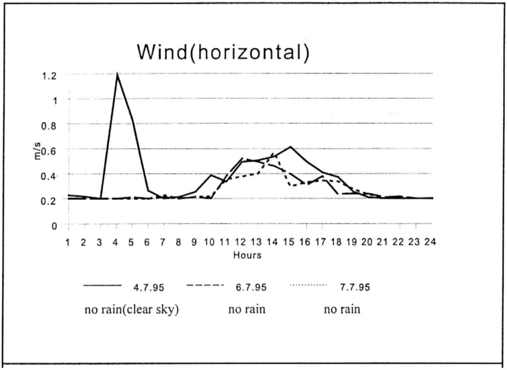


Figure 6.3(a): Horizontal wind speed for days with no rain.

The result in figure 6.3(a) showed that the variation in wind speed did not exceed 0.6 m/s except for a distinct peak in the early morning on 4.7.95. Usually it was observed that the maximum values of wind speed tend to coincide with the maximum of global radiation and net radiation, i.e. in the afternoon. During cloudy days , the wind speed was decrease in comparison to days of clear sky. A high value of wind speed was observed at about 0400 LT on 4.7.95 when the sky was clear at hour 0400 LT in the early morning. This might be due to the situation where there was turbulence but there was no rain.

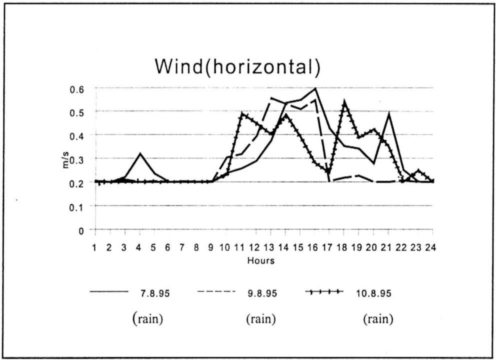


Figure 6.3(b): Horizontal wind speed for days with rain

Figure 6.3(b) showed more fluctuation of wind speed during the period of rain. It can be seen that when it rain heavily, the wind speed also increased, even though the rate of increment was not that high. Comparing figure 6.3(a) and 6.3(b), the time for the wind speed to exceed 0.2 m/s when there was no rain is shorter(0900 LT - 2200 LT). However, during days with rain or no rain, the wind speed was at the same range of between 0.2 m/s up to 0.6 m/s.

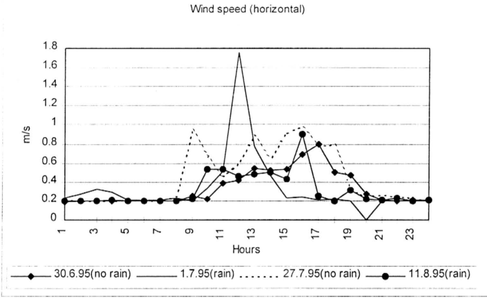


Figure 6.3(c): Horizontal wind speed for days with no rain and with rain

The results showed when there was no rain (27.7.95 & 30.6.95), the wind speed was reduced as the intensity of the radiation reduced (cloudy) and the wind speed increased during periods of heavy rain (1.7.95 & 11.8.95). (Figure 6.3(c)).

The existence of a relatively high wind speed in the early morning at about 0400 LT observed on 4.7.95 with a direction of 260^{o} from north could be due to the existence of squall-lines in the Straits of Malacca. These Squall-lines tend to occur during the southwest monsoon (May-August) which are often accompanied by violent thunderstorms. These always appear at night or early morning and usually last for about an hour.

Average wind velocity.

Time(hour)	Average wind velocity (m/s)			
	30.6.95 no rain(cloudy day)	**1.7.95 (rain)**	**4.7.95 no rain(clear sky)**	**5.7.95 no rain(cloudy day)**
0100 - 0600	0.1982	0.2552	0.4856	0.2126
0700 - 1200	0.2810	0.5434	0.3149	0.3059
1300 - 1800	0.6013	0.3557	0.4892	0.2035
1900 - 2400	0.2626	0.1668	0.2109	0.2412

Time(hour)	Average wind velocity (m/s)			
	6.7.95 no rain(cloudy day)	**7.7.95 no rain (cloudy day)**	**27.7.95 no rain (cloudy day)**	**7.8.95 (rain)**
0100 - 0600	0.2022	0.2002	0.2056	0.2292
0700 - 1200	0.2883	0.2655	0.5187	0.2308
1300 - 1800	0.3797	0.3805	0.8312	0.4715
1900 - 2400	0.2174	0.2188	0.2516	0.2925

Time(hour)	Average wind velocity (m/s)		
	9.8.95 (rain)	**10.8.95 (rain)**	**11.8.95 (rain)**
0100 - 0600	0.2031	0.2	0.2001
0700 - 1200	0.2693	0.2951	0.3580
1300 - 1800	0.4263	0.3891	0.4598
1900 - 2400	0.2053	0.3012	0.2301

Table 6.3(b): The average values of wind velocity(m/s)

Based on the average downward transfer of wind velocity, the wind speed tend to increase between 1300 LT - 1800 LT increasing the momentum due to convection. The latent heat flux and the sensible heat flux were also greater during the same period of time. The rate of evaporation will increase if the rate of wind speed increases since the wind can advect away the saturated air over the evaporative surface and replace it with dry air. The slow wind speed may not be an important parameter in determining the amount of evaporation but the wind helps in the process of evaporation.

6.4 Latent heat flux, LE and sensible heat flux, H from eddy correlation technique.

Figure 6.4(a) - 6.4(e) shows a variations of sensible heat and latent heat flux for five selected days of observation. The average hourly value of vertical wind(w) was observed to be small. It was greatest during the day, with either positive or negative values and it was generally less than 0.2 m/s.

The variation patterns shows that there was a relationship between the value of LE calculated using the EC method with cloudy sky and rain episode. This will be discussed for each selected observation. During the daytime the values of H were very small compared to the values of LE . Whereas during nighttime, there was not much difference between LE and H. Both fluxes decrease and fluctuate in a similar manner. The maximum values of LE obtained during the observation period was 373 Wm^{-2} on 11.8.95.

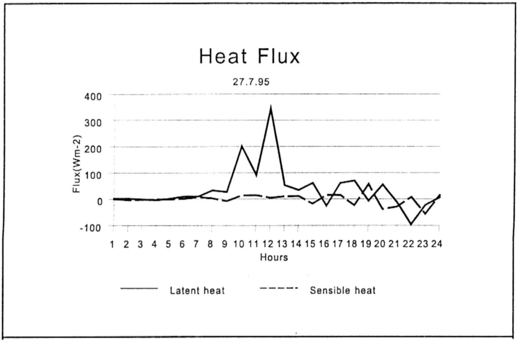


Figure 6.4(a): Latent heat flux and sensible heat flux on 27.7.95

Figure 6.4(a) showed that LE tend to increase from 0700 LT am until 1000 LT am and then decreased for an hour between 1000 LT to 1100 LT and 1200 LT to 1600 LT due to the effect of cloud cover. The wind speed will not contribute an effect to LE and H during daytime due to its small values. During nighttime it was observed that the values of H were more than LE after 2000 LT and is positive sign compared to LE which was negative. This could be due to contribution of sensible heat flux from the warmer soil. On the other hand, values of H were small during daytime in comparison to LE, indicating the important of evaporation.

Figure 6.4(b) shows in the early morning, LE and H had a small values, about zero point. Light rain had occurred around 0600 LT to 0700 LT that might have given some effect to the results. During daytime there was some fluctuation between 1100 LT to 1200 LT due to cloud cover over the site (accompany with a decreased of global radiation and net radiation). Another period of cloud cover also observed during 1400 LT to 1600 LT. With decrease in energy reaching the earth surface, the evaporation that can take place will also decrease and so as the LE and H. Whereas during nighttime the values of H were close to zero and LE gave more fluctuation with negative and positive sign. Rain occurred again between 2000 LT to 2300 LT so this gave some effect to the results also. There was a higher LE just before rain fall (at 1100, 2000 and 2300 LT). This is due to the process whereby turbulence induced by friction between air and the underlying ground surface which increase the LE from the ground surface immediately before rain fall.

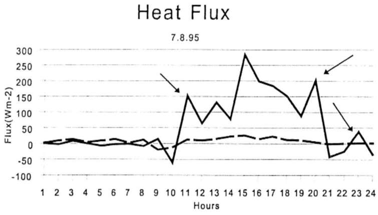


Figure 6.4(b): Latent heat flux and sensible heat flux on 7.8.95

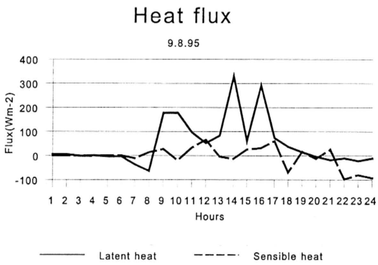


Figure 6.4(c):Latent heat flux and sensible heat flux on 9.8.95

Figure 6.4(c) showed the fluctuation of LE and H during a clear day where the wind speed was variable until 1300 LT. Light rain occurred at 1500 LT. The LE values fluctuated from negative in the early morning, 0700 LT to 0800 LT and became positive from 0900 LT to 1200 LT. During the light rain period LE decrease rapidly, due to decrease in global radiation. The sensible heat flux, H fluctuated with small positive values during daytime and a negative or near zero values in the nighttime. The sensible heat flux was -100 Wm^{-2} at about 2200 LT and 2400 LT indicating a downward transfer of heat flux from atmosphere to the surface. During the same period LE was observed to be slightly negative, indicating a downward transfer of moisture too.

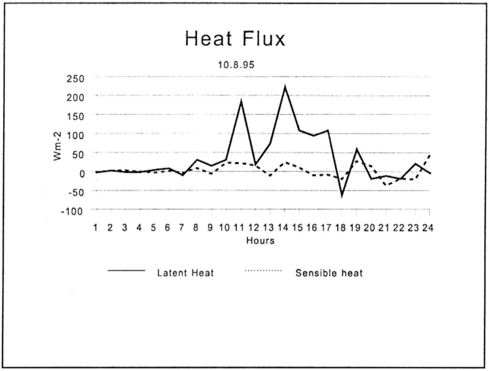


Figure 6.4(d): Latent heat flux and sensible heat flux on 10.8.95

Figure 6.4(d) showed that the maximum of LE and H was at 1100 LT and this is at the same time for the maximum of global and net radiation (figure 6.1h). It started to decrease further with cloudy skies. The rain that occur between 1700 LT to 1900 LT resulted in a decrease in LE . It can be seen that the decrease in radiation lead to a decrease in LE and H. It is also seen that when heavy rain occurred LE decrease and was negative.

In figure 6.4(e), LE and H begin to decrease at 1000 LT until 1300 LT associated with the cloudy skies. LE and H increased until reached a maximum at about 1400 LT. Between 1500 LT to 1600 LT it rained and 1800 LT to 1900 LT the values decrease due to rain. After the rain had stopped , LE increased again at 2000 LT to 2100 LT before dropping to negative values. H values did not behave in a similar manner during this period.

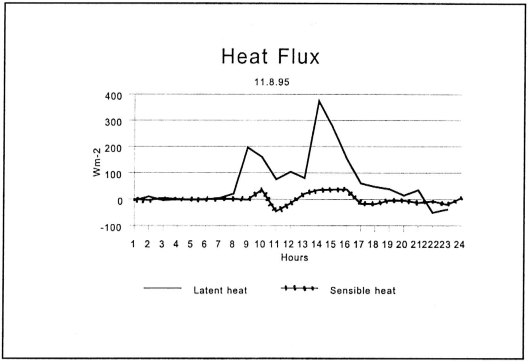


Figure 6.4(e): latent heat flux and sensible heat flux on 11.8.95

From figures 6.4(a)-6.4(e), it was observed that usually the heat flux begin to be significant from about 0900 LT up to 2200 LT. After this the heat flux fluctuate around zero until the early morning (0100 LT-0700 LT).

When there were cloudy days with no rain, for instance on 27.7.95, LE was observed to increase as net radiation increase and decrease with increase cloud cover. The maximum value of LE recorded in the daytime was 343.5 Wm^{-2}. At night the value of LE is usually negative. This indicate a downward transfer of moisture. The value of H in comparison to LE is smaller, with a daytime maximum is 15.9 Wm^{-2}. At night H too was observed to be near zero or slightly negative. Hence, LE and H tend to vary in a similar manner.

For the days with rain, both values of LE and H decreased during cloudy episode, e.g on 10.8.95 when net radiation rapidly decrease from 382.25 Wm^{-2} to 118.01 Wm^{-2} (1100LT- 1500LT), LE decrease from 183.269 Wm^{-2} to 107.43 Wm^{-2} .Similar H decrease from 22.36 Wm^{-2} to 10.869 Wm^{-2}. It was observed that the effect of cloud plays an important role in modulate LE and H. This indicate the important of solar radiation in the transfer of LE and H.

On some occasion in the day, LE was observed to decreased significantly with an increase in global radiation, such as on 27.7.95 at 10.00 LT-1100 LT and also on 9.8.95 at 1000-1100 LT. This could be due to the fact that in the morning, the morning solar radiation use to evaporate dew that had developed overnight on the surface. After the dew has been evaporated, there was a drop of LE, since now the source of moisture is from evapotranspiration from the vegetation. Hence, evaporation is not a continues process, but is also dependent on other factors such as vegetation cover.

Usually a decrease in global radiation indicated the existence of cloud over the site will normally result in a decrease in LE. However LE could decrease eventhough global radiation increase due to the above factors since LE is control by different moisture sources.

If rain occurred late in the afternoon, there was a slight increase in LE after rain stopped due to availability of moisture at the surface after, e.g on 7.8.95 at 2200 LT-2300 LT and 10.8.95 at 2000 LT-2100 LT. At the same time warm soil surface released heat to the atmosphere. This energy consumed in the evaporation in the early night will increase LE with positive values and negative H. This last for about two hours and then decrease again after there was no more supply of energy.

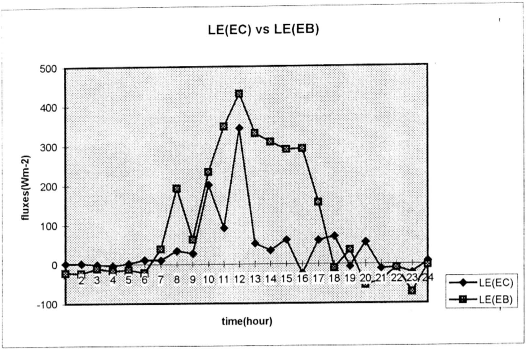
6.5 The estimation of latent heat from eddy correlation and energy balance equation.

Figure 6.5(a) - 6.5(e) describes a relationship of latent heat obtained from eddy correlation (LE) and energy balance equation (residual LE). A basic regression analysis of the form Y = mX + C was perfomed between the two estimates. Where Y is residual LE and X is LE from EC.

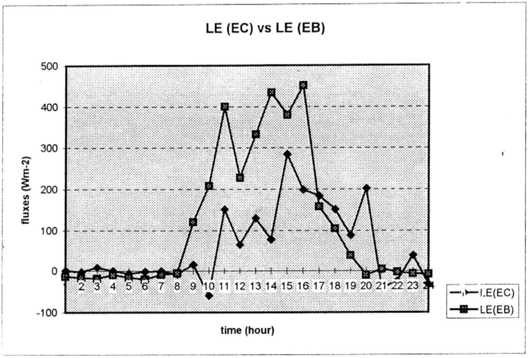
The results have shown that the values derive from the energy balance estimate were higher than the values from the eddy correlation (figure 6.5a - figure 6.5e). The highest value of interception was -37.14 (11.8.95) and the lowest was -58.60 (10.8.95). The average value was at the -51.6211.

Analysis of the correlation coefficient showed that, the latent heat of eddy correlation and the residual latent heat of the energy balance equation showed a good correlation with positive values of correlation coefficient. The values were 0.624 (27.7.95), 0.624 (7.8.95), 0.554 (9.8.95), 0.484 (10.8.95) and 0.556 (11.8.95). This indicates that both methods showed similar fluctuations, but have different absolute values (appendix 4).

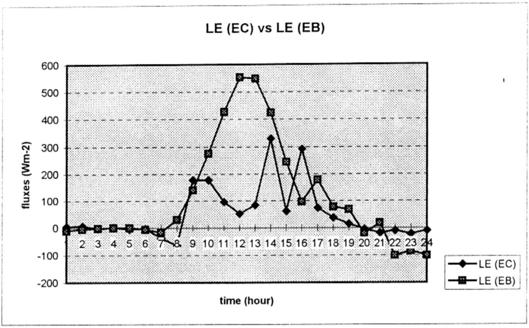
The EC technique can be checked by looking at the difference between the daytime available energy (R_n-G) and the turbulent fluxes (H+LE) where LE is from EC. The results showed that the daytime available energy was more than the turbulent fluxes (figure 6.5f to figure 6.5j) . The difference is greatest at about midday (around 1200 LT-1300 LT). The underestimate of daytime LE using EC is accepted since this technique measures the vertical movement of water vapour irrespective of the horizontal transfer of moisture.



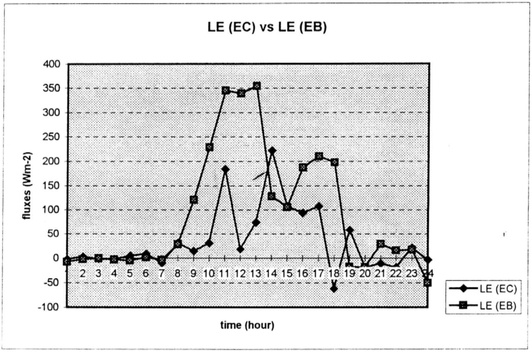
date : 27.7.95 Figure 6.5(a)



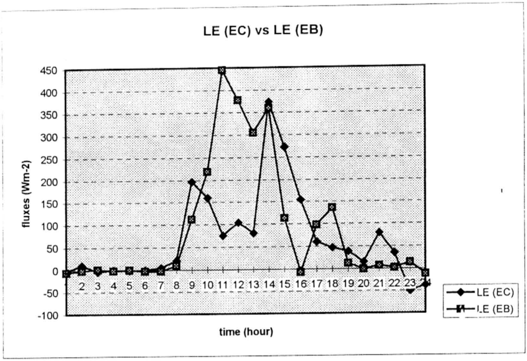
date : 7.8.95 Figure 6.5(b)



date : 9.8.95 Figure 6.5(c)



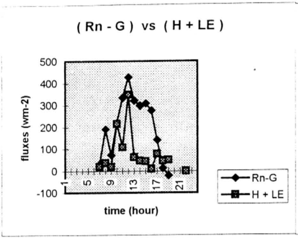
date : 10.8.95 Figure 6.5(d)



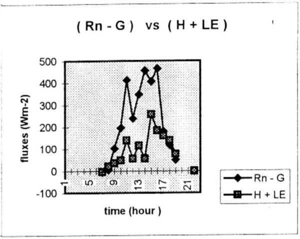
date : 11.8.95

Figure 6.5(e)

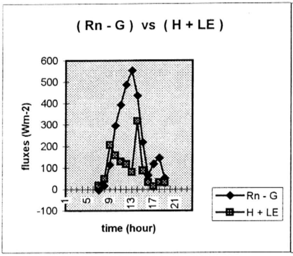
Figure 6.5(a)-figure 6.5(e): The graphs shows values of latent heat fluxes obtained from EC technique and energy balance equation for 5 days of observations.



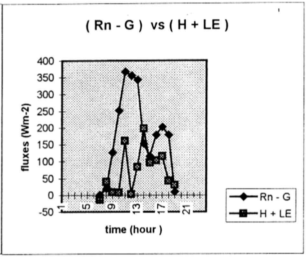
27.7.95 (f)



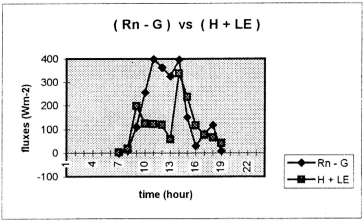
7.8.95 (g)



9.8.95 (h)



10.8.95 (I)



11.8.95 (j)

Figure 6.5

Figure 6.5(f)-figure 6.5(j): The graphs shows values of available energy(R_n-G) and turbulent fluxes(H+LE) for 5 days of observations.

6.6 The variation of surface energy budget in response to the daily weather condition obtained by eddy correlation technique.

Cloudy days with no rain.

Daytime

During daytime with sunrise, the radiation increased indicating an energy gain at the surface. This is followed by the increment in ground heat flux , G with the intensify with surface temperature. These two fluxes showed the positive values of net radiation which indicate a downward flux to the surface. Whereas sensible heat, H and latent heat, LE fluxes were also positive with an upward transport away from the surface. Their values were also enhanced by the supply of energy from the ground surface since there was energy storage at the surface where the available energy (R_n - G) was more than the turbulent fluxes (H+LE). In other words, if R_n increased the values of LE, H, and G will also increase (see appendix 1).

Cloud absorbs the incoming radiation which reduces the values of net radiation , R_n. Thus, the LE , H and G tend to decrease with heavy cloud cover, hence resulting in the LE and H close to zero. This will recover again after the cloud dissipate. It can be seen sometimes that the values of LE and H was negative during overcast period. The cloud itself absorbed the radiation from the atmosphere, which reverses the flows of heat from downward direction to upward direction.

Time (hour)	Net rad, Rn(Wm^{-2})	Ground heat flux,G(Wm^{-2})	Sensible heat Flux, H(Wm^{-2})	Latent heat flux, LE(Wm^{-2})
0700	23.535	-6.911	8.007	9.582
0800	190.94	0.5	2.424	33.343
0900	69.796	-1.186	**-7.998**	26.844
1000	222.51	2.639	14.101	201.19
1100	346.36	13.207	14.633	92.032
1200	447.53	20.946	4.97	343.5
1300	337.3	17.486	10.471	52.138
1400	308.86	11.804	11.486	33.998
1500	314.71	7.143	**-17.718**	60.986
1600	280.3	4.393	15.993	**-24.986**
1700	142.37	2.104	15.909	60.656
1800	7.949	-4.689	**-23.723**	70.177

Table 6.4(a): Daytime heat fluxes on 27.7.95 shows an upward heat transfer

Figure 6.1(e) and figure 6.2(a), showed that during extensive cloud cover, the incoming radiation and net radiation can be reduced by as much as 100 Wm^{-2}/hour whilst the surface temperature also decreased by as much as 1^{o}C/hour . However, the wind speed at the surface could increase to ~ 1 m/s from figure 6.3(c). The maximum reached by the fluxes is at the middle of the day and then the values decrease until sunset . It means that if R_n decrease so are the LE, H and G.

Nighttime

During nighttime there is no radiation, so there is a net outgoing net radiation away from the surface, indicated by the negative values of radiation fluxes, together with the loss of heat by the ground surface. LE and H are mostly negative (indicate downward flux to the surface). LE values fluctuated with less than 100 Wm^{-2}/hour and H had values sometimes the opposite sign of LE . On the average the values of H is bigger than LE .

It is assumed that there is no radiation received by the surface from a clear sky but for a cloudy night , as cloud can be regarded as a black body at the temperature of its lower surface from which the surface will receive radiation. Thus low clouds can reduce loss of heat by the surface and this explain small contribution of LE during nighttime. This phenomena showed by Monteith (1966) that at night when the air in the grass cover is saturated, evaporation takes place by the diffusion of water vapour from the soil surface through a thin layer of air. This is also included the nighttime cloud factor.

Cloudy days with rain.

Rain starts either late in the afternoon or at early night. Wind speeds typically increased during rain but there were occasions of rain but with calm wind (9.8.95). This is especially so, when the rain was not heavy. Cloudy episode reduces the potential values of net radiation and also the rest of the other fluxes. H flows downward from the atmosphere to the ground surface which is the reverse from its normal direction. Rain always occurs late in the afternoon or during nighttime and these resulted in LE and H descending to a small values or close to zero. If the amount of rain is small, the effect is not as significant in comparison with heavy rainfall. It can be seen that, values of LE and H are not constant during that period with negative values interrupted by the positive values. The wind speed is so small or considered as calm and should have no effect on the LE and H. There were great fluctuations of LE and H but the wind speed varied within small range of values. Thus, the wind had no great effect on LE and H. Although the wind speed was small, the peaks of LE and H were at the same point of maximum wind speed ÈC technique is not recommended to use under rain condition, since water will damage the transducers used in CA27 Sonic Anemometer.

If there is no energy flows of LE and H (the activity stopped) during rain, values of G also decreases (exceed - 10 Wm^{-2}) and the potential values of R_n that can be reached are also reduced. Thus, if there is no LE and H or only a small amount of it during this incident, the only variables/parameters left in the energy budget equation are only R_n and G.

Anyway this phenomena can happen clearly for heavy rain days only. This can be seen on 10.8.95(table 6.4(b)) where the amount of rain was nearly 40 mm.

Date	time of rain (LT)	Amount of rain (mm)	LE (Wm^{-2})	H(Wm^{-2})	(R_n-G)/ (Wm^{-2})
7.8.95	0600-0700 2000-	0.3 20.1	-0.792 -41.714	2.281 -1.158	-6.6308 -6.335
9.8.95	1500-1600 2000-2100	1.5 9.8	61.461 -4.009	26.306 -12.729	216.579 -9.5
10.8.95	1800-1900	**38.4**	**-62.725**	**-19.425**	**177.703**
11.8.95	1500-1600	18.4	273.07	36.448	149.471

Table 6.4(b): Values of latent heat(LE), sensible heat(H) and Rn-G during rain