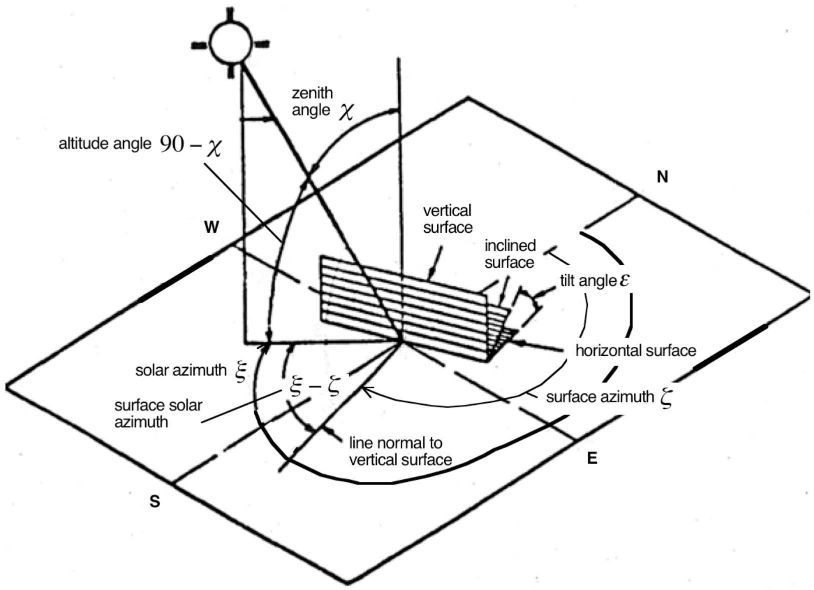
Project 1. **Due date: Tuesday October 2, 2018.**

You may team up with a partner for this project. Do not share information or results with other groups.

General Information

Solar Incident Flux Computation (see Chapter 12 of text)



Given local solar time t in hours and decimal fractions of hours (24-h clock)

Latitude = λ (= 37.9 °N for Berkeley, CA)
Surface azimuth angle = ζ
Surface inclination from horizontal ε
Hour angle = $\alpha = 15(t-12)$ in degrees

Declination $\delta \Rightarrow \quad \delta = 23.44 \sin\left[\frac{360}{365.25}(d-80)\right]$, d = the number day of the year

Solar zenith angle $\chi \Rightarrow \quad \cos\chi = \sin\lambda\sin\delta + \cos\lambda\cos\delta\cos\alpha$

Solar azimuth angle $\xi \Rightarrow \quad \tan\xi = \dfrac{\sin\alpha}{\sin\lambda\cos\alpha - \cos\lambda\tan\delta}$

Use the chart from chapter 12 of the text to determine ξ:

Sign(α)	Sign($\tan\xi$)	ξ
+	+	180° + arctan(tanξ)
+	−	360°+ arctan(tanξ)
−	+	arctan(tanξ)
−	−	180°+ arctan(tanξ)

Intensity of direct normal radiation: $I_{DN} = Ae^{-B/\sin(90-\chi)}$, $A = 1310$ W/m^2, $B = 0.18$
Incident direct solar flux $I_D \Rightarrow \quad I_D = I_{DN}\left[\cos\chi\cos\varepsilon + \sin\varepsilon\sin\chi\cos(\xi-\zeta)\right]$

Task 1
Write a computer program to calculate the incident direct radiation per square meter of a surface (I_D) for specified solar time, latitude, day of the year d, surface azimuth angle ζ, and surface inclination ε. Use the program to determine the direct solar incident heat flux per m^2 on a surface with a 200° azimuth and a tilt angle of 36° on April 30, 2018 at 1:00 PM solar time in Berkeley, CA (note: compute t by converting clock time to a 24 h clock time).

Task 2
Modify your program developed in Task 1 to calculate the total energy incident on a surface of area A_c between 10:00 AM and 4:30 PM solar time for specified latitude, day of the year d, surface azimuth angle ζ, and surface inclination ε. To do this, break up the total time into short intervals Δt and integrate using a trapezoidal rule method. Take Δt small enough that I_D changes less than 2% over the time interval. Use the program to determine the total direct radiant energy that strikes a surface with a 200° azimuth and a tilt angle of 36° on April 30, 2018 between 10:00 AM and 4:00 PM solar time in Berkeley, CA.

Task 3
Modify your program developed in Task 2 to include the effect of the solar collector efficiency. To do this, make $I_D\eta_{coll}$ the integrand in your trapezoidal rule method, where the collector efficiency is given by

$$\eta_{coll} = \overline{F}_R\left[\tau_g\alpha_c - \frac{U_{loss}}{I_D}\left(T_i - T_a\right)\right]$$

where $\overline{F}_R$ is the heat removal factor defined as

$$\overline{F}_R = \frac{1-\exp\{-A_cU_{loss}/\dot{m}c_p\}}{A_cU_{loss}/\dot{m}c_p}$$

The resistance analogy for heat loss from the absorber plate (neglecting end effects) yields the following equation for the total conductance $U_{loss}A_c$:

$$U_{loss}A_c = \left[\frac{1}{h_{conv,o}A_c} + \frac{\delta_g}{k_gA_c} + \frac{1}{h_{conv,i}A_c}\right]^{-1} + \left[\frac{1}{h_{conv,o}A_c} + \frac{\delta_{ins}}{k_{ins}A_c}\right]^{-1}$$

where
$h_{conv,o}$ = outside air convective heat transfer coefficient
δ_g = glazing thickness
k_g = glazing thermal conductivity
$h_{conv,i}$ = convection coefficient between absorber and glazing (inside)
δ_{ins} = thickness of insulation on backside of collector
k_{ins} = insulation thermal conductivity

Organize your program so these parameters are inputs that can be easily modified.
Initially use the following values:

Collector glazing transmissivity τ_g = 0.89
Collector absorber plate absorptivity α_c = 0.85
$h_{conv,o}$ = 7 W/m^{2}K
δ_g = 0.7 cm
k_g = 1.3 W/mK
$h_{conv,i}$ = 3.1 W/m^{2}K
δ_{ins} = 6 cm
k_{ins} = 0.045 W/mK
water: c_p = 4186 J/kg°C, $\dot{m}$ = 0.0267 kg/s

Use your program to determine the efficiency of a collector operating with a 200° azimuth and a tilt angle of 36° on April 30, 2018 between 2:00 and 3:00 PM solar time in Berkeley, with an ambient temperature of 12 °C and a water inlet temperature of 16 °C. By how much does the efficiency improve if the insulation thermal conductivity is decreased to 0.018 W/mK?

<u>Task 4</u>
Use the version of your program developed in Task 3 to analyze the system design for heating water described below.

A residential apartment building in Berkeley, CA will have three solar collectors on it for heating city water for use by the residents. The solar collectors to be used have the following parametric characteristics:

Collector glazing transmissivity τ_g = 0.89
Collector absorber plate absorptivity α_c = 0.85
$h_{conv,o}$ = 7 W/m^{2}K
δ_g = 0.7 cm
k_g = 1.3 W/mK
$h_{conv,i}$ = 3.1 W/m^{2}K
δ_{ins} = 6 cm
k_{ins} = 0.045 W/mK
water: c_p = 4186 J/kg°C, $\dot{m}$ = 0.0267 kg/s

Absorber area of each collector = 3.25 m^2

The design target is to heat water from an inlet temperature of 16 °C to 65 °C on a sunny but cool (spring design day) April 30th in Berkeley, CA, between 10:00 AM and 4:00 PM (solar time). For the design conditions, assume that between 10:00 AM and 4:00 PM the ambient temperature varies linearly between 9 °C and 16 °C. The mass flow rate, surface azimuth angle, surface tilt angle and flow arrangement of the collectors (in series, or in parallel) can be chosen by the designer (you).

(a) The water enters the collectors from the city water line at 16 °C and must be heated in one pass through the collectors and delivered to the storage tank (at the exit temperature from the bank of solar collectors). Recommend design values of the water mass flow rate $\dot{m}$, surface azimuth angle ζ, surface tilt angle ε, and the flow arrangement that maximize the number of gallons of water heated to 65 °C over the six hour period. Justify your design choices with plots and/or tables summarizing your computed results. For your recommended design, report the number of gallons of water heated between 10 AM and 4 PM, and the average temperature of the heated water at the end of the 6 hour process.

(b) If the design target is to heat 350 gallons of water from 14 °C to 65 °C each day, will the three collector system achieve this? If not, determine how may kilograms of natural gas would have to be burned at 90% efficiency on the design day to meet the 350 gallon target. The lower heating value of natural gas (CH_4) is 50,050 kJ/kg.

(c) If the system design you recommended in part (a) operated and collected energy at the same rate on 200 days per year and used it instead of natural gas to heat water, how much CO_2 (in kg) would be prevented from being released into the atmosphere each year.

Task 5a (ME146 and ME246 students)

After your design specified in Task 4 has been installed, the owner of a neighboring property has developed plans to build a tall adjacent building that will cast a shadow that blocks sunlight from reaching the collectors in your system before 11:00 AM in the morning at all times of the year. Assume that during the year, on the average, 46% of the hours between 10:00 AM and 4:00 PM are cloudy and provide no solar energy input. With this information, use your design program to estimate (a) how much energy collection by the system will be reduced over the year with the new building in place. Also (b) determine how much natural gas would have to be burned at 90% efficiency to compensate for the loss, and (c) estimate the total yearly cost of the gas needed to compensate. The suggested approach is to compute the system day-long performance at two-week intervals over the year and integrate their contributions numerically.

Task 5b (ME246 students only)

For your design specified in Task 4 determine how much additional energy could be collected between 11:30 AM and 4:30 PM if the collectors are on a motorized frame that moves so that the surface azimuth angle always matches the solar azimuth angle ($\xi = \zeta$). (Note that the tilt angle ε stays fixed at your specified value.) Specifically, you are to determine whether this modified design can produced enough extra energy to compensate for the loss due to the new building shadow while collecting energy only between 11:30 AM and 4:30 PM. For 11:30 AM and 4:30 PM collection (due to the shadow), present a table that summarizes:

(a) the total heat collected with and without the motorized frame
(b) the percentage increase in yearly collected energy collected over the original fixed frame design
(c) how the extra energy obtained for the motorized frame compares to the shadow loss for the original fixed frame design over a full year.

Based on your results, discuss whether this use of a motorized frame is a viable way to compensate for the effect of the building shadow.

<u>Tasks to be divided between coworkers:</u>

(1) Assemble analysis and algorithms for performance programs
(2) Implement algorithms into code and debug
(3) Run code to define design recommendation
(4) Analysis of results, plot or indicate trends in tables
(5) Write-up of results and conclusions

<u>Deliverables:</u>

Written final report should include:

(1) Written summary of how the work was divided between coworkers
(2) Documentation of analysis used to set up your computational scheme and a summary of idealizations used.
(3) A flow chart or algorithm summary for the program used must be submitted. Reasoning behind the program structure should be described.
(4) Document design analysis results in plots. Describe and discuss the computed results in Task 4 and describe the recommended design. A copy of your program should be attached to the report as an appendix. (**Due 10/2/18 @ 5:00 PM**).
(5) A summary of your results for Task 5.

To get full credit, be sure your summary provides the information and/or plots requested in each task.

<u>Grade will be based on:</u>

(1) thoroughness of documentation of your analysis
(2) accuracy and clarity of interpretation
(3) thoroughness of the design investigation and the documentation of the reasons for your design choice