A Calculation Model for Assessment of Reliability in Solar Combisystems

A Report of IEA SHC - Task 26

Solar Combisystems

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A technical report of Subtask A

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1 Introduction

This report describes a method to assess the reliability of solar combisystems. It was developed in the framework of IEA SH&C Task 26. It is intended for use as a “design tool” in the development of new systems, thus providing a means to assess different options regarding quality, complexity and maintenance.

2 Background

Much effort has been spent on developing solar thermal systems for the past 20 years. In optimising different concepts, high thermal performance has been the main focus, often resulting in rather advanced and complex systems. Parameters as economy, user friendliness and high reliability have had a tendency to be left aside, but are being more and more taken into consideration as new generations of systems are developed. This report is a summary of a diploma work [1] initiated by one of the researchers of Task 26 and inspired by an earlier IEA work on HVAC systems [2]. It was performed in Sweden in 2000. The work resulted in two different kinds of analyses where one could be characterised as a relative comparison of system complexity between the generic systems of Task 26. It has been described in the Task 26 Design Handbook [3]. The second approach, presented in the following, is a calculation model where the component’s quality levels and maintenance frequencies are included in addition to the lifetimes that were used as input in the first approach.

3 Aim

A calculation model has been developed to provide manufacturers of solar thermal systems with a “design tool” that can be used in the assessment and development of new systems. The model inputs, presented in an Excel workbook, can easily be adapted to any type of system. A prerequisite for an adequate assessment is of course that knowledge exists about the different components’ lifetimes and how different quality levels affect these. The model has some obvious limitations in it’s present shape and those are further described below. However it would be possible to develop this concept further in order to get away from these limitations without too much effort.

4 Assumptions and system borders

The model does not take into account the different criticality of single components to the system function, nor the effects of possible degradation with time. All components with the same estimated lifetime are thus considered to be equally critical to the system function and a component either works or it doesn’t work. Where maintenance is considered, it’s assumed to bring a component back to a state ‘as new’. The profound knowledge of a specific system and it’s components required to get the full benefit of an analysis like this has not been available in the design of this model. For example, alarm functions, ’smart controllers’ or other features that might improve the reliability of a system have not been assessed. Furthermore, the model assumes that the system is ‘perfectly’ installed and fully functional from the start and also the user is assumed to be ‘perfect’.

The system border incorporates all storage units and the components directly related to the collector loop and the dhw loop: sensors, controller, heat exchangers etc. The space heating loop is <u>not</u> included, neither are the auxiliary heating equipment, it’s controller, sensors, heat exchangers etc. The latter is a major drawback in particular when analysing systems with boilers or burners integrated in the storages as the integration of auxiliary heating in the store often can be the most critical issue in a solar combisystem from the reliability point of view.

5 The model

Reliability is defined as the probability that a unit functions as intended or better. This is valid for components and for systems. The reliability of components and thus of the systems they form is reduced with time and it's obvious that the risk of failure increases with time as the component is in operation. This is normally expressed as a lifetime and the lifetime has a certain distribution. Furthermore the reliability is affected by the quality of the components and by the maintenance. Possible failure modes can be divided in two categories, spontaneously occurring failures and failures due to degradation. The latter means that the performance of a component slowly decreases due to wear, deposits or similar mechanisms. These have not been analysed in this work and the model is restricted to assessment of functioning or not functioning components / systems. A system is considered to be fully operational when all it's components are functioning.

The model is implemented in an Excel workbook. The first sheet (input) is a list of the different components of a solar combisystem. In this case, System #12 in the generic system overview [4] [5] has been used as a test case. The sheet contains lifetimes and their distributions for three different quality levels and the related maintenance intervals for all components within the system borders. Lifetime data has been gathered by contacts with researchers and manufacturers. Distributions and maintenance intervals are based on own assumptions. Each possible combination has a separate sheet in the workbook where component reliabilities are first calculated separately and then multiplied into a system reliability. The model allows the use of a maintenance interval equal to zero, which is probably often the case in privately owned smaller systems. The lifetime of the system has been set to 30 years, corresponding to the assumed lifetime of an average collector. Before that, any component that reaches it's predicted lifetime is replaced by a new one.

These are the equations used in the model to calculate the reliability (R) of a component.

$$\text{if } t < m$$

$$Equ.1: \quad R(t,m,s) = \frac{1}{(1+e^{-p(t,m,s)})}$$

$$\text{if } t \geq m$$

$$Equ.2: \quad R(t,m,s) = 1 - \frac{1}{(1+e^{-p(t,m,s)})}$$

$$\text{where; } p(t,m,s) = \frac{|t-m|}{s} * \left[1{,}5976 + 0{,}070566 * \left(\frac{t-m}{s}\right)^2\right]$$

Where

$R =$ *reliability of a component*

$p =$ *function for probability*

$t =$ *time in years after maintenance*

$t' =$ *totally elapsed time in years*

$m =$ *average lifetime in years*

$s =$ *spread in lifetime in years*

$u =$ *maintenance frequency in years*

The definition of time t is:

$$t = t' - u * \text{ integer}\left(\frac{t'}{u}\right)$$

This definition is based on the assumption that the component will be ’as new’ after maintenance, i.e. elapsed time is then reset to zero. Thus t, time since last maintenance, is the variable on which the reliability depends as follows:

$$if\,(t' - u * \text{ integer}\left(\frac{t'}{u}\right)) < m, \, then\ equation\ 1, \, else\ equation\ 2$$

When u equals zero for any component, *m* is used instead.

6 Input data for the analysis of one system

The model has been implemented in the Excel workbook “input eng.xls”. The workbook is structured in four parts:

1. A sheet with generic data (lifetimes and spreads related to quality levels, assumed maintenance intervals) for components covering most of the generic systems of the Task 26 survey [4] [5] as defined by the system borders in this work.

2. A sheet where the components of generic system #12 are selected as a basis for the analysis of this particular system.

3. An output sheet

4. Nine sheets, each containing the system reliability calculation for System #12, but based on different levels of maintenance and quality.

To apply the model to another system, the following steps are recommended:

- Start with the Excel sheet ”Input eng.xls” and choose (not copy) the components that constitutes or will constitute the system. Note that there are different values for each component depending on quality and maintenance interval
- On the sheet ”system 12” there is a list of components in three different quality levels and three maintenance intervals for each quality. Use this system and these components as a start-up.

To add and / or take away components, thereby adapting the list to the system to be analysed the following procedure is used:

- For cells containing figures for components that shall not be included, the figures are replaced with figures for any new component if it exists. (do not forget to replace all three quality levels and maintenance frequencies)
- If one component is not replaced by another, the whole line is removed.
- If more components than the number of components in System #12 should be included, new lines must be added to the original list.
- After completing the list, it is linked to the following nine sheets. This is not true for manually added component's figures. If such values were added, the components and their figures should be linked. If components were completely removed from the "system 12" list, they must also be (manually) removed from the other sheets.
- Make sure that the time channel is correct and that every component has a corresponding column to the right on the sheet where the reliability is calculated. Cells where calculations shall take place shall have been given a value.
- Check that the "Complete system"-column multiplies the correct cells.
- Choose the time interval over which the system is to be analysed by shortening/ enlarging the time column to the relevant length
- Shorten/ enlarge other relevant columns to the same length as the time column

Provided all steps have been made correctly, the reliability of the new system shall now have been calculated. See also chapter 7 below for more input.

7 Output from the calculations

The results for nine combinations of quality and maintenance are calculated as "system lifetime averages" of a reliability indicator. These are compiled in the sheet "output system 12". The indicator's variation with time can easily be studied in a graph (not included) and compared to other quality/ maintenance combinations for the same system.

8 Documents for download

The Excel workbook "input eng.xls" described above can be downloaded from: ftp://ftp.sp.se/public/solarcombisystems reliability calculation

At the same web address the complete report on this work [1] can be found. Furthermore, the Excel workbook "component lists.xls" can be found at this site. In this workbook, all nineteen generic system concepts of the Task 26 overview have been analysed according to the first, more basic approach described in [1]. These lists may also serve as inputs for a deepened analysis similar to that made on System #12 in "input eng.xls".

9 References

[1] Johannesson K, Persson J, Reliability analysis of solar combisystems. A method and a model. Swedish National Testing and Research Institute Work Report SP AR 2001:37

[2] Kronvall J, Ruud S, System safety analysis on the performance of mechanical ventilation systems- the quantitative approach. 1997. 18th annual AIVC conference, Athens, Greece

[3] Weiss W (ed.), Solar heating systems for houses – A design handbook for solar combisystems, James & James Science Publishers Ltd., London, 2003

[4] Suter J-M, Letz T, Weiss W, Inäbnit J (ed.). Solar Combisystems in Austria, Denmark, Finland, France, Germany, Sweden, Switzerland, the Netherlands and the USA – Overview 2000, IEA SHC Task 26 Solar Combisystems, 2000, ISBN 3-905583-00-3

[5] http://www.iea-shc.org/task26/index.html