Software Requirements Specification for Solar Cooker Energy Calculation: A Software for calculating heat loss and observed heat

Deesha Patel

February 4, 2023

Contents

Revision History

Date	Version	Notes
02/04/2023	1.0	Initial Release

1 Reference Material

This section records information for easy reference.

1.1 Table of Units

Throughout this document SI (Système International d'Unités) is employed as the unit system. In addition to the basic units, several derived units are used as described below. For each unit, the symbol is given followed by a description of the unit and the SI name.

symbol	unit	SI
m	length	metre
kg	mass	kilogram
s	time	second
°C	temperature	centigrade
J	energy	joule
W	power	watt ($\mathrm{W} = \mathrm{J\,s^{-1}}$)

1.2 Table of Symbols

The table that follows summarizes the symbols used in this document along with their units. The choice of symbols was made to be consistent with the heat transfer literature and with existing documentation for solar water heating systems. The symbols are listed in alphabetical order.

symbol	unit	description
A_{g}	m^2	Area of glass
A_{m}	m^2	wet surface area over which heat is transferred in
A_r	m^2	Area of Reflector
A_{ref}	m^2	Reflector area with respect to different reflectors
C_W	J/(kg°C)	Specific Heat Capacity of Water
E_W	J	Change in heat energy in the Water
f	-	Fluid
G	$\mathrm{W/m^2}$	Incidental solar radiation
h	$\mathrm{W/m^2K}$	heat transfer convection coefficient
$int2$	-	Inner 2
L	m	Length
m_W	kg	Mass of Water

n	-	Number of Reflector
r	-	Reflector
T	°C	Temperature
T_W	°C	Temperature of Water
ϵ	-	Emittance
τ	-	Transmittivity
θ	-	Reflector Angle
σ	-	Steffan-Boltzman constant
ρ	-	Reflectivity

1.3 Abbreviations and Acronyms

symbol	description
A	Assumption
DD	Data Definition
GD	General Definition
GS	Goal Statement
IM	Instance Model
LC	Likely Change
PS	Physical System Description
R	Requirement
SRS	Software Requirements Specification
T	Theoretical Model

2 Introduction

As fossil fuels adversely affect the environment, many countries like India, where they have good Solar rays throughout the year, have started to implement devices for utilizing solar energy and transforming it into valuable energy. It includes Solar Water heaters, Solar panels, and Solar Cookers. It is indeed a fact that the demand for renewable energy has increased to deal with the problem. Focusing on solar cooker, several design such as Solar Panel Cooker, Solar Parabolic Cooker, and Solar Box Cooker has been proposed to utilize more solar energy. Using internal reflectors, we would like to improve the utilization of solar energy during cooking a food.

The following section provides an overview of Software Requirement Specification (SRS) for a box-type Solar Cooker. This section explains the purpose of the document, the scope of requirements, the characteristic of the intended reader, and the organization of a document.

2.1 Purpose of Document

We are going to use the Solar Box Cooker in this software. The main purpose of this document is to describe a mathematical model of a Solar Cooker which can provide a calculation for internal reflector in solar box that can help to improve the temperature in the box. It includes a variety of parameters that attempts to define the intended functionality required. Thus, this document provides detailed requirements of the software which will be used in planing for design stage. Therefore, this document is intended to be used as a reference to provide ad hoc access to all information necessary to understand and verify the model. This document describes goals, assumptions, theoretical models, and important definitions to understand the problem. The SRS is abstract because the content here says *what* the problem is. But it does not say anything related to *how* to solve it.

This document will be used as a starting point for subsequent development phases, including writing the design specification and the software verification and validation plan. The design document will show how the requirements are to be realized, including decisions on the numerical algorithms and programming environment. The verification and validation plan will show the steps that will be used to increase confidence in the software documentation and the implementation. Although the SRS fits in a series of documents that follow the so-called waterfall model, the actual development process is not constrained in any way. Even when the waterfall model is not followed, as Parnas and Clements (3) point out, the most logical way to present the documentation is still to "fake" a rational design process.

2.2 Scope of Requirements

There are Numerous algorithm has been proposed to improve the efficiency of Solar Cooker. The scope of the requirement includes a mathematical model to determine the thermal function of a box-type solar cooker with an internal reflectors. With the help of different inputs, this system calculates the achieved temperature by implementing the proposed solution. However, this project not focusing on more than one iteration for the reflections.

2.3 Characteristics of Intended Reader

Firstly, Intended Reader or Reviewer should have knowledge of heat transfer theory and radiant solar energy. A person should have completed a Heat Transfer course during their bachelor of engineering (Mechanical Engineering expected). A reader should have knowledge about the coupled differential equation; offered in the Calculus course.

2.4 Organization of Document

The organization of this document follows the template for an SRS for scientific computing software proposed by (2) and (4). The presentation follows the standard pattern of presenting goals, theories, definitions, and assumptions. For readers that would like a more bottom up approach, they can start reading the instance models in Section 4.2.5 and trace back to find any additional information they require. The goal statements are refined to the theoretical models, and the theoretical models to the instance models. The instance model (Section 4.2.5) to be solved is referred to as IM1. The instance model provides the Ordinary Differential Equation (ODE) that model the solar water heating system. SWHS solves this ODE.

3 General System Description

This section provides general information about the system. It identifies the interfaces between the system and its environment, describes the user characteristics and lists the system constraints.

3.1 System Context

The system context is shown in Figure 1 below. The circles represent the user, who is both responsible for handling the inputs and the outputs. The box represents the program itself, and the arrows indicate what data and information is passed from the user to the program.

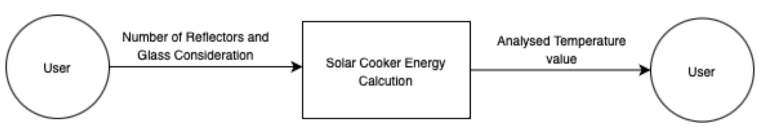

Figure 1: System Context

- User Responsibilities:
  - Provide required inputs including number of reflectors, glass area, thickness, dimension and size.
  - Ensure all inputs are in correct format.

- Responsibilities:
  - Detect data type mismatch, such as a string of characters instead of a floating point number
  - Determine if the inputs satisfy the required physical and software constraints such as thickness of the glass can not be a negative value
  - Calculate and plot the required outputs of temperature

3.2 User Characteristics

The end user of the system is expected to be familiar with Undergraduate level Calculus and basic physics. They should also know basics about the Reflector angle and heat flows in solar cooker.

3.3 System Constraints

There are no system constraints for this project.

4 Specific System Description

This section first presents the problem description, which gives a high-level view of the problem to be solved. This is followed by the solution characteristics specification, which presents the assumptions, theories, definitions and finally the instance models (ODE) that models the Solar Cooker Reflections.

4.1 Problem Description

Solar Cooker Energy Calculation is intended to investigate the temperature inside the solar cooker box with internal reflectors.

4.1.1 Terminology and Definitions

This subsection provides a list of terms that are used in the subsequent sections and their meaning, with the purpose of reducing ambiguity and making it easier to correctly understand the requirements:

- Reflectivity: The fraction of radiation reflected by the surface is called the reflectivity (ρ)
- Transmittivity: The fraction of radiation transmitted is called the transmissivity (τ)
- Emittance: the energy radiated by the surface of a body per second per unit area (ϵ)

- Reflactor Angle: the angle between a reflected ray and the normal drawn at the point of incidence to a reflecting surface (θ)
- Heat flow Convection: Convection is the transfer of heat from one place to another due to the movement of fluid
- Heat flow radiation: a process where heat waves are emitted that may be absorbed, reflected, or transmitted through a colder body
- Heat Convection Coefficients: The rate of heat transfer between a solid surface and a fluid per unit surface area per unit temperature difference (h)
- Steffan-Boltzman constant: is a physical constant expressing the relationship between the heat radiation emitted by a black body and its absolute temperature (σ)
- Heat Flux: the amount of heat energy passing through a certain surface

4.1.2 Physical System Description

The physical system of Solar Cooker Energy Calculation, as shown in Figure 2, includes the following elements:

PS1: A cover with two flat glasses (glass 1 and glass 2)

PS2: Lead of the recipient and recipient itself

PS3: Fluid inside the recipient

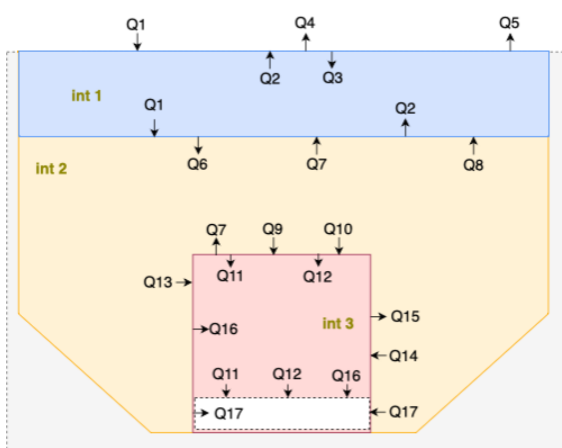

Figure 2: Heat Flows in Solar Cooker

4.1.3 Goal Statements

Given the thermal attributes and solar box characteristics the goal statements are:

GS1: predicts the Balance of temperature on the recipient.

GS2: predicts the cooking energy in the recipient over time.

4.2 Solution Characteristics Specification

The instance model (ODE) that governs Solar Cooker Energy Calculation is presented in Subsection 4.2.5. The information to understand the meaning of the instance model and its derivation is also presented, so that the instance model can be verified.

4.2.1 Assumptions

This section simplifies the original problem and helps in developing the theoretical model by filling in the missing information for the physical system. The numbers given in the square brackets refer to the theoretical model [T], general definition [GD], data definition [DD], instance model [IM], or likely change [LC], in which the respective assumption is used.

A1: The emissivity(ϵ) have been considered constant [GD1, DD3, DD4, IM1]

A2: The reflectivity (ρ) have been considered constant [DD2]

A3: The Transmisivity (τ) have been considered constant [DD2]

A4: The material in the recipient (Container) is liquid for this case (For us, it's water). This implies that the temperature will not drop below melting point and not rise above the boiling point [IM1, T2]

A5: The temperature T_{int2} are obtained in function of others temperatures by means of the following supposition: [IM1, DD1]

$$T_{\text{int2}} = \frac{T_{\text{g2}}+T_t+T_r}{3}$$

A6: The solar radiation impact over the solar cooker occurs in perpendicular way. [IM1, DD2]

A7: The only form of energy considered in this problem is thermal energy. Other energy such as mechanical energy are assumed to be a negligible. [IM1, LC1]

A8: The temperature of the reflector is constant over the different time. [DD6, LC2]

4.2.2 Theoretical Models

This section focuses on the general equations and laws that Solar Cooker Energy Calculation is based on.

Number	TM1
Label	**Convective Heat Transfer Coefficient**
Equation	h $= \frac{q}{\triangle T}$
Description	The above equation is used to calculate the heat transfer typically by convection or phase transition. h is the heat transfer convection coefficient ($\mathrm{W/m^2}K$). q is the thermal flux vector ($\mathrm{W\,m^{-2}}$). $\triangle$T is the change in temperature.
Notes	none.
Sources	https://en.wikipedia.org/wiki/Heat_transfer_coefficient
Ref. By	GD1, IM1

Number	TM2
Label	**Sensible Heat energy Calculation**
Equation	Q $= Cm\triangle T$
Description	This calculation occurs until the highest or lowest temperature reach, as assumed in [A4] Q is the quantity of heat transferred to or from the object m is the mass of the object C is the specific heat capacity of the material the object is composed of $\triangle T$ is the resulting temperature change of the object
Notes	none.
Sources	https://www.physicsclassroom.com/class/thermalP/Lesson-2/Measuring-the-Quantity-of-Heat
Ref. By	IM2

4.2.3 General Definitions

This section collects the laws and equations that will be used in building the instance models.

Number	GD1
Label	**Heat Flow Convection**
SI Units	W
Equation	$Q(t) = hA\Delta T(t)$
Description	Heat Flow Convection is related to Newton's law of cooling describes convective cooling from a surface. The law is stated as: the rate of heat loss from a body is proportional to the difference in temperatures between the body and its surroundings. $Q(t)$ is the thermal flux ($\mathrm{W\,m^{-2}}$). h is the heat transfer coefficient ($\mathrm{W\,m^{-2}\,{}^{\circ}C^{-1}}$). A is the exposed surface area ($\mathrm{m^2}$). $\Delta T(t)$ is the temperature difference (${}^{\circ}\mathrm{C}$).
Source	https://en.wikipedia.org/wiki/Convection_(heat_transfer)
Ref. By	IM1

Number	GD2
Label	**Heat Flow Radiation**
SI Units	J
Equation	$Q(t) = \sigma e A \triangle T^4$
Description	An object emits radiant energy in all directions unless its temperature is absolute zero. If this energy strikes a receiver, part of it may be absorbed, part may be transmitted, and part may be reflected. Heat transfer from a hot to a cold object in this manner is known as radiation heat transfer . The higher the temperature, the greater is the amount of energy radiated. $Q(t)$ is the heat flow radiation ($\mathrm{W\,m^{-2}}$). σ is the Steffan-Boltzman constant ($5.669X10^{-8}W/m^2K^4$). e is the emissivity of object(W/m). A is the exposed surface area ($\mathrm{m^2}$) $\triangle T(t)$ is the temperature difference (°C).
Source	(1)
Ref. By	IM1

4.2.4 Data Definitions

This section collects and defines all the data needed to build the instance models. The dimension of each quantity is also given.

Number	DD1
Label	**Data Definition of Q13**
Symbol	$Q13$
SI Units	$\mathrm{W\,m^{-2}}$
Equation	$\mathbf{Q13} = A_r h_{\text{r-int2}}(T_{\text{int2}} - T_r)$
Description	This equation calculates the Heat flow convection of recipient to inner 2 A_r is the Area of Reflector (m^2). $h_{\text{r-int2}}$ is the thermal flux difference between Reflector and Inner area inside the box $T_{\text{int2}} - T_r$ is the temperature difference between inner area and reflector (°C).
Sources	(6)
Ref. By	IM1

Number	DD2
Label	**Data Definition of Q14**
Symbol	$Q14$
SI Units	$\mathrm{W\,m^{-2}}$
Equation	$\mathbf{Q14} = \sum_{i=1}^{n} \rho A_{\text{ref,n}} G \tau_g^2 cos(90 - \theta_{\text{ref,n}})$
Description	This equation calculates the Heat flow reflection of incident radiation on the reflectors ρ is the reflectivity constant ($\mathrm{kg/m^3}$). $A_{\text{ref,n}}$ is the Area of the number of reflectors G is Incidental solar radiation taken as an input ($\mathrm{W/m^2}$) τ_g is the Transmittivity constant for glass ($0 \leq \tau \leq 1$) $cos(90 - \theta_{\text{ref,n}})$ is the angle difference of reflectors.
Sources	(6)
Ref. By	IM1

Number	DD3
Label	**Data Definition of Q15**
Symbol	$Q15$
SI Units	$\mathrm{W\,m^{-2}}$
Equation	$\mathbf{Q15} = A_r \sigma \epsilon_r (T_r^4 - T_{\mathrm{g2}}^4)$
Description	This equation calculates the Heat flow radiation of recipient toward glass 2 A_r is the Area of Reflector (m^2). σ is the Steffan-Boltzman constant ($5.669 X 10^{-8} W/m^2 K^4$) ϵ_r is the Emittance of Reflector (W/m) $T_r - T_{\mathrm{g2}}$ is the temperature difference of reflectors and glass 2 (°C).
Sources	(6)
Ref. By	IM1

Number	DD4
Label	**Data Definition of Q16**
Symbol	$Q16$
SI Units	$\mathrm{W\,m^{-2}}$
Equation	$\mathbf{Q16} = A_r \sigma \epsilon_r (T_r^4 - T_f^4)$
Description	This equation calculates the Heat flow radiation of recipient toward the fluid A_r is the Area of Reflector (m^2). σ is the Steffan-Boltzman constant ($5.669 X 10^{-8} W/m^2 K^4$) ϵ_r is the Emittance of Reflector (W/m) $T_r - T_f$ is the temperature difference of reflectors and fluid(°C).
Sources	(6)
Ref. By	IM1

Number	DD5
Label	**Data Definition of Q17**
Symbol	$Q17$
SI Units	$\mathrm{W\,m^{-2}}$
Equation	$\mathbf{Q17} = A_m h_{\text{r-f}}(T_r - T_f)$
Description	This equation calculates the Heat flow convection of recipient toward the fluid A_m is the wet inside the container ($\mathrm{m^2}$). $h_{\text{r-f}}$ is the thermal flux difference between Reflector and fluid inside the container $T_r - T_f$ is the temperature difference between reflector and fluid (°C).
Sources	(6)
Ref. By	IM1

Number	DD6
Label	**Heat flux over all different object**
Symbol	q
SI Units	$\mathrm{W\,m^{-2}}$
Equation	$q(t) = h_r(T_r - T_W(t))$, over area A_r
Description	It is necessary to know the thermal conductivity of a material if you want to calculate the heat energy transferred through it q is the heat flux h_r is the convective heat transfer coefficient between reflector and water T_r is the temperature of reflector °C $T_W(t)$ is the temperature of water °C t is the time (s)
Sources	https://www.omnicalculator.com/physics/thermal-conductivity
Ref. By	IM1

4.2.5 Instance Models

This section transforms the problem defined in Section 4.1 into one which is expressed in mathematical terms. It uses concrete symbols defined in Section 4.2.4 to replace the abstract symbols in the models identified in Sections 4.2.2.

Number	IM1
Label	**Balance of energy on the recipient to find T_W**
Input	A_r, ϵ_r, T_r, T_f, T_{int2}, A_m, T_f, G The input is constrained so that $\epsilon_t \leq 0$
Output	$T_f(t)$, $t \geq 0$, such that $\mathbf{m_W c_W \frac{dT_W}{dt} = Q13 + 4Q14 - Q15 - Q16 - Q17}$
Description	A_r is the Area of Reflector (m^2). ϵ_r is the Emittance of recipient (W/m). T_r is the Reflector temperature (°C). T_{int2} is a temperature inside the box (°C). G is the Incidental solar radiation (W/m^2). T_f is a current temperature of Fluid (°C). The above equation applies as long as the fluid is in liquid form, $0 < T_f < 100^o\text{C}$, where 0^oC and 100^oC are the melting and boiling points of water(as we are using water for testing), respectively.
Sources	(6)
Ref. By	None

Number	IM2
Label	**Heat energy in the recipient**
Input	C_W, m_W, T_{init}, $T_W(t)$
Output	$E_W(t)$, $0 \leq t \leq t_{\text{final}}$, such that $E_W(t) = C_W m_W (T_W(t) - T_{\text{init}})$
Description	The above equation is derived using T**??**. E_W is the change in thermal energy of the liquid water relative to the energy at the initial temperature (T_{init}). C_W is the specific heat capacity of liquid water and m_W is the mass of the water. The change in temperature is the difference between the temperature at time t, T_W, and the initial temperature, T_{init}, this equation applies as long as $0 < T_W < 100^o$C (A4).
Sources	(5)
Ref. By	None

4.2.6 Input Data Constraints

Table 1 shows the data constraints on the input output variables. The column for physical constraints gives the physical limitations on the range of values that can be taken by the variable. The column for software constraints restricts the range of inputs to reasonable values. The software constraints will be helpful in the design stage for picking suitable algorithms. The constraints are conservative, to give the user of the model the flexibility to experiment with unusual situations. The column of typical values is intended to provide a feel for a common scenario. The uncertainty column provides an estimate of the confidence with which the physical quantities can be measured. This information would be part of the input if one were performing an uncertainty quantification exercise.

5 Requirements

This section provides the functional requirements, the business tasks that the software is expected to complete, and the nonfunctional requirements, the qualities that the software is expected to exhibit.

5.1 Functional Requirements

Table 1: Input Variables

Var	Physical Constraints	Software Constraints	Typical Value	Uncertainty
L	$L > 0$	$L_{\min} \leq L \leq L_{\max}$	0.12 m	-
C_w	$C_w > 0$	$C_w^{\min} \leq C_w \leq C_w^{\max}$	4186 J/ (kg°C)	-
τ_g	$0 \leq \tau_g \leq 1$	-	0.48 m	-
A_g	$A_g > 0$	$A_g \leq A_g^{\max}$	0.24 m^2	-
n	$n > 0$	$n_{\min} \leq n \leq n_{\max}$	1	-
T_{init}	$0 < T_{\text{init}} < 100$	-	40 °C	-
G	$G > 0$	$G_{\min} \leq L \leq G_{\max}$	476 W/m^2	-
T_{f}	$0 < T_{\text{f}} < 100$	-	40 °C	-

Table 2: Output Variables

Var	Physical Constraints
T_r	$T_{\text{init}} \leq T_r$
E_w	$E_w > 0$

R1: Provide the inputs specific to Solar Box (Area of glass, Current Temperature of reflector/fluid/glass, Area of reflector) and other parameters (Incidental Solar Radiation, Reflectors angle, and number of reflectors)

R2: Verify the given inputs are in correct form and satify the required physical constraints given in the table 1

R3: Calculate and output the balance of energy on recipient $T_W(t)$ over the simulation time(from IM1)

R4: Calculate and output the energy in the water (fluid - recipient) $E_W(t)$ over the simulation time(from IM2)

5.2 Nonfunctional Requirements

This problem is small in size and relatively simple, so performance is not a priority. Any reasonable implementation will be very quick and use minimal storage. Rather than performance, the non-functional requirement priorities are correctness, verifiability, understandability, reusability, and maintainability.

6 Likely Changes

LC1: A7 The other form of energy such as Mechanical energy may apply as a part og energy consideration.

LC2: A8 The temperature of the reflector will change over the different time during the day which is totally based on the sun rays.

7 Unlikely Changes

LC3: A5 The given calculation for the inner temperature for the box(int2) in the assumption will not change throughout the whole process.

8 Traceability Matrices and Graphs

The purpose of the traceability matrices is to provide easy references on what has to be additionally modified if a certain component is changed. Every time a component is changed, the items in the column of that component that are marked with an "X" may have to be modified as well. Table 5 shows the dependencies of theoretical models, general definitions, data definitions, and instance models with each other. Table 3 shows the dependencies of instance models, requirements, and data constraints on each other. Table 4 shows the dependencies of theoretical models, general definitions, data definitions, instance models, and likely changes on the assumptions.

	IM1	IM2	4.2.6	R1	R2	R3	R4
IM1		X				X	
IM2	X						X
R1							
R2			X				
R3	X						
R4		X					

Table 3: Traceability Matrix Showing the Connections Between Requirements and Instance Models

	A1	A2	A3	A4	A5	A6	A7	A8
T1	X							
T2	X							
GD1	X							
GD2	X							
DD1	X							
DD2	X							
DD3	X							
DD4	X							
DD5	X							
DD6	X							
IM1	X							
IM2	X							
LC1	X							
LC2	X							

Table 4: Traceability Matrix Showing the Connections Between Assumptions and Other Items

	T1	T2	GD1	GD2	DD1	DD2	DD3	DD4	DD5	DD6	IM1	IM2
T1			X		X						X	
T2												X
GD1	X				X				X			
GD2							X	X				
DD1	X		X								X	
DD2											X	
DD3				X							X	
DD4				X							X	
DD5	X		X								X	
DD6	X										X	
IM1	X				X	X	X	X	X	X		
IM2		X										

Table 5: Traceability Matrix Showing the Connections Between Items of Different Sections

References

[1] Ibrahim Dinçer and Marc A. Rosen. *Thermal Energy Storage : Systems and Applications*. John Wiley Sons, Canada, 2010.

[2] Nirmitha Koothoor. A document drive approach to certifying scientific computing software. Master's thesis, McMaster University, Hamilton, Ontario, Canada, 2013.

[3] David L. Parnas and P.C. Clements. A rational design process: How and why to fake it. *IEEE Transactions on Software Engineering*, 12(2):251–257, February 1986.

[4] W. Spencer Smith and Lei Lai. A new requirements template for scientific computing. In J. Ralyté, P. Ȧgerfalk, and N. Kraiem, editors, *Proceedings of the First International Workshop on Situational Requirements Engineering Processes – Methods, Techniques and Tools to Support Situation-Specific Requirements Engineering Processes, SREP'05*, pages 107–121, Paris, France, 2005. In conjunction with 13th IEEE International Requirements Engineering Conference.

[5] H Terres, A Lizardi, Sayra Chávez, R López, and Mabel Mier. Evaluation of the cooking power in three different solar cookers box-type. *Journal of Physics: Conference Series*, 792:012013, 01 2017.

[6] Hilario Terres, Arturo Lizardi, Raymundo Lpez, Mabel Vaca, and Sandra Ch°vez. Mathematical model to study solar cookers box-type with internal reflectors. *Energy Procedia*, 57:1583–1592, 2014. 2013 ISES Solar World Congress.