Engineering of Solar Thermal Energy Systems

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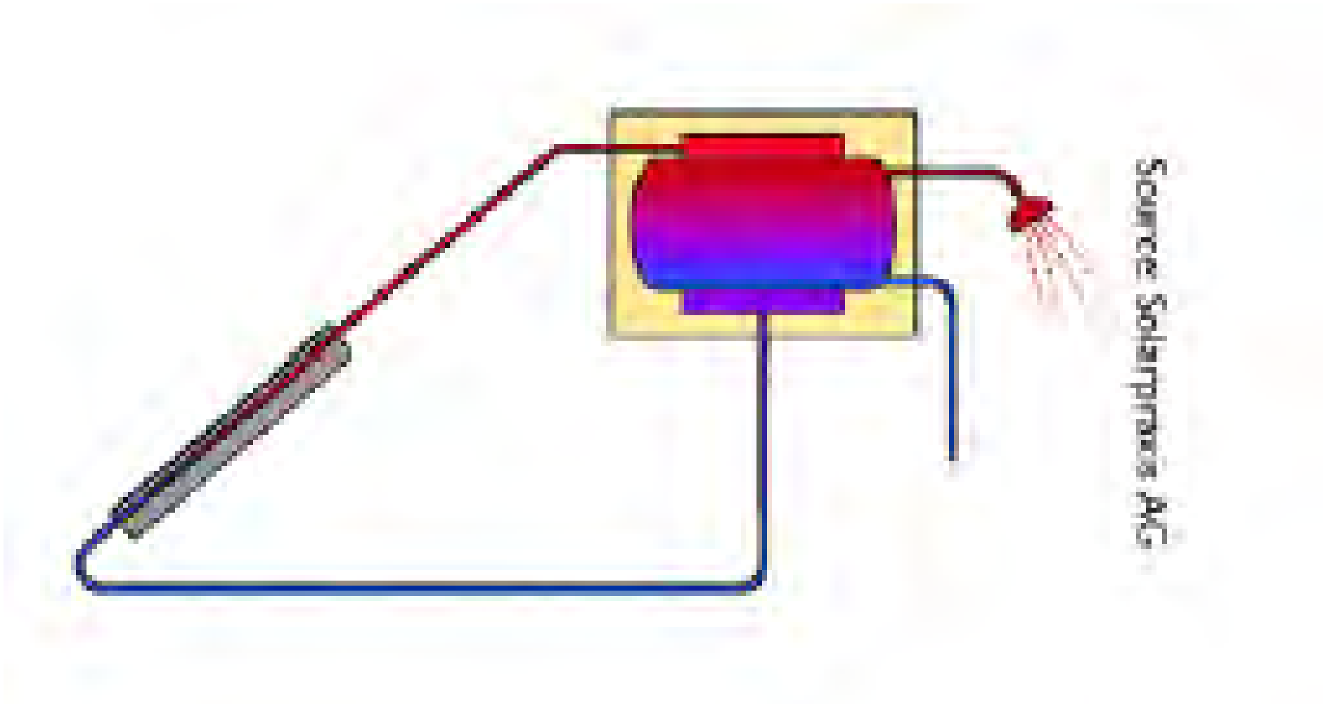
Types of DHW Systems

- Passive:
  - thermosyphon systems use natural convection to drive flow through collector
  - requires that storage tank be located in attic (above collectors)
- Active:
  - pumps are used
  - direct (water flows through collector)
  - indirect (glycol flows through collector)

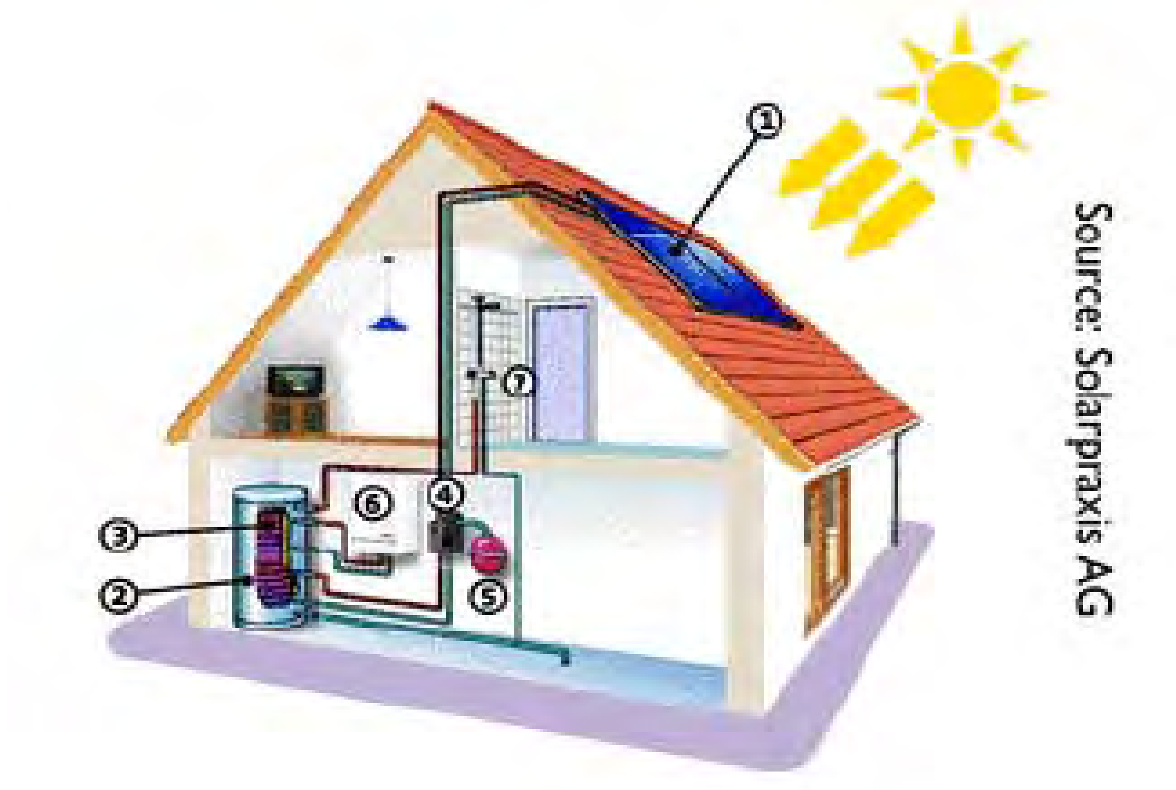
Example of Passive Solar DHW System

- tank is integrated with collector
- relatively inexpensive
- suitable for warm climates or seasonal use (cottages)
- problems with freeze protection and morning loads!

Example of Thermosyphon DHW



Active Solar DHW



1 Collector - 2 Tank - 3 Heat exchanger - 4 Control unit

5 Expansion Tank - 6 Back-up heater - 7 Consumer

Example of Active Solar DHW System

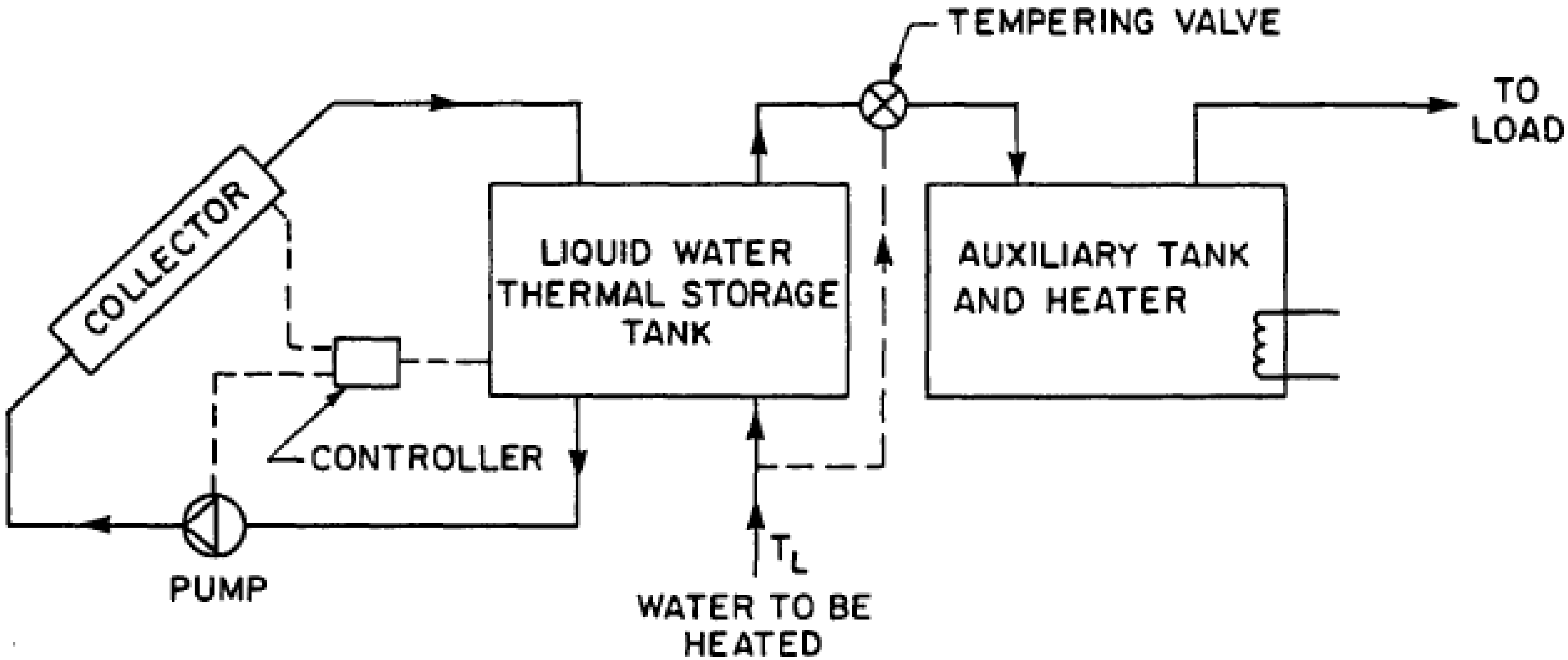


Fig. 1. Schematic of typical solar hot water system (heat exchangers not shown).

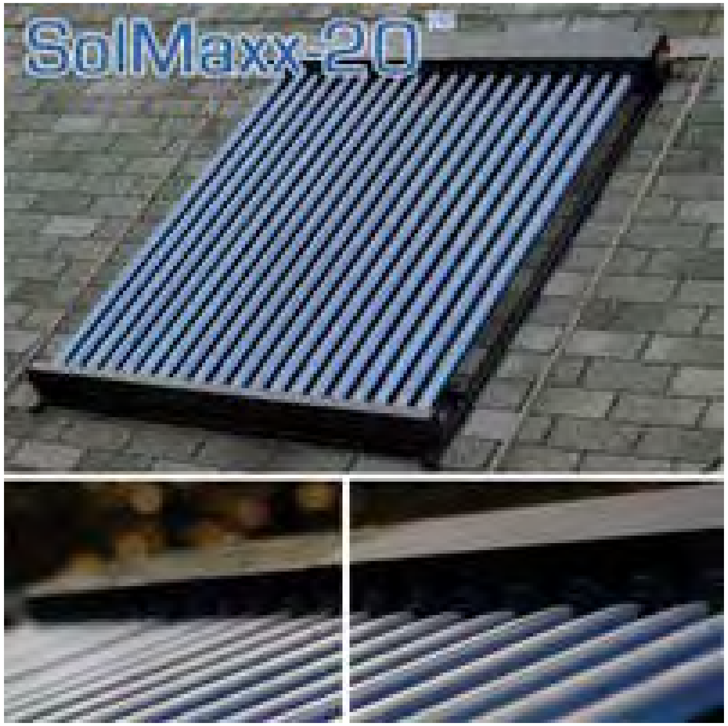
From: Hollands and Lightstone, *Solar Energy*, Vol. 43, 97-105,1989

Design Variables

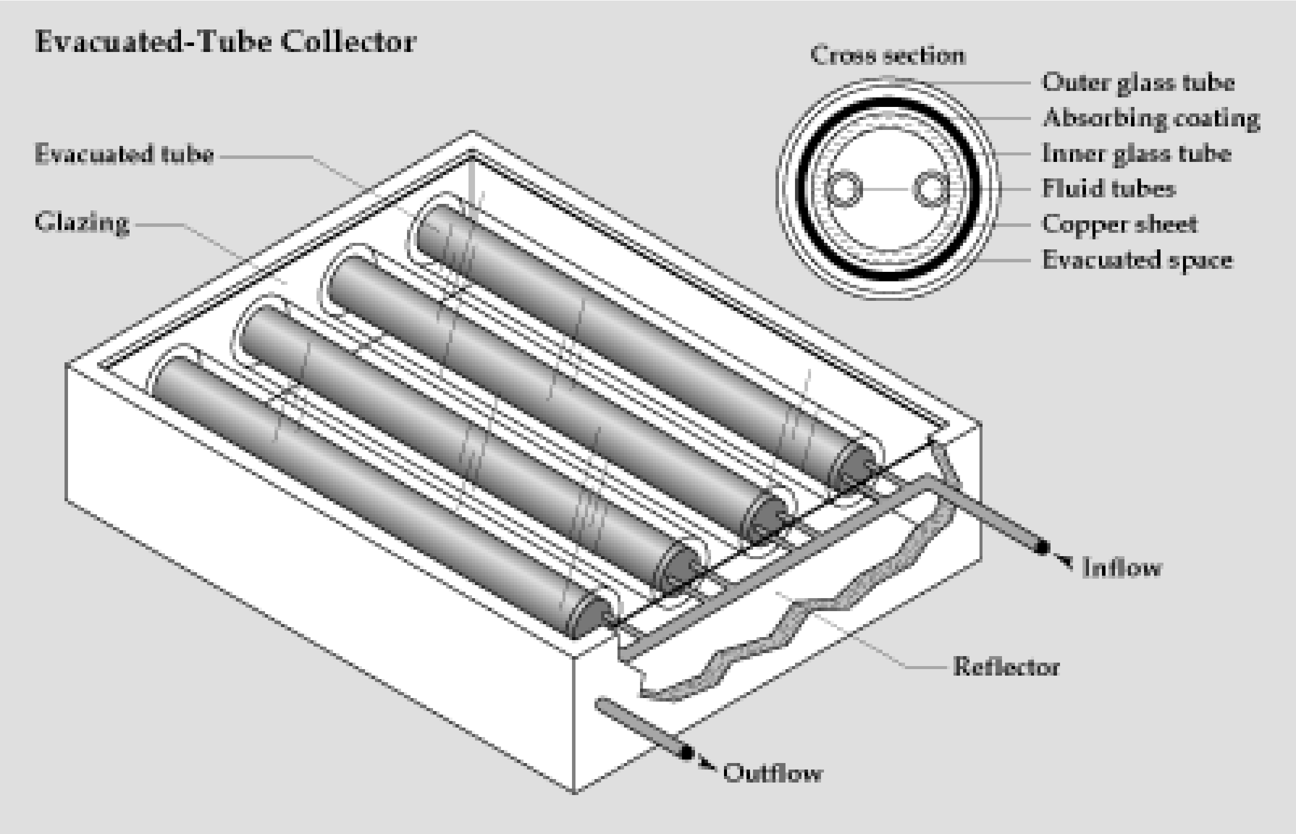
- Collector: area, glazing, surface radiation characteristics (selective surface), insulation, materials, working fluid
- pump, controller
- heat exchanger
- tank geometry, inlet piping geometry
- auxiliary tank (or tankless water heater $$$)

Solar Collectors

Evacuated Tube Collector:

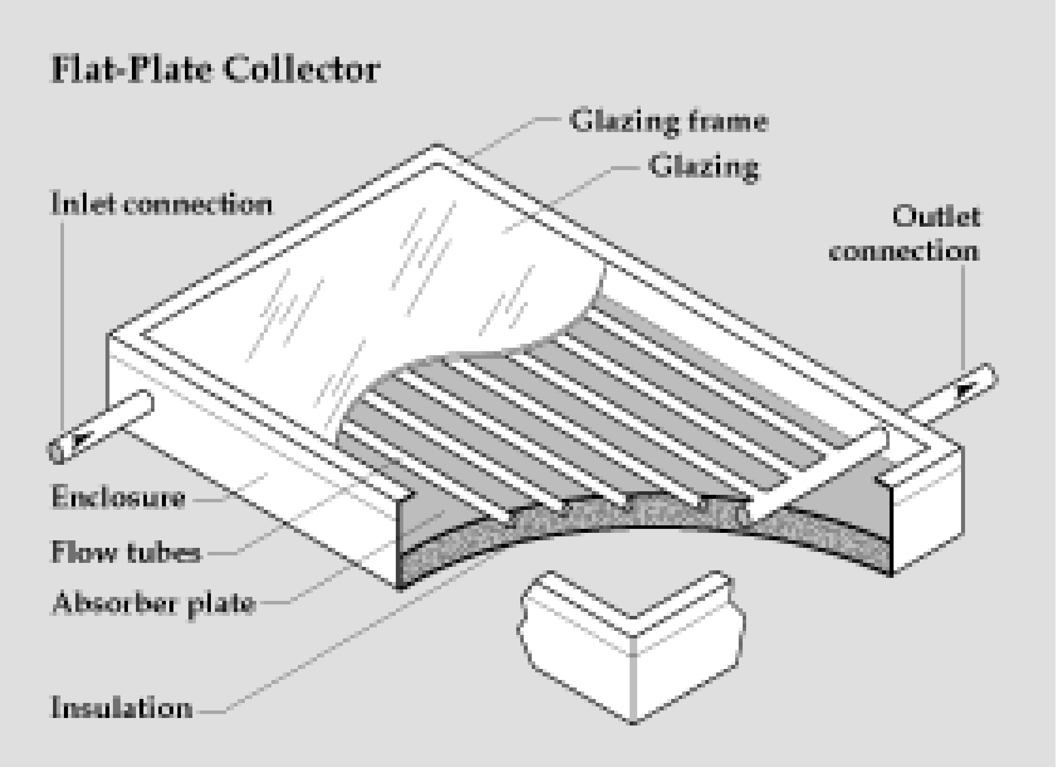


Evacuated Tube Collector - detail



Flat Plate Collectors

Flat plate collector - details



Fluid temperature at outlet can be as high as 60^{o}C greater than outdoor temperature. Special insulation + selective surface.

Technical Issues

- Freeze protection:
  - glycol antifreeze
    - potential for leaks to mains water
    - limited life expectancy (becomes corrosive if gets too hot!)
  - drainback
    - water drains from collector if freezing conditions occur
    - reliability issues!

Technical Issues

- Stagnation Temperature:
  - pump failure (for example if electricity is off)
  - can lead to very high fluid temperatures (150^{o}C) in the collector if cooling source is removed
  - big problem if glycol is the coolant since glycol becomes corrosive at high temperatures (greater than about 120^{o}C)

Potential Solution to Stagnation Problem

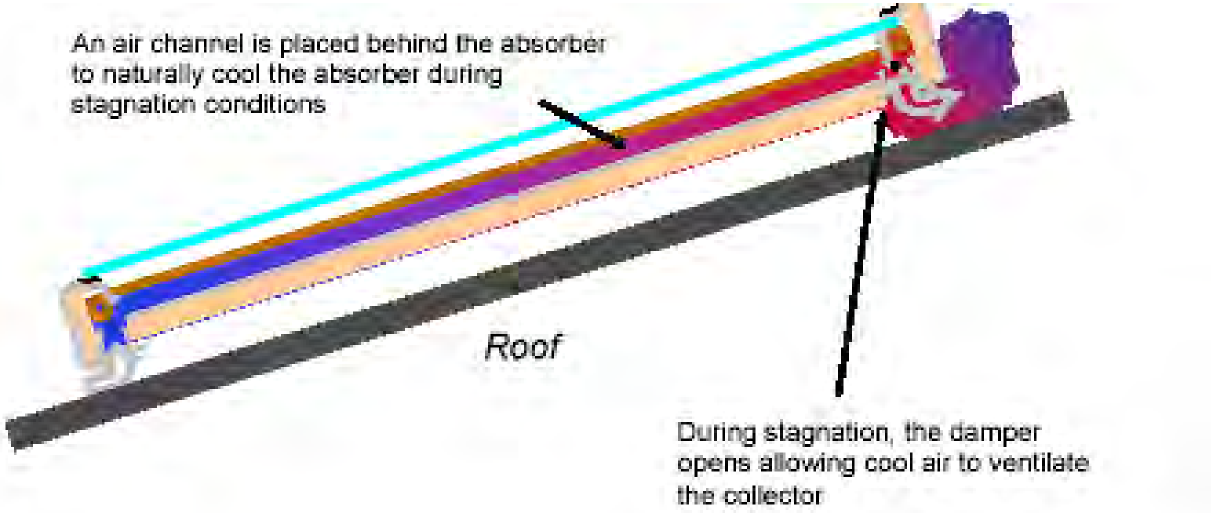


Figure 2: Conceptual design of a solar collector with integral stagnation temperature control.

From: Harrison, Lin, and Mesquita, 'Integral Stagnation Temperature Control for Solar Collectors', SESCI 2004 Conference

Experimental Results

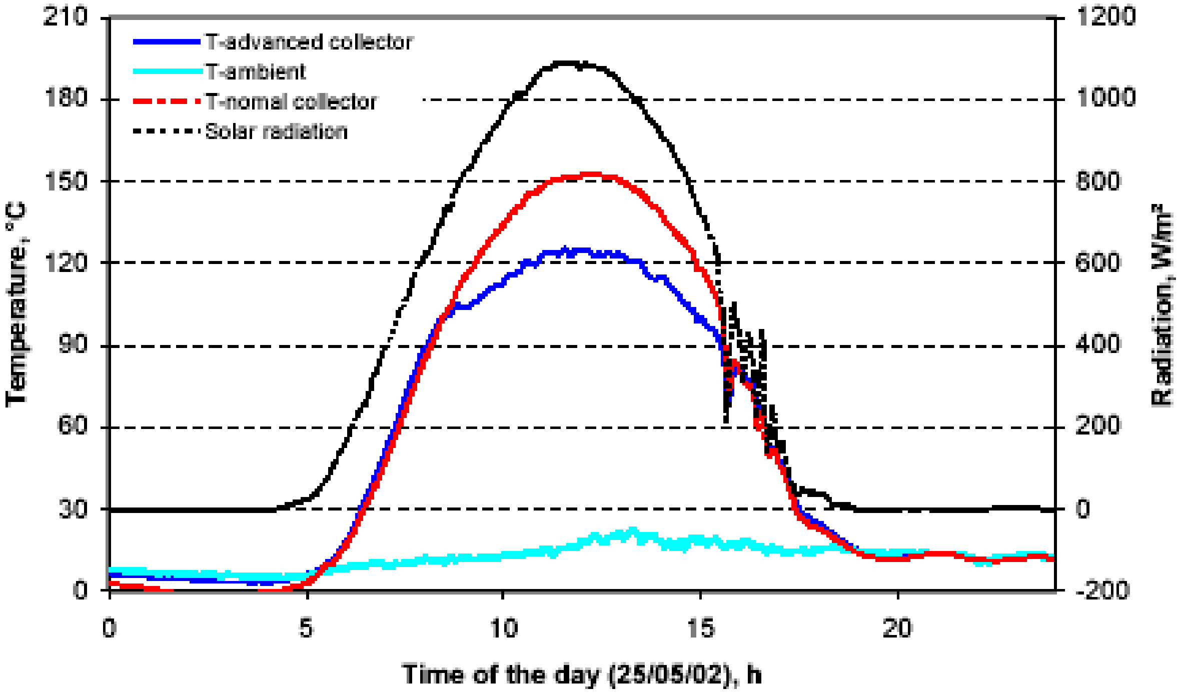


Figure 7: Recorded temperatures and solar radiation intensity on May 25, 2002, (temperatures recorded for the ISTC collector are designated "T-advanced Collector").

Flat Plate Collector Analysis

$$Q_u = A_c F_R\{S-U_L(T_i-T_a)\}$$

Q_u = energy collected [W]

A_c = collector area [m^2]

S = solar radiation absorbed [W/m^2]

U_L = overall heat loss coefficient [W/m^2K]

T_i = inlet fluid temperature [^oC]

T_a = ambient outdoor air temperature [^oC]

F_R = collector effectiveness [-]

Flat Plate Collector Analysis

$$Q_u = A_c F_R\{S - U_L(T_i - T_a)\}$$

F_R = collector effectiveness [-]

- F_R approaches unity at collector flow rates
- F_R decreases as mass flow rate decreases

<u>**Conclusion** (based on collector equation):</u>

"High mass flow rates will give higher system efficiencies (solar fraction) than low flow rates"

But what if we consider the full DHW system?

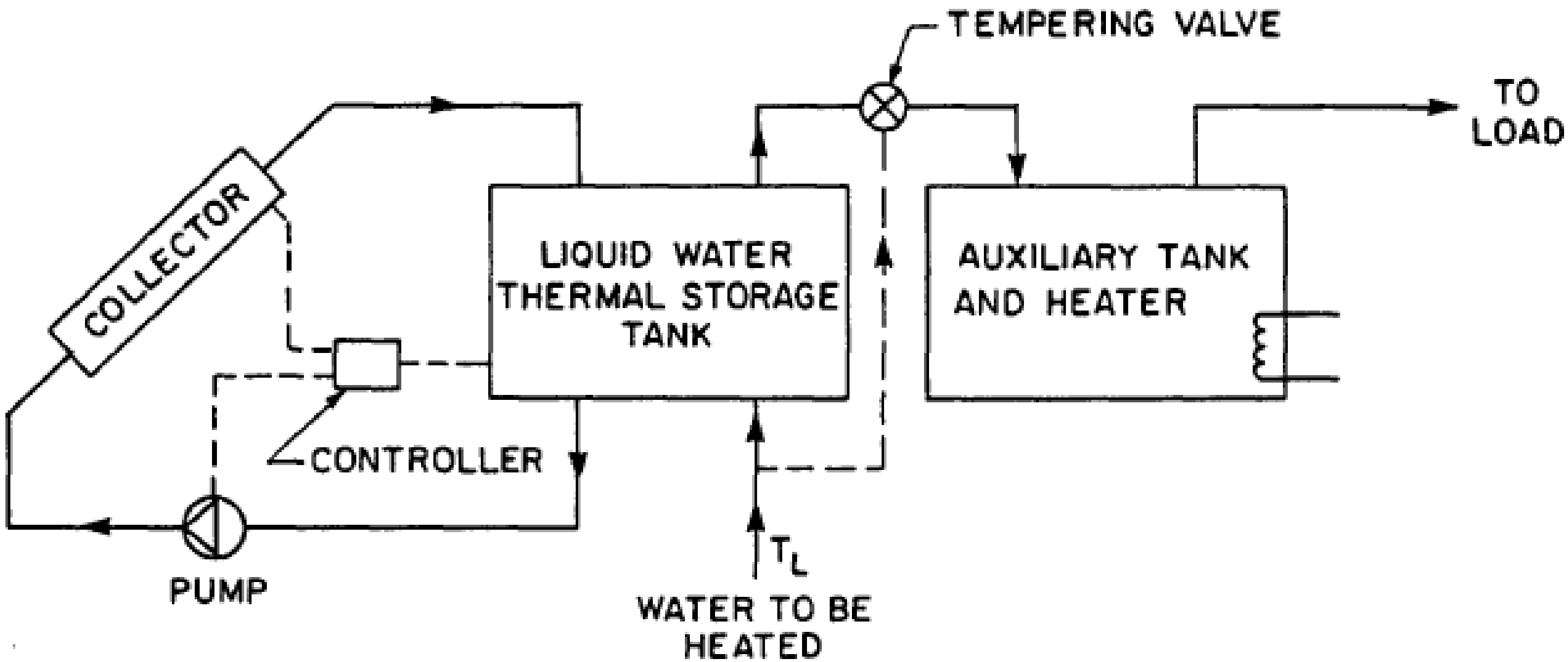


Fig. 1. Schematic of typical solar hot water system (heat exchangers not shown).

From: Hollands and Lightstone, *Solar Energy*, Vol. 43, 97-105,1989

WATSUN Simulation

- Simulation code for DHW systems
- models heat transfer and fluid flow in the system (piping, tank, collectors, …)
- uses hourly radiation and weather data
- simulates system over one year
- goal is to calculate solar fraction (the fraction of the required energy for DHW use provided by the solar collectors)

Sample Load Data

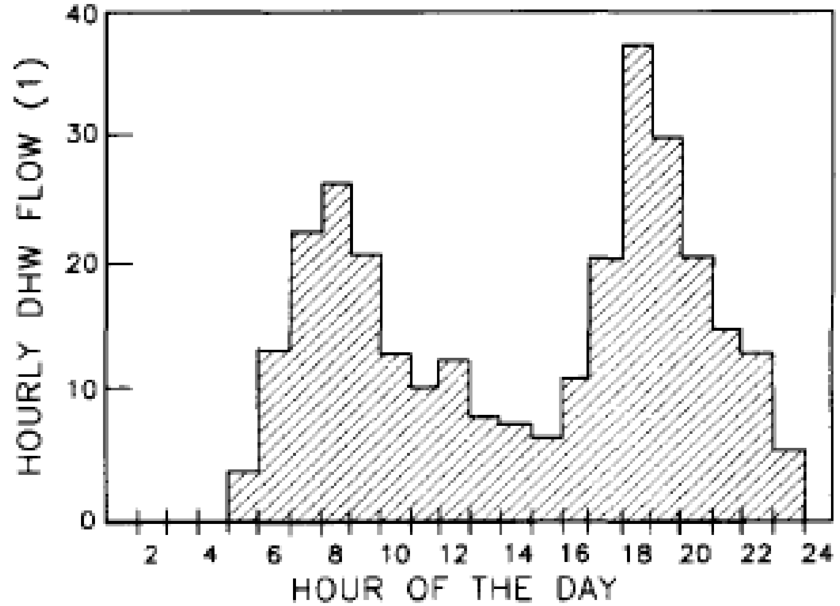
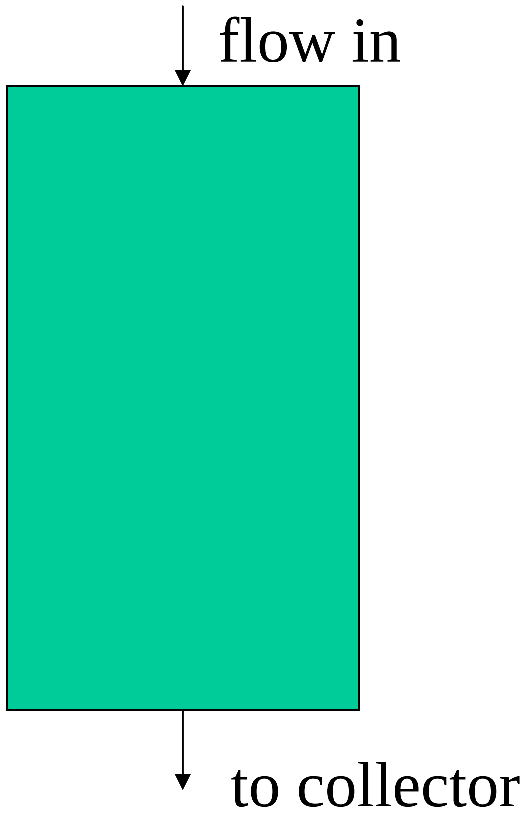


Fig. 2. The RAND[14] hourly DHW volume load profile used in this study.

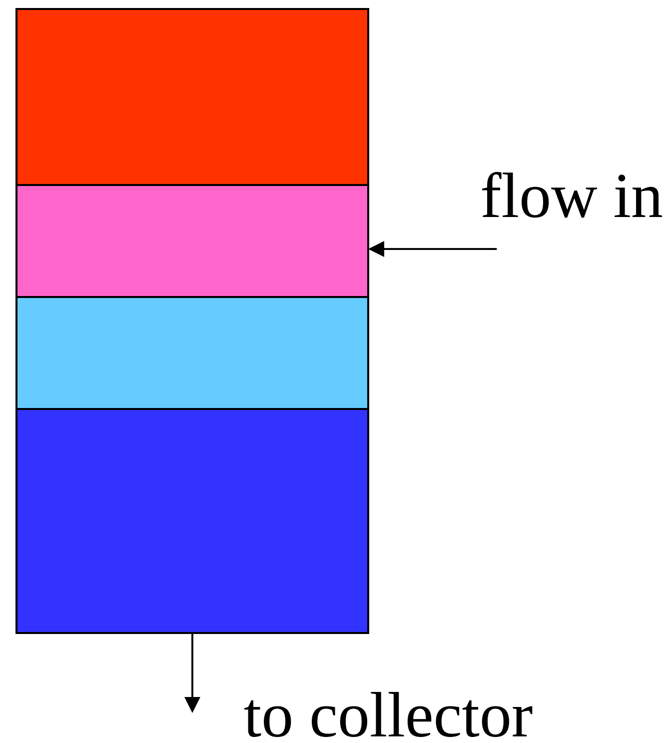
From: Csordas, Hollands, Brunger, and Lightstone, *Solar Energy*, *Vol 49*, *pp497-505*, *1992*

Solar Storage Tank Models

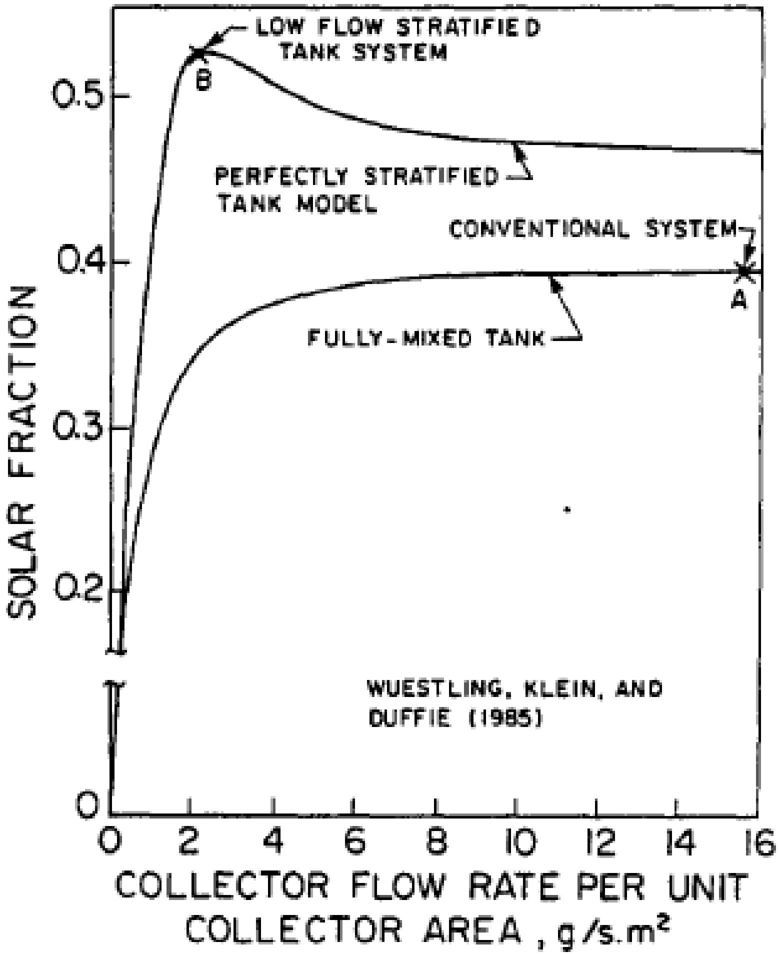
1. **Fully Mixed**



2. **Perfectly Stratified (Register Model)**



Solar Fraction Results



Plume Entrainment Tank Model

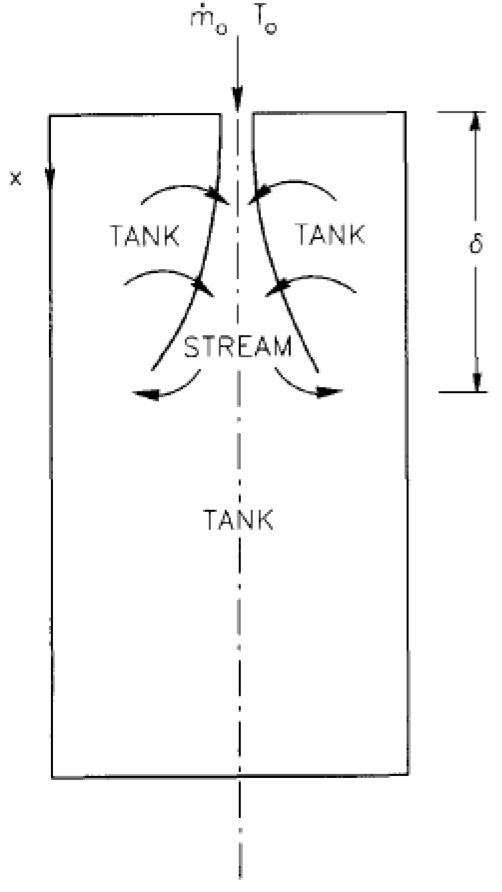


Fig. A1. Plume and nonplume regions in the tank.

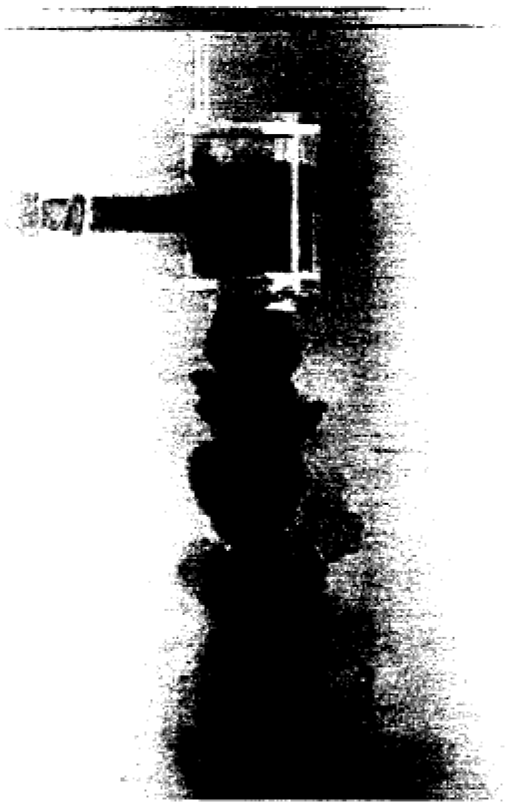


Fig. 6. Photo of plume (Gari and Loehrke[18]).

Simulation Results (Toronto)

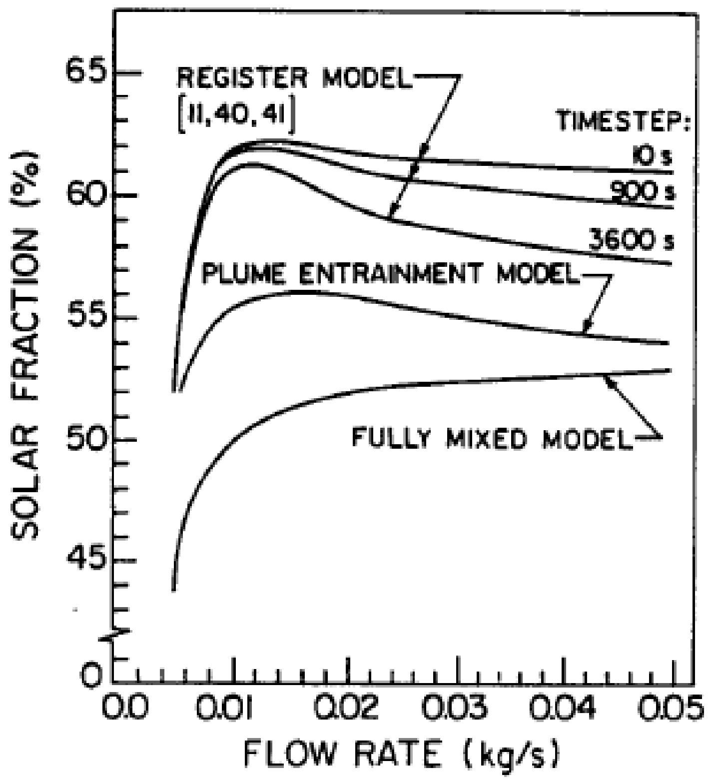


Fig. 8. Solar fraction vs. collector mass flow rate for a domestic hot water system operating in Toronto, Canada, calculated according to various tank models (adapted from Lightstone *et al.*[44]).

Esthetics: Building Integration

- Hamburg, Germany
- 3000 m^2 of collector area

Solar DHW + Space Heating
Austria (80 m^2 collector area)

Summary

- Solar DHW systems can provide over half the hot water energy requirements for a southern Ontario household
- relatively expensive, maintenance (glycol)
- esthetic issues
- well suited for new housing using building integration technologies
- conservation is still key!