

TSP-6: Solar Water Heater

Introduction

A company called *SmartOptions* has developed a rugged, cheap solar hot water system for use in dry, remote areas such as outback Australia and the Solomon Islands. The system features several advantages over existing commercial hot water systems that make it particularly suitable for these areas, in particular:

- protection against water loss through evaporation via boiling;
- a light, compact system able to be mounted without a crane;
- simple fittings able to be shipped as a kit which does not require a plumber to assemble.

The unit is required to meet Australian standards, both for sale into local markets and as a benchmark for export. In particular, it must be established that the unit will not allow the incubation or transmission of legionella bacteria. The system must be able to automatically detect conditions inside the tank that might support dangerous levels of legionella contamination. In the event that such conditions exist, the water outlet is automatically closed by a valve until the water is deemed safe. Australian Standard AS 3498 specifies a set of conditions under which the system can be assumed to harbour acceptable levels of legionella.

The hot water system has been installed on the roof of PS1 at La Trobe University (ask your demonstrator to take you up on to the roof so you can take a look!) The unit consists of a cylindrical storage tank with a capacity of about 200L, and three black collector panels. Cold water passes through the outlet on the left end of the storage tank and into these collector panels where it is exposed to solar radiation. Warm water feeds back into the tank via an inlet positioned on the right end of the storage tank.

Aim

The purpose of this experiment is to evaluate the performance of the hot water unit and write a professional report summarising your findings. The format of the report is different to the other senior lab reports, as the emphasis is on applying simple science to make useful statements about the suitability of a product for a particular application. This experiment is based on a recent project where the Physics Department was contracted by a company to test this same unit.

Broadly, your report should answer the following questions:

1. Does the sensor algorithm for detecting conditions for dangerous levels of legionella bacteria perform as designed?
2. How often do you expect such conditions to arise?

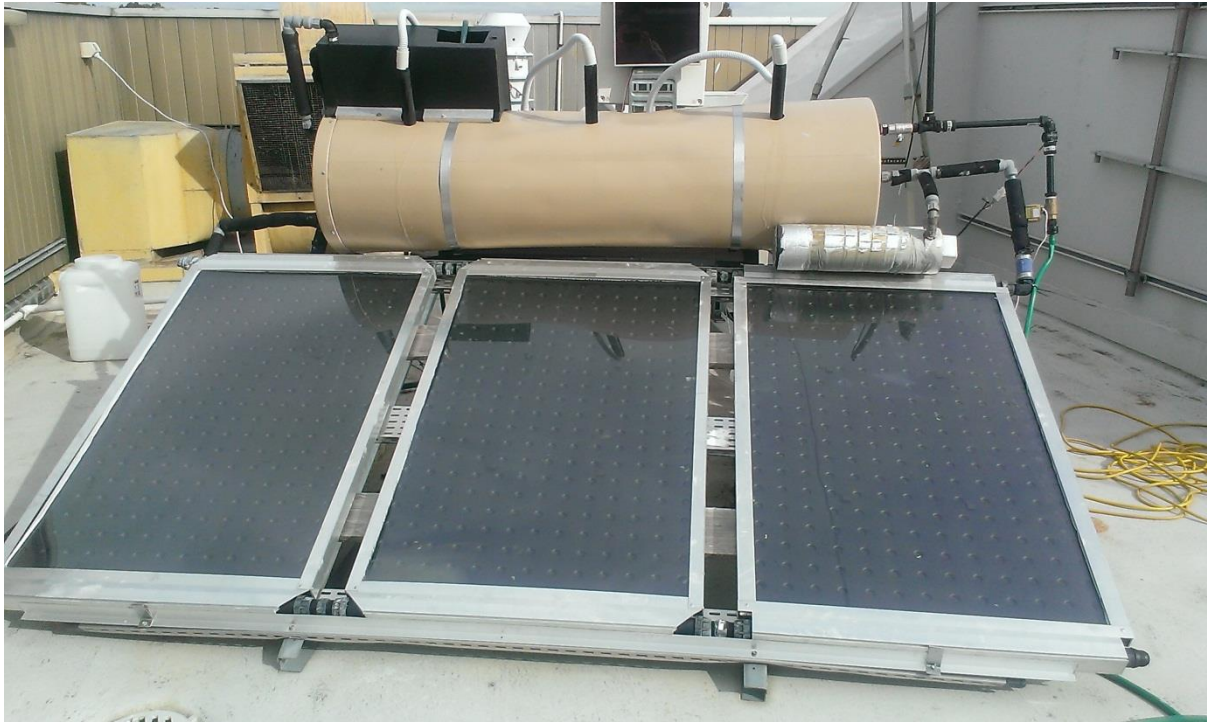


Figure 1: SmartOptions system installed on the roof of PS1

What is a “Standard”?

A standard is a published document which contains specifications and procedures designed to ensure products and services are safe, reliable, and perform as intended. Standards cover areas including consumer products, energy and water services, construction, engineering, and management of the environment.

Australian Standard AS 3498, *Authorization requirements for plumbing products---Water heaters and hot-water storage tanks*, is provided on the LMS. Scan through this document to find the section on inhibiting the growth of legionella bacteria in a water-heating appliance, and identify which condition(s) are relevant to the solar water heater.

Experiment

1. Bench test of sensor algorithm

The company has provided an electronic monitoring system to detect when dangerous levels of legionella bacteria may be present in the storage tank. You are required to test that this system functions correctly. The system tests whether the water temperature satisfies either condition (i) or (ii) of Section 7.1 of AS 3498.

DO NOT UNDER ANY CIRCUMSTANCES PRESS THE RESET BUTTON ON THE GREEN CIRCUIT BOARD

The monitoring system has been set up in Room 318 by the window (enter via room 319). Figure 2 is an annotated photo of the circuit board. The system has four temperature sensors: (1) ambient temperature, (2) temperature of the top of the tank, (3) 90% sensor and (4) 45% sensor. You will only need to use the 90% and 45% sensors in this experiment. You should be able to work out what is meant by 90% and 45% sensors from the relevant section of AS 3498.

Use Figure 2 to determine which temperature sensors correspond to 1-4 above.

In the lower left corner of the circuit board are 3 coloured LEDs. The LEDs are designed to flash as follows:

- The **green** LED will flash for as long as the hot water system meets the requirements of temperature.
- The **blue** LED will flash instead of the green if the system has gone for 24 hours without reaching 60°C. This indicates that the first test has failed.
- If the **red** LED flashes then the hot water system will have been under temperature for 7 days. In this case, a valve will close to prevent water from being removed from the storage tank.

The microprocessor samples the temperature of each sensor once per minute and the data are written to a micro-SD card.

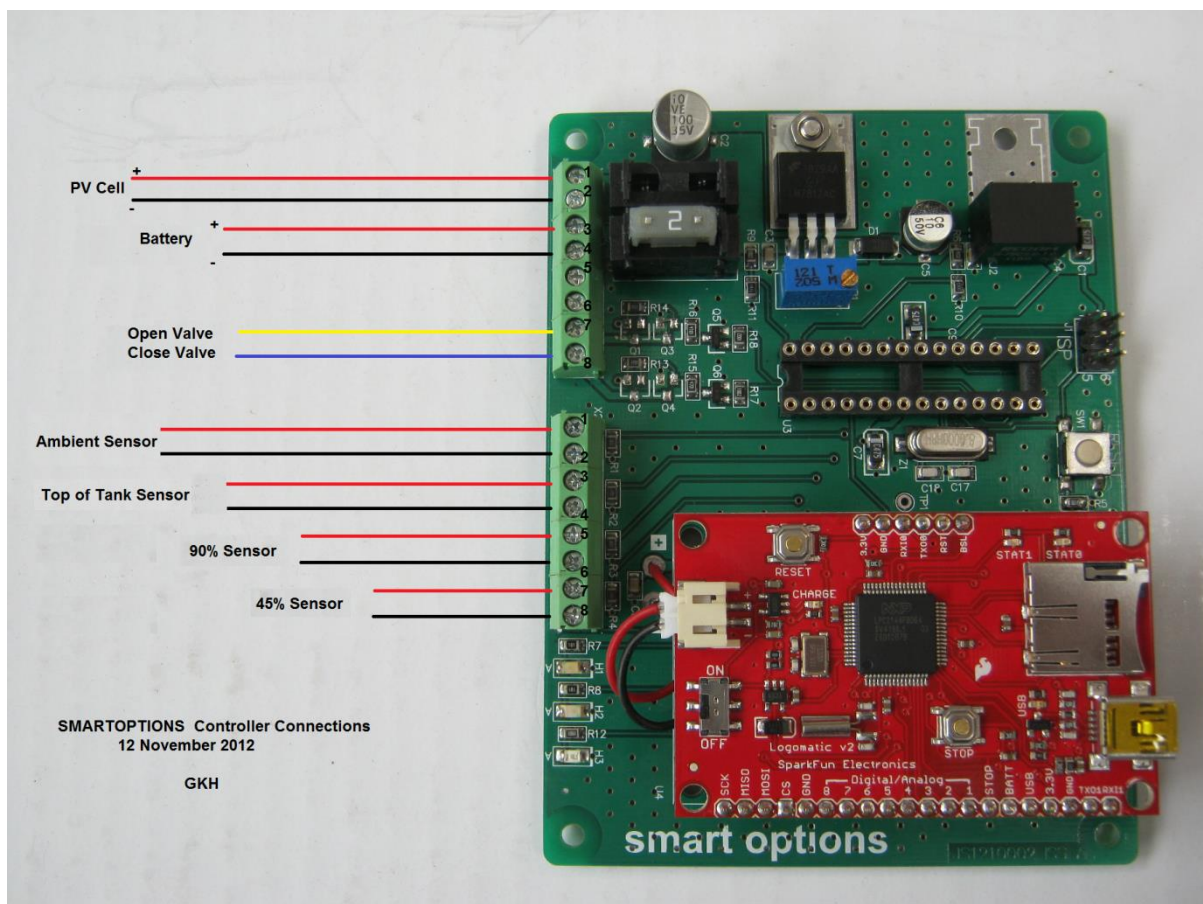


Figure 2: Microcontroller unit

Your first task is to establish that the temperature sensors record the correct temperature values. This will be achieved by comparing the temperatures measured by the 45% and 90% sensors with simultaneous measurements using the thermocouple provided. Immerse the sensors and the thermocouple probe in a beaker of water and record the temperature measured by the thermocouple every minute for several minutes.

To read the sensor data on the micro-SD card you have two options:

1. If you have a laptop available, carefully connect the USB cable to the yellow slot next to the SD card slot and to your laptop. Be very careful doing this as the board is fragile. You will get a message such as “unrecognised drive”. Locate the RESET button on the **RED** circuit board and press it once. **DO NOT PRESS THE RESET BUTTON ON THE GREEN PCB** . The data logger will now be recognised as a valid drive. Copy the files labelled LOGxx.TXT to your computer.
2. If you do not have a laptop available, carefully remove the SD card from the slot and insert it into the SD reader provided. Then insert the SD reader into the desktop computer in the lab. Copy the files labelled LOGxx.TXT to your computer.

The most recent data will be stored in the highest numbered LOGxx.TXT file. Each row in the file corresponds to one set of measurements, so one new line is added to the file every minute. The columns in the file correspond to:

Ambient temperature	Top of tank temperature	45% sensor	90% sensor	Battery voltage	Solar panel
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Compare the temperature measurements recorded by the data logger and the thermocouple and comment on the accuracy of the temperature sensors.

Your second task is to test that the unit shuts down (red light flashes) when neither of the temperature conditions has been satisfied.

You will need to set up the experiment and leave it running for at least 7 consecutive days. Since the microprocessor algorithm cannot be reset, you should ensure that both temperature conditions have been met at the start of the testing period. The simplest way to do this is to immerse both the 90% and 45% sensors in a beaker of hot water (above 60°C) for at least 32 minutes. At this point the green LED will be flashing. Hot water can be obtained from room 412.

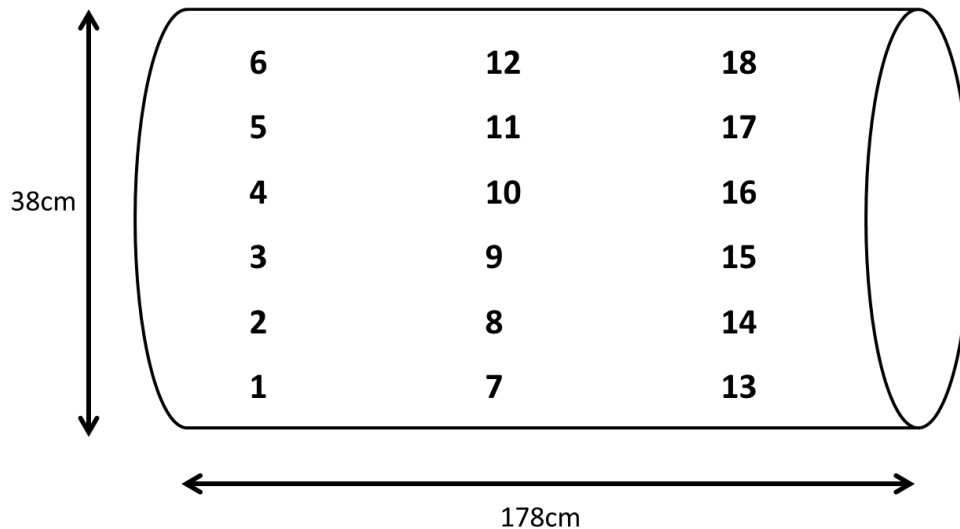
Does the blue LED flash when condition (i) has failed?

Does the red LED flash when both conditions (i) and (ii) have failed?

Did you see any of the LEDs flash when they weren't supposed to?

2. Temperature monitoring

In this section you will be measuring the temperature of the water at different locations inside the storage tank using an array of 18 temperature sensors. The approximate positions of these sensors is shown below:



Temperature measurements for each sensor are recorded every 5 seconds. The data can be downloaded from www.farlabs.edu.au. (Navigate to Environment -- Solar Water Heater -- Explore.)

To get a feel for how the data have been recorded, download 24 hours of data for a couple of sensors and save it as a text file. The first line of the file has the column headings. Each subsequent line contains the date and time of the measurement, followed by the temperature readings for each sensor in numerical order. Note that sensors T19 and T20 measure ambient temperature.

You will be using MATLAB (or any other scientific plotting package, but NOT Excel) to visualise the temperature data. The following code can be used to import the data into MATLAB:

```
function data=importtankdata(file,N)
%IMPORTTANKDATA(FILE,N)
% Imports data from the specified file
% FILE: file to read
% N: number of sensors in file

% Import the file
rawdata=importdata(file);

% determine number of lines in file
fid=fopen(file,'rb');
fseek(fid, 0,'eof');
fileSize=ftell(fid);
frewind(fid);
T=fread(fid, fileSize, 'uint8');
numLines=sum(T==10);
```

```

fclose(fid);

%extract temperature values into the matrix called data
data=zeros(numLines,N);
for i=2:numLines
    s=rawdata{i};
    [~,temperature]=strtok(s,'"');

    %fill data array with temperature values for each sensor
    for j=1:N
        [T, temperature]=strtok(temperature,'"');
        data(i,j)=str2num(T);
    end
end

end

```

Generate contour plots showing the temperature distribution inside the tank at different times of the day. Locate the coldest and warmest parts of the tank and explain why you think they exhibit such temperatures.

With reference to AS 3498, explain where in the tank the 45% and 90% sensors should be placed to most accurately monitor the system for conditions in which legionella bacteria may be present.

Generate plots of temperature versus time for a number of different time intervals. State whether or not the conditions to inhibit the growth of legionella bacteria were satisfied in each time interval.

In this section you will need to consider several aspects of the experimental design yourself. That is, which sensor(s) to plot and over what time intervals. Since the unit is installed in Melbourne your conclusions will be based on its suitability to Melbourne's climate. However, you may speculate briefly on how you think the unit might perform under warmer conditions for which it was designed.

Extension Work

Estimate the efficiency of the system and compare it with other systems in the literature. List ways in which the thermal efficiency could be improved, supported by evidence.

How to structure your report

The purpose of the report is to provide the company with an assessment of a potential commercial product. The company will be most interested in your conclusions, so these should be placed in a summary at the beginning of your report. It is important to include the details of the experiment to justify your conclusions, however these can be placed later in the report.

Your report should be formatted using the La Trobe University report template provided on the LMS.

Your report should include the following:

- Explanation of the relevant section of Australian Standard AS 3498 that the system must comply with
- Explain how water is able to move through the system without a mechanical pump
- Assessment of the performance of the sensor algorithm
- Discussion on existence of conditions that favour legionella growth.

General notes on technical report writing:

<http://www.monash.edu.au/lis/lionline/writing/engineering/technical-report/index.xml>

<http://grcpublishing.grc.nasa.gov/Editing/vidcover.CFM>