Solar Thermal Technology - Daily Water Heating Energy Load

Refrigeration and Air conditioning Techniques Engineering Department

Subject : Renewable Energy

Grade: 4th Class

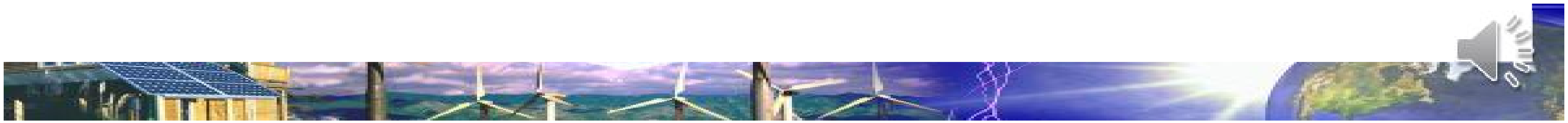
Lecture :7

Estimate Daily Water Heating Load

Dr. Eng. Azher M.Abed

E-email : azhermuhson@gmail.com

2019-2020



Simple Evaluation Procedure _-Solar Water Heater

- Estimate Daily Water Heating Load
- Determine Solar Resource
- Calculate Solar System Size
- Calculate Annual Energy Savings
- Calculate Annual Cost Savings
- Estimate System Cost
- Calculate Savings-to-Investment Ratio and Simple Payback Period

Daily Water Heating Energy Load

$$L = MC\,(T_{hot} - T_{cold})$$

L = Daily Hot Water Energy Load (kWh/day)

M= mass of water per day (kg/day), 3.785 kg/gallon

C = specific heat of water= 0.001167 kWh/kg°C

T_{hot}= hot water delivery temperature (°C), often 50 ° C = 120 ° F

T_{cold} = cold water temperature (° C), often 18 ° C = 65 ° F

Typical Hot Water Usage:

Dormitory (مبنى للطلبة او القسم الداخلي
13 gal/day/person

Motel	15 gal/day/unit
Hospital	18 gal/day/bed
Office	1 gal/day/person
Food Service	2.4 gal/meal
Residence	40 gal/day/person
School	1.8 gal/day/student

Solar Water Heating System Size and Savings

Solar System Size

$A_c = L / (\eta_{solar} I_{max})$

A_c = collector area (m^2)

L = Daily Load (kWh/day)

η_{solar}= efficiency of solar system (typically 0.40)

I_{max} = maximum daily solar radiation (kWh/m^2/day)

Annual Energy Savings

$E_s = A_c I_{ave} \eta_{solar} 365 / \eta_{boiler}$

I ave = average solar radiation (kWh/m2/day)

η_{boiler} = auxiliary heater efficiency

gas	0.43 to 0.86
electric	0.77 to 0.97
propane	0.42 to 0.86
oil	0.51 to 0.66

Solar Water Heating System Cost and Savings

Solar System Cost

$$C = c_{solar} A_c$$

C = Installed Cost of Solar System ($)

c_{solar} = per-unit-area cost of installed solar system ($/m^2), typically

$300/ m^2 for large system

$1000/m^2 for small systems

$650/ m^2 might be average

Annual Cost Savings

$$S = E_s C_e$$

S = annual cost savings ($/year)

Ce = cost of auxiliary energy

typically:

Electricity	$0.084/kWh
Natural Gas	$0.020/kWh
Propane	$0.040/kWh
Oil	$0.025/kWh

Solar Water Heating System Cost and Savings

Solar Water Heating
System Cost Effectiveness

Savings-to-Investment Ratio

SIR = S*pwf / C

project is cost effective if SIR>1.

pwf = present worth factor for future savings stream, = 24 years for 40 year lifetime and 3% real discount rate (specified by NIST).

EISA 2007 specifies the 40 year analysis period (lifetime)

Simple Payback Period

SPB = C / S

Example: 4 person residence in Denver against electricity

- M=4person*40gal/person/day*3.785 kg/gal=**606 kg/day**
- $L=MC(T_{hot}-T_{cold})$ =606 kg/day*0.001167kWh/kgC*(50C-18C) =**22.6 kWh/day**
- For Denver, Imax = 6.1 and I ave = 5.5 kWh/m2/day
- $A_c = L / (\eta_{solar} I_{max})$=22.6 kWh/day / (0.4 * 6.1 kWh/m2/day)=**9.3 m2**
- $E_s = A_c I_{ave} \eta_{solar} 365 / \eta_{boiler}$ = 9.3 m2 * 5.5 kWh/m2.day * 0.4 * 365days/year / 0.97 = **7,665 kWh/year**
- $C = c_{solar} A_c$ = \$650/m2 * 9.3 m2 = **\$6,045**
- $S = E_s C_e$ = 7,665 kWh/year * \$0.084/kWh = **\$644/year**
- SIR = S*pwf / C = \$644/year * 15.5 years / \$6,045 = **1.65**
- ***SO IT IS COST EFFECTIVE!***

Hot water demand

The most important parameter that needs to be considered in the design of a water heating system is the hot water demand over a certain period of time (hourly, daily, or monthly). The energy demand, L, required for the generation of sanitary hot water can be obtained if the volumetric consumption, V, is known for the required time period. Also required are the temperatures of the cold water supplied by public mains, Tm, and the water distribution, Tw. Then

$$L = V \rho c_p (T_w - T_m)$$

for the monthly water demand, the following equation can be used:

$$V = N_{days} N_{persons} V_{person}$$

where

N_{days}: number of days in a month.

N_{persons}: number of persons served by the water heating system.

V_{person}: Volume of hot water required per person.

Hot water demand

Example : Estimate the hot water energy demand for a family of four, with medium normal consumption, cold water mains supply of 18°C, and water distribution temperature of 45°C.

Solution:

According to Table 3.4, the consumption per day per person is 40 L. Therefore, the daily demand, V, is 160 L/d or 0.16 m3/d.

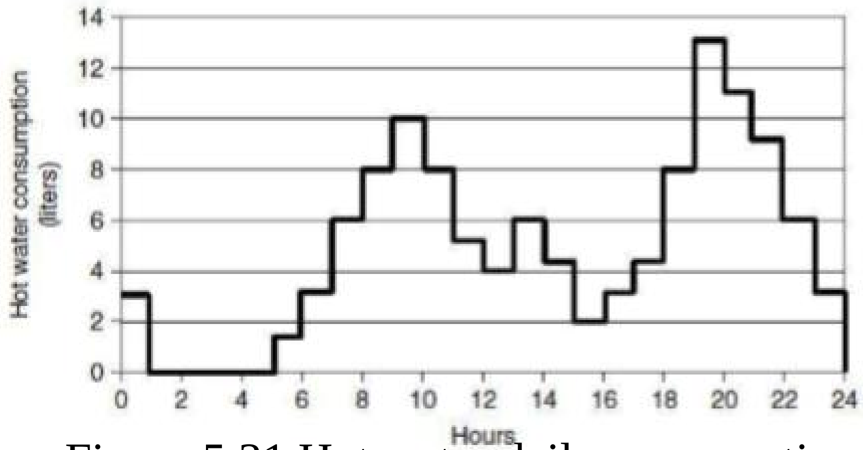


Figure 5.31 Hot water daily consumption profile

Guideline	Low	Medium	High
Normal consumption	26	40	54
Maximum consumption	66	85	104

Table 3.4 Hot Water Daily Demand for a Family of Four Persons in Liters per Person

Symbol and Formula Used

$$Q_u = A_c F_R \left[S - U_L \left(T_i - T_a \right) \right]$$

- Q_u = useful energy or output of the collector (J/m^2)
- F_R = heat removal factor
- A_c = collector area (m^2)
- S = solar energy absorbed by a solar collector (J/m^2)
- U_L = overall heat loss coefficient between the black plate and the surroundings (W/m^{2}C)
- T_i = the fluid inlet temperature
- T_a = the ambient temperature

(Note: Qu would be 0 if the result of calculation is negative value)

Question

The solar energy absorbed by a solar collector *S* and the ambient temperatures are given in the table below. The collector has U_L = 5.2 W/m^{2}C, Ac = 1 m^2 and F_R = 0.92. Determine the useful output of the collector for the day in the question if the inlet temperature is constant at 35 C.

Hour	*S*, MJ/m^2	T_a, C	Hour	*S*, MJ/m^2	T_a, C
7 – 8	0.01	–3	12 – 1	3.42	9
8 – 9	0.40	0	1 – 2	3.21	11
9 – 10	1.90	4	2 – 3	1.54	5
10 – 11	2.85	5	3 – 4	1.07	1
11 – 12	3.02	7	4 – 5	0.52	–4

Solution

- Identify data given from question:

  U_L = 5.2 W/m²C, F_R = 0.92, A_c = 1 m² , T_i = 35°C

- Identify data given from table:

  10 hourly S and T_a are given, starting 7- 8 a.m.

  Example: 7 – 8 a.m. S = 0.01 MJ/m², T_a = -3°C

- Apply formula to find useful/output energy from collector

$$Q_u = A_c F_R [S - U_L (T_i - T_a)]$$

$$Q_u = 0 MJ / m2$$

Solution

Hour	*S* MJ/m²	T_a C	$U_L (T_i - T_a)$ MJ/m²	q_u MJ/m²
7 – 8	0.01	–3	0.711	0
8 – 9	0.40	0	0.655	0
9 – 10	1.90	4	0.580	1.214
10 – 11	2.85	5	0.562	2.105
11 – 12	3.02	7	0.524	2.296
12 – 1	3.42	9	0.487	2.699
1 – 2	3.21	11	0.449	2.540
2 – 3	1.54	5	0.562	0.900
3 – 4	1.07	1	0.636	0.399
4 – 5	0.52	–4	0.730	0
			SUM	11.080

Hence, useful energy of the collector for the day = 11.080 MJ/m2

H.w

Q1: Design a system for 500LPD for domestic used. The useful output of a solar collectors are 3 MJ/m^2 h from 10 Am until 3 Pm . The collector has U_L = 6.2 $W/m^2\,^oC$, and FR = 0.747, the inlet temperature is constant at 35 ^oC and the solar energy absorbed by a solar collector and the ambient temperature are S=2.85 MJ/m^2 h, Ta= 2 ^oC respectively. What kind of system you will prefer? How many collectors will you use?