Lecture #7

In this lecture, we continue our discussion of flat-plate solar-thermal collectors and systems for heating water and air.

Let's continue talking about solar hot water systems.
We write the solar energy flux incident on the collector as:

$$G_{tc} = G_b^{*}\cos\theta + G_{dh}\left[\cos\frac{\beta}{2}\right]^2 + \rho G_{th}\left[\sin\frac{\beta}{2}\right]^2$$

This equation was derived in the addendum to the Lecture 5 notes. Note, the collector harvests beam radiation, diffuse radiation, and reflected radiation. Of course, usually, on average, the beam radiation is predominant.

The units of G_{tc} are W/m^2.

We multiply this by the face area of the collector, A. Thus, $G_{tc} A$ = watts of solar power incident on the collector at any instant. We want as much of this solar power as possible to be transmitted through the glass cover (i.e., glazing) of the collector. We write the transmissivity (or transmittance) of the glazing as τ (not to be confused with τ of the atmosphere).

The solar power now falls on the black absorber plate of the collector (see Fig 2.21, p59, of text). We want as much as possible of this solar power to be absorbed by the plate. The absorptivity (or absorptance) of the plate is α.

Thus, the amount of solar power absorbed by the plate is:

$$\boxed{G_{tc} A \tau \alpha}$$

We want as much as possible of this absorbed solar power to "flow" into the water in the pipes of the solar collector.

However, some of the heat absorbed by the plate is lost. The loss mechanisms are the following:

1) Conduction: some heat is conducted through the materials of the collector to the underlying supports or building structure.

2) Convection: some heat is convected away from the collector to the ambient air. Their are two mechanisms for this:
   - Forced convection: wind flowing over the collector carries heat away.
   - Natural convection: hot bodies, when surrounded by cooler air,

generate "thermals", that is, currents of hot air moving upwards are generated around the hot body. These convect heat away.

3) Radiation: The collector radiates thermal energy away to its surroundings. The major effect is usually the radiation from the face of the collector to the sky. The nominal sky temperature is 6 degrees C less than the ground-level ambient air temperature.

Note: if the black absorber plate were exposed directly to the environment, the convective and radiation losses would be high, and not too much energy would be available to heat the water. The glazing of the collector reduces the convective and radiation losses by reducing the face temperature of the collector. Double glazing would be better than single glazing in this regard; however, double glazing, compared to single glazing, would reduce the transmission of the solar radiation through the glass cover of the collector. There is a tradeoff: less energy loss vs less energy collected.

We write the overall thermal power loss of the collector as:

$$\text{Loss(watts)} = \frac{T_{\text{collector}} - T_{\substack{\text{ambient}\\ \text{air}}}}{R}$$

where R = resistance to heat loss. The units of R are degrees C/watt

The thermal power available to heat the water flowing through the collector is:

$$Q_{\text{fluid}} = G_{tc} A \tau \alpha - \frac{\left(T_{\text{collector}} - T_{\substack{\text{ambient}\\ \text{air}}}\right)}{R}$$

We need to "clean this up a bit". For example, how do we determine the temperature of the collector? It might vary from place to place on the collector. To get around this uncertainty, we use the temperature of the fluid entering the collector, $T_{fluid,in}$.

This "works" because:

1) It is well defined and easily measured.
2) For each pass through the collector, the water heats up only a little. That is, the water temperature entering the collector is only a small amount less than the collector temperature.

   Note: the collector, the water flowing through it, and the water in the storage tank essentially heat up in <u>unison</u>.

We also note that there is some resistance to heat flow from the collector plate to the fluid. The term that accounts for this is F_R.

Thus, our final equation is:

$$Q_{fluid} = G_{tc} A \tau\alpha F_R - \frac{(T_{fluid\ in} - T_{\substack{ambient\\ air}})}{R'}$$

Note, R' has been adjusted to account for $T_{fluid,in}$ and F_R

The efficiency of the collector is defined as:

$$\eta_c = \frac{Q_{fluid}}{G_{tc} A} = \tau\alpha F_R - \frac{(T_{fluid,in} - T_{\substack{ambient\\ air}})}{G_{tc} R' A}$$

where $R'A = r = 1/U$

and U = conductance

The units are: r = °C-m²/watts

U = watts/°C-m²

Look at the lecture notes from last year:
www.me.washington.edu/~malte/engr342/class_notes/wq2001_lectures/342.01.lecture10.xls

This shows the following:

1) A plot of the efficiency of a solar hot water collector

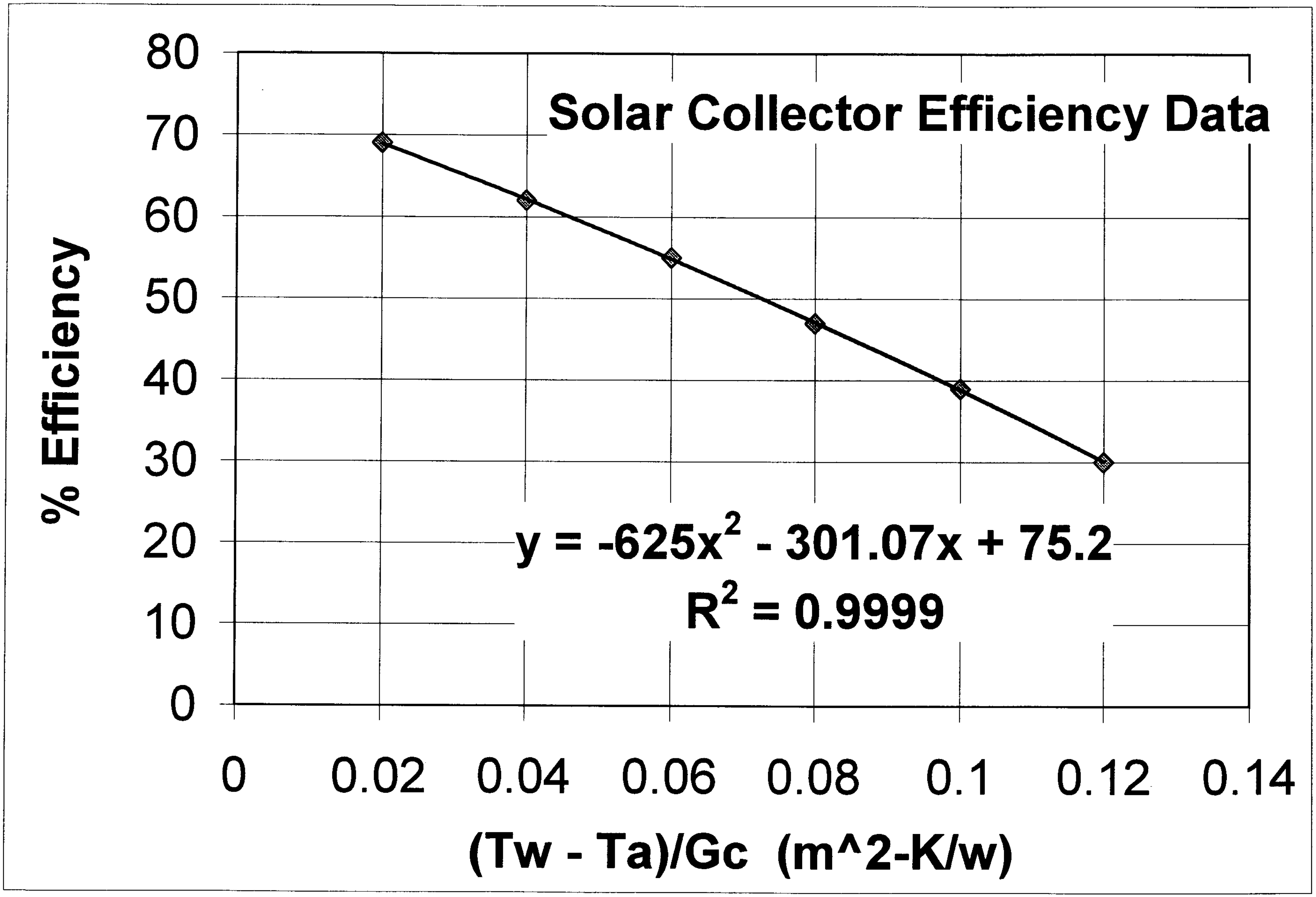
$$\eta_c \quad vs \quad (\underset{\overset{\uparrow}{T_{fluid,in}}}{T_w} - \underset{\overset{\nwarrow}{T_{ambient\,air}}}{T_a}) / \underset{\overset{\nwarrow}{G_{tc}}}{G_c}$$

Note the nearly linear fall off of the efficiency as the term $T_w - T_a / G_c$ increases. That is, as the collector warms up, it loses more heat.
A cold collector and a bright sun are best for collector efficiency.

2) A plot of water temperature vs time. Note: 50 gallons of water were heated from 20° to 70°C on a very sunny day (the peak value of G_{tc} was 1034 w/m^2). The collector area = 2.4 m^2.

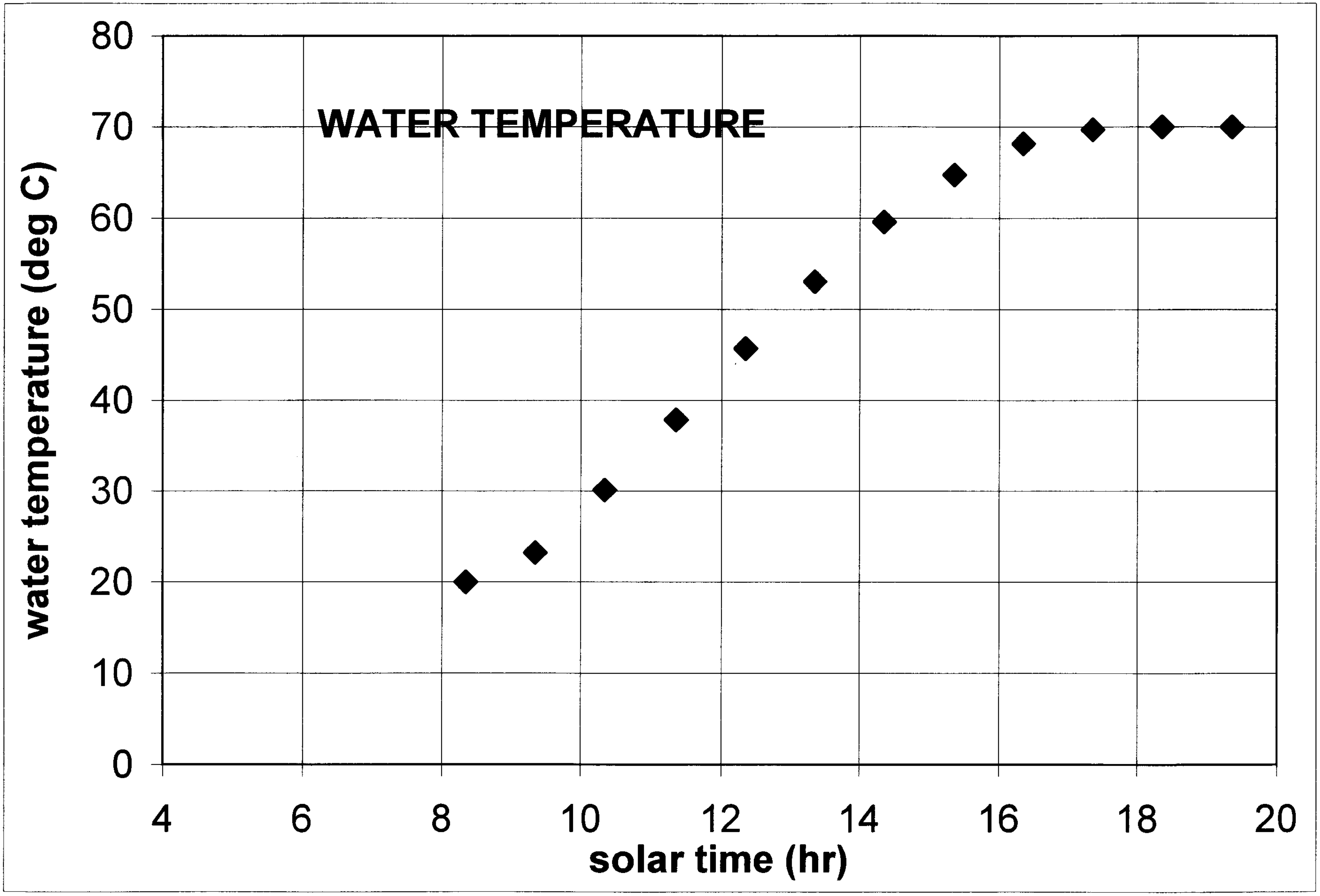
Note: the hot water was not used during the day -- it was used after being fully heated.

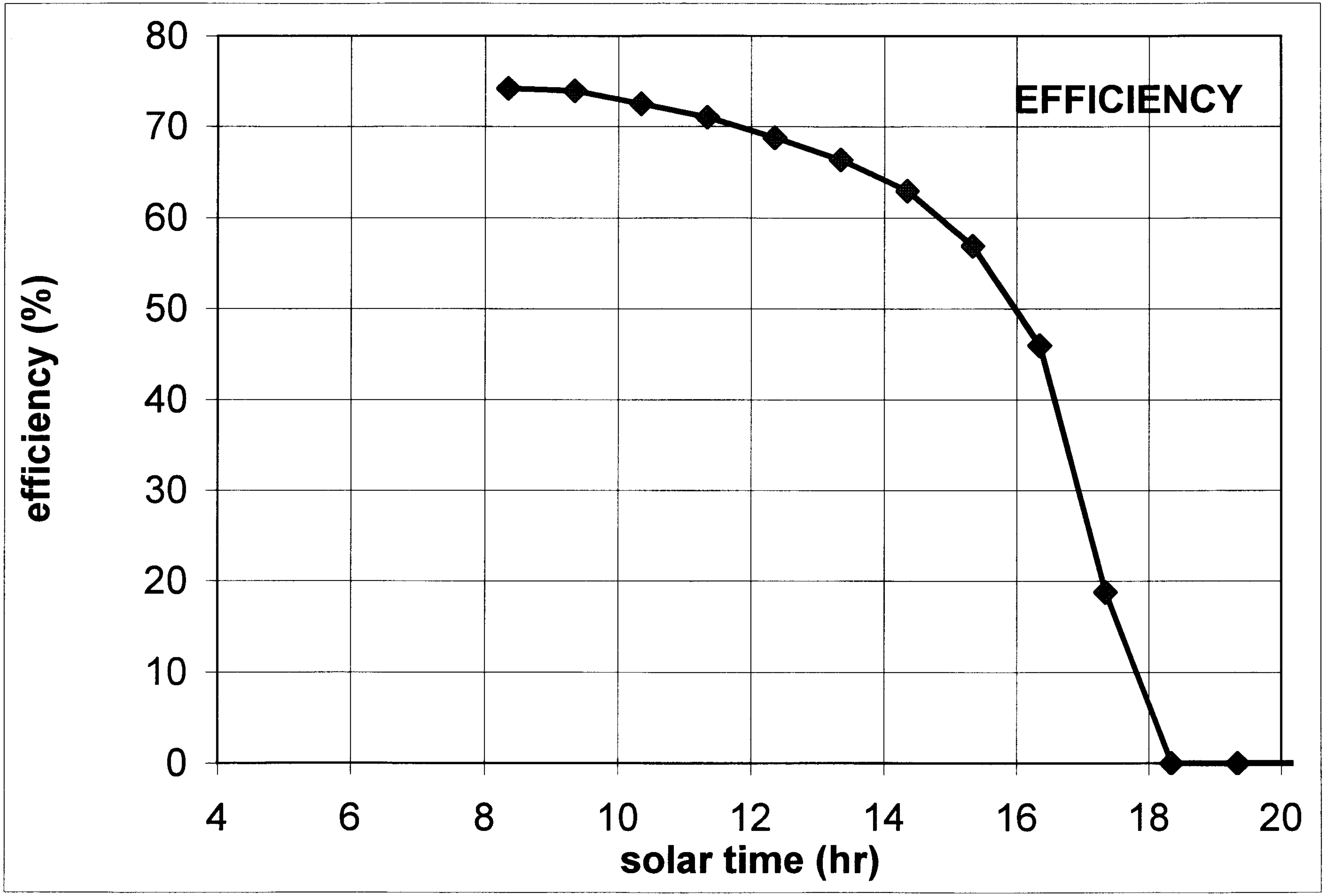
3) A plot of collector efficiency versus time. Note the rapid drop-off in efficiency around 16.0 hrs, as T_w became large and G_c fell.



$y = -625x^2 - 301.07x + 75.2$

$R^2 = 0.9999$


WATER TEMPERATURE
water temperature (deg C)
80
70
60
50
40
30
20
10
0
4
6
8
10
12
14
16
18
20
solar time (hr)


EFFICIENCY
efficiency (%)
80
70
60
50
40
30
20
10
0
4
6
8
10
12
14
16
18
20
solar time (hr)

A example of solar-thermal air heating is found in the article: " The Solar-Coffee Connection" in Solar Today, March/April 2000.

In this application, solar energy is used to generate warm air for use in a drying system for coffee beans. Additionally, solar PV is used to generate electricity to run the warm air blowers of the drying chamber. The article desribes the system and its advantages compared to conventional drying used wood-fired dryers.