**Principles and Performance of Solar Energy Thermal Systems*: A Web Course by***
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# Appendices

## A1 Exercises

***Shortly, more Exercises (Module wise) and the solution manual shall be included***

### Exercises Module 1

1.1 Compile the data on estimated oil, coal and natural gas reserves, region/location wise for India

1.2 Find and list the sources of meteorological information for Indian locations. *The exercises regarding specific information follow later!*

### Exercises Module 2

2.1 Estimate the radiation emitted by the sun assuming the sun to be a black body at an effective temperature of 5762 K. Stefan-Boltzman constant = 5.67 x$10^{-8}$ W/($m^2K^4$). The other data needed may be extracted from the subject material in this module.

### Exercise Module 3

3.1 What is the fraction of the solar radiation that reaches the earth's surface? (Hint: The total amount of radiation emitted is known from Exercise 2.1

3.2 Calculate the angle of incidence of direct radiation at 1100 solar time on January 20 at latitude of $28^0$ N on surfaces with the following orientations:

a. Horizontal
b. Tilted to south at slope of $35^0$
c. At slope of $35^0$, but facing $25^0$ east of south
d. Vertical, facing south
e. Vertical, facing west

3.2 Calculate the angle of incidence of direct radiation at 1100 solar time on June 20 at a latitude of $35^0$ N for surfaces with the following orientation:

f. Vertical, facing south
g. Vertical, facing north

3.3 Determine the sunset hour angle and day length for Srinagar and for Port Blair, for the following dates: Dec. 23, March 22, June 23.

3.4 When it is noon as per the clock time (or Indian Standard time), what is the solar time on Jan $20^{th}$ in Mumbai, (Latitude: 19° 1'N, Longitude: 72° 67' E) Kolkata (Latitude: 22° 39'N, Longitude: 88° 27' E), and Kohima (Latitude: 25° 40' N, Longitude: 94° 07' E) on Jan. 20.

3.5 What are the sunset hour angles and the day length for the following: i) $\varphi = 15^0$, $\delta = 15^0$: ii) $\varphi = 45^0$, $\delta = 23^0$: iii) $\varphi = 45^0$, $\delta = -23^0$: iv) $\varphi = 77^0$, $\delta = 15^0$: v) $\varphi = 82^0$, $\delta = -15^0$

**Exercise Module 4**

4.1 Consider TMY2 or TMY3 data meteorological data. The hour by hour meteorological data for 244 North American locations are available. You can find the website by simply giving TMY2 or TMY3 in 'Google'. Or try,
http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/
For any location of your choice, choose a month and a day in the month. a) Convert the data to solar time. b) Calculate $\bar{I}, \overline{I_d}$ and $\overline{I_b}$ for any hour you choose c) $H, H_d, H_b$ for all days in the month, d) hence calculate $\bar{H}, \bar{H}_d, \bar{H}_b$.

**Exercise Module 5**

5.1 What is the solar radiation received by a plane normal to sun's rays if the atmosphere is 100% transparent for the days, March 21, June 23, Sept 23 and Dec. 23.

5.2 What is the extraterrestrial radiation on a horizontal surface, $I_o$ at Chennai, ($\varphi$ = 13° 00' N ) during the hour 10.30 AM to 11.30 AM on Jan 15. What is the daily $H_o$ (for Jan 15) and the monthly (for January) average daily extraterrestrial radiation on a horizontal surface, $\overline{H}_o$ ?

**Exercise Module 6**

6.1 If the daily horizontal radiation for Jan 15, in the above problem has been measured to be 19.8 MJ/($m^2$-day), what is the daily clearness index?

6.2 If the global radiation on a horizontal surface has been found to be 1.8 MJ/($m^2$-hr) for the hour 10-11 at a location of latitude $40^o$, on monthly mean day of January, find the clearness index.

**Exercise Module 7**

7.1 Estimate the monthly average radiation for January and July from the average hours of sunshine data given for Poona., ($\varphi$=18° 32' N). The constants in the Angstrom relation, a=0.3 and b=0.51. The average sunshine hours in percentage of possible being 37 and the range 25-49.

7.2 Solar radiation on a horizontal surface integrated over the day of December 22nd at Srinagar ($\varphi$=34° 05' ) is 5.12 MJ/$m^2$. What is the clearness index, $K_T$, for that day? What is the estimated fraction of the day's energy which is diffuse?

7.3 Consider the location chosen in Exercise 4.1. a) Calculate the values of the hourly diffuse fraction for a chosen day. Compare the values thus obtained with the values that you would obtain by using the correlation for the hourly diffuse fraction. b) Compare the daily diffuse fraction values calculated from the data of the location chosen in Exercise 4.1 with the values obtained by using the correlation for the daily diffuse fraction. c) Compare the monthly average daily diffuse fraction value calculated from the data of the location chosen in Exercise 4.1 with the value obtained by using the correlation for the monthly average daily diffuse fraction.

**Exercise Module 8**

8.1 Estimate the ratio of direct radiation on a surface tilted $45^0$ toward the south to that on a horizontal surface, if located at a latitude of $40^0$ on March 1, **a** at noon, **b** at 3:30 pm.

8.2 Estimate maximum likely error in the ratio of direct radiation on a surface, facing south, tilted at $50^0$ , to that on a horizontal surface, if located at a latitude of $40^0$ on Nov. 15, for the hour, 11AM -12 Noon.

8.3 Estimate the ratio of direct radiation on a surface tilted $45^0$ toward the south to that on a horizontal surface, if located at a latitude of $40^0$ on March 1, **a** at noon, **b** at 3:30 pm.

8.4 At $\varphi=28^0$ on December 22, $K_T$ was 0.63.

. a. Estimate the total horizontal radiation for 10 to 11.
b. Estimate the direct and diffuse for 10 to 11.
c. What is $R_b$ for that hour?
d. If all the radiation is treated as direct, what is total radiation on the tilted surface for that hour?
e. If the diffuse radiation is isotropic , and ground reflectance is 0.2, what is $I_T$ for that hour?

8.5 The day's radiation on a horizontal surface in Srinagar ($\varphi$ = 34° 05') on a December 22 is 7.77 MJ/m$^2$. Estimate the diffuse radiation, ground-reflected radiation and the total radiation on a south-facing vertical surface during the hour 11 to 12. There is a fresh snow cover on the ground.

8.6 What will be the hourly direct and diffuse components of solar radiation on a collector on January 13 in Delhi ($\varphi$ = 28° 34' N ) at a slope of $45^0$, facing south. if the total radiation on a horizontal surface for that day is 7.9 MJ/m$^2$, and ground reflectance is 0.2?

**Some Exercises on Design Methods**

1. At a location of latitude $40^0$N, a process heating system employing flat plate collectors, facing south with a slope of $40^0$ ,of area 50 m$^2$ has been installed. The collector parameters are $F_RU_L$ = 2.63 W/m$^2$ $^0$C and $F_R(\tau\alpha)_n$=o.0.72. The system is required to supply energy at a minimum temperature of $60^0$C at a rate of 12 kW for 12 hrs a day. Assume that the ground reflectance to be 0.2. Calculate the following for the month of January if $\bar{H} = 8.6 MJ/(m^2 - day)$, $\bar{T}_a = -5^0 C$ .What is the critical radiation level? What is the non-dimensional critical radiation level? (From Duffie and Beckman [1])

2. In the Problem No. 1, above, what is the monthly average daily utilizability?

3. What is the solar load fraction met by the system for the specifications given in Problem 1.

4. Include the tank losses for the system described in Problem 1 and calculate the solar load fraction. The tank $(UA)_{tank}$=5.9 W/$^0$C and the surrounding temperature is $20^0$C.

5. For the system described in Problem 1, estimate the solar load fraction if the load heat exchanger has $\varepsilon_L C_{min}$=1350 W/$^0$C

6. A space heating system is to be designed for Srinagar φ=34° 05', for the month of December. Calculate the Degree days and the space heating load, if $(UA)_h$ =400 W/$^0$C, http://www.indiaenvironmentportal.org.in/files/srd-sec.pdf

7. A space heating system is to be designed for Srinagar φ=34° 05', for the month of December. Assume $\beta$=50$^0$ and $\gamma$=0With the space heating load calculated in Problem 6, obtain the solar load fraction if the liquid based solar collectors have, $F_RU_L$ = 2.63 W/m$^2$ $^0$C and $F_R(\tau\alpha)_n$=0.72, employ a storage tank of 125 l/m$^2$ and has a standard heat exchanger. You may assume $(\overline{\tau\alpha})/(\tau\alpha)_n = 0.94$ $\frac{(\overline{\tau\alpha})}{(\tau\alpha)} = 0.94$. The collector area is 50 m$^2$. For the month of December, for Srinagar $\bar{H} = 6.99 MJ/(m^2 - day)$, $\bar{H}_d = 4.99 MJ/(m^2 - day)$ and $\bar{T}_a = 2.8^0 C$.

8. What will be the solar load fraction if air based collectors with standard flow rate have been employed, with standard storage and assume $F_RU_L$ = 2. 63 W/m$^2$ $^0$C and $F_R(\tau\alpha)_n$=0.72 remain the same as the values for the liquid based collector. You may also assume $(\overline{\tau\alpha})/(\tau\alpha)_n = 0.94$

9. What will be the solar load fraction if the air based collector system of the Problem 8, employs double the standard flow rate?

10. Calculate the solar load fraction met by the liquid based space heating system described in Problem 8, using the $\bar{\phi}, f - Chart$ method.