D9: Delivery of the Energy Auditing Tool (EAT)

(FINAL VERSION)

Contents

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1.0. Introduction / summary

The following document gives an overview of the Energy Auditing Tool (EAT). A detailed description of the underlying calculus and the user interface is contained within the document D6/D7/D8: Reference Greenhouse Specifications, Core Calculation module and Graphical User Interface module for the Energy Auditing Tool. A detailed user manual for the software is contained within the document D11: Software Users Manual.

The potential structure of the software and the required underlying calculus was defined initially in Version 1 of the 'Software Specification Document' written in October 2006. This document resulted from initial discussions during the summer of 2006 (subsequent to the 6 month project meeting in Athens the previous May) and more detailed discussions of the software requirements during the 12 month project meeting in the UK during September 2006. Version 2 of the 'Software Specification Document' was written in November 2006 in response to collated comments from consortium partners. It is this document that formed the basis for D6/D7/D8: Reference Greenhouse Specifications, Core Calculation Module and Graphical User Interface module for the EAT.

The EAT software has been developed in three parts. The structural specifications of the greenhouse and its management ('Reference Greenhouse Specifications') define the variables used within the 'Core Calculation module'. The 'Core Calculation module' uses energy balance and crop models to allow derivation by the user of the optimal greenhouse parameters for a given reference (baseline) greenhouse. Thirdly, the 'Graphical User Interface module' displays the results to the user in an easily accessible format.

In summary the software operates as follows:
1. User selects the location of the greenhouse. This will determine the climatic parameters and solar radiation to be used in the calculations
2. User enters basic structural information about their greenhouse, i.e. type and size.
3. User then selects which components are located in their greenhouse such as type of glazing, screen material, fuel type, efficiency of boiler and type of lighting.
4. User enters crop(s) being grown in the greenhouse and their dates.
5. User enters set-points for internal greenhouse temperature, use of screens, humidity levels, supplementary lighting, and CO_2 levels.
6. Software calculates / models temperature, humidity, plant growth and yield hourly for one calendar year (365 days). This is the baseline or reference greenhouse.
7. Software generates a report showing inputs (energy and fuel) and crop yields. Some of this data is available at hourly resolution or else is summarised as a total for the year.
8. User can then create alternative greenhouses and run the model and generate a new report. They can then compare the energy consumption and yield for their baseline (existing) greenhouse with those of the alternative greenhouses (thus allowing 'What If' comparisons).
9. Management strategies that result in a reduction in the greenhouse energy requirement can be easily highlighted, compared and any potential impact upon crop yield and thus overall efficiency determined.

2.0. Greenergy Software Version 1.0.6. Installation Instructions

2.1. Installation Notes:

Please Note: In order to run the installation file you will need Microsoft Windows Installer. If you are running Windows XP with Service Pack 2, then you will already have this. If you do not have this then it can be downloaded from Microsoft (click here for Windows XP and 2000 or here for Windows 98/ME).

Please follow the steps below to install the software:
1. Close all other programs on your computer
2. Open Windows Explorer or My Computer and Select the CD-ROM Drive (a box labelled 'Greenergy 106' should appear next to the disc icon in the CD-ROM Drive)
3. 3. Double-click on the MSI file to start the installation. Sometimes on Windows XP, the installer will display "Source could not be verified - Run or Cancel?", if it does, select Run.
4. On the Welcome screen of the installation click on 'Next'
5. On the Installation Folder screen either accept the default folder or use the Browse button to select an alternative folder. Then click on 'Next'.
6. On the Confirm screen, to start the installation click on 'Next'
7. The installer will now copy the files on to your computer (this may take a few minutes).
8. You will be informed if the installation has been successful.
9. Click on 'Next' and then 'Close' to finish the installation.
10. Restart you computer

2.2. Software Notes:

The installer will place a short-cut to start the software on your desktop, double-click on the icon to start the software (it can also be found under the Programs section of your Start menu).

Please Note: This version of the software is classed as a 'demonstration version'. This means that it is incomplete and untested so it may contain errors and bugs. Please report any problems to aeru@herts.ac.uk.

2.3. System Requirements:

The software has been designed to work on Microsoft Windows XP, 2000 and 98/ME. It should also work on Windows Vista, but this has not been tested yet. You will also need at least 50 MB disk space (About 35 MB of this free space must be on your C: drive, or the drive where Windows is installed), 128 MB RAM or higher, and a Pentium processor (PIII or higher recommended).

3.0. Brief outline of the software

The start-up screen of the software is shown in Figure 1. The user selects the 'My Greenhouses' option (top left hand corner) and creates a new greenhouse profile ('Edit' then 'New greenhouse') or opens a previously saved profile which may then be edited as required. If a new profile is created the user navigates in sequence down the icons located on the left-hand side of the screen (firstly selects and inputs 'Country and latitude' followed by 'Type and dimensions' then 'Components and materials' etc). The entered parameters of the greenhouse are then summarised in the table labelled 'Greenhouse details' on the right hand side.

Figure 1. GREENERGY software start-up screen.

3.1. Construction of the user's own greenhouse (Deliverable 6: 'Reference Greenhouse Specification')

It was highlighted by grower advisors (IAG's) that the construction of a suitable benchmark greenhouse as originally proposed for Deliverable 6: 'Reference greenhouse specifications' would be difficult on account of variation between growing practices for each region. As an alternative the software allows the growers (SMEs) to construct the equivalent of their own actual greenhouse, the parameters of which are then used within model. This may be conducted under the guidance of the IAG organisations responsible for the dissemination of the software as necessary. The construction of their own greenhouse is undertaken in the 'greenhouse builder' stage of the software after selecting the geographic location then entering the type and dimensions, the materials and components, the cropping regime and the greenhouse set-points. These are described briefly in the following sub-sections of this document.

3.1.1. Country and latitude

The user begins by selecting the location of their greenhouse by selecting the 'Country and latitude' option then selecting their country from the list boxes. The resolution of the underlying climate and solar radiation databases that are held for different locations in Europe has determined the number of default weather files included in the software. The hourly resolution that is needed was available for the following partner countries: Denmark, Finland, Netherlands, UK, Estonia and Spain.

3.1.2. Type and Dimensions

The 'Type and dimensions' of the greenhouse include it's basic geometric shape and it's size in metres (length, width, height) from which the software will automatically calculate it's ground area, exposed surface area and volume (Figure 2). The presence of shelters (windbreaks that reduce the windspeed) adjacent to the structure (the height and distance from the structure) are also entered in this section.
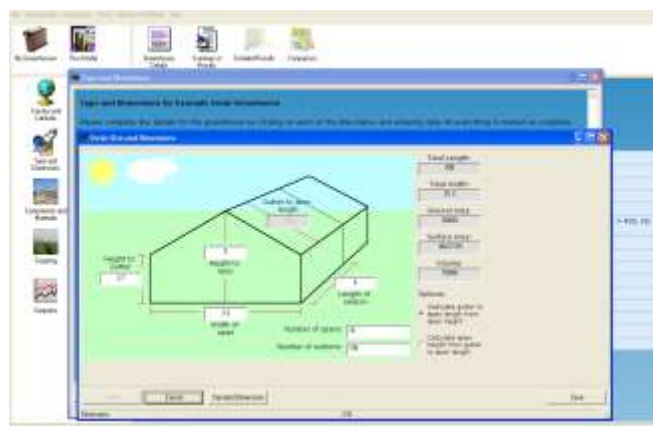

Figure 2. Example of 'Type and dimensions' data entry screen.

3.1.3. Components and Materials

The user enters the materials with which the greenhouse is constructed, for example the type of glazing and type of thermal or blackout screen (if any), the fuel type and efficiency of the boiler used.

3.1.4. Cropping

The crops that are grown in the greenhouse during the year available for the user to select include truss tomatoes (representative of fruit vegetables), cut chrysanthemum (representative of cut flowers) and potted roses (representative of pot-plants).

3.1.5. Set-points

The user then defines the environmental parameters within the greenhouse by selecting the 'Set-points' icon. They include temperature, humidity, lighting and carbon dioxide (CO_2). The temperature and humidity set-points are used to decide when heating or venting is required. The lighting set-points are used to control the supplementary lighting. The user interface allows the user to select, for example, hourly set-points over a weekly period for each year. The maximum and minimum setting is entered and coded by colour, this colour is then selected in each data entry cell (Figure 3). A 'brush' allows selection of a large number of cells rapidly (by holding down the left mouse button simultaneously to moving the cursor over each cell) without having to enter each number individually.
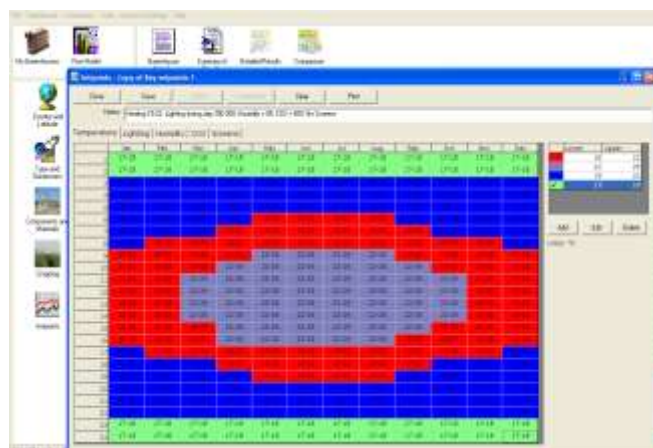

Figure 3. Example of 'Set-points' data entry screen (for temperature).

Once the user has selected the location of the greenhouse and described its dimensions, components, set-points and cropping regime, they can then run the model.

3.2. Running the model (Deliverable 7: 'Core Calculation module')

The greenhouse parameters entered into the software define the variables used within the 'Core calculation module' described in detail in the documentation for Deliverable 7. The user selects the 'Run model' icon at the top of the screen and a progress bar will appear to inform the user of progress with respect to the:
1. Formatting of climate data
2. Formatting of set-points
3. Modelling of the greenhouse
For a given greenhouse located within a given country with given internal environmental management parameters the software models the overall energy consumption (input) and crop yield (output).

3.2.1. Greenhouse energy balance and supplementary energy requirement

Given the type of greenhouse, its size, components, thermal properties, optimal conditions, and the management regime the software will then make calculations for each hour, for each day for a year, i.e. 8760 hours. For each hour the following calculation will be made using the underlying database for climate and solar radiation:

1. solar gain (energy, visible light and PAR) (W m^{-2})
2. assimilation lighting inputs
3. longwave radiation losses
4. transpiration losses (through vapour balance)
5. ventilation losses (and leakage)
6. convection losses
7. heating inputs

These should balance out at zero for the following equation:

$$\text{Energy flux (MJ)} = \text{solar gain + heating + lighting – transpiration – ventilation – convection – longwave radiation}$$

The equation may be manipulated to calculate the desired variables such as heating and ventilation to maintain the required environment within the greenhouse, namely temperature and relative humidity.

3.2.2. Crop yield

The ideal greenhouse requires the smallest additional energy input per tonne of yield. Some greenhouses may use lower quantities of additional energy in total, but if the yield is reduced significantly as a consequence, then the input per tonne of commodity output may be greater than if more energy is consumed coupled with a higher yield. Similarly, energy inputs could be substantially increased in order to increase yields, but if that increase in yield is only slight, then the energy input per tonne can be higher than a crop that had a slightly lower yield, but with a much lower energy input. In order to include yield as part of the assessment simple crop models have been incorporated into the software. These are based on rate of photosynthesis and dry weight production. Crop growth and yield is simulated with a photosynthesis driven model. Firstly, crop dry weight (DW) is simulated from crop gross photosynthesis (Pgc), maintenance respiration (Rm) and conversion efficiency (Cf), dry weight is then allocated to the separate plant organs as leaves, stems, and generative organs. This allocation is controlled by the temperature sum and is crop specific.

The formulae from which the core calculation module was built were run initially within the software package MATLAB® prior to conversion into the software package Visual Basic® to be linked with the Graphical User Interface.

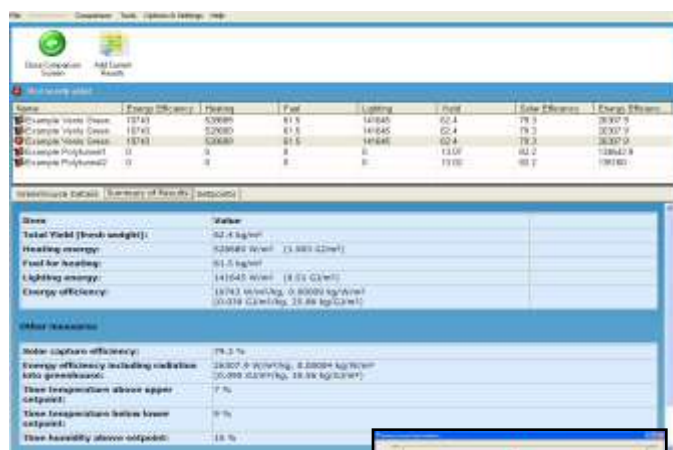## 3.3. Model outputs (Deliverable 8: 'Graphical User Interface module')

Once the model has been run the results are displayed in an easily accessible format both graphically and tabular. Further details are described in the accompanying document to deliverable D8 'Graphical User Interface module'.

3.3.1. Baseline greenhouse analysis

After the model has run to completion the user is presented with a summary table of energy consumption, crop yield etc for the selected cropping period. The outputs, the energy profile of the greenhouse, that can be examined include a summary table of the greenhouse structure, fuel used, crop grown and set-points in addition to the energy consumption. The user may display monthly output or input data by selecting the graph icon on the right hand side of the table. A more detailed breakdown of input /output data inclusive of hourly, daily, weekly and monthly inputs (external global radiation, temperature, relative humidity and wind speed) and outputs (radiation into greenhouse, greenhouse temperature and humidity, accumulated crop growth and crop growth with yield) may also be displayed graphically (Figure 10 (inset)). To access this data the user selects the 'Detailed Results' icon located at the top of the screen.

3.3.2. Comparison of user's actual greenhouses with 'what if' scenarios

An analysis of the baseline greenhouse is a provides the user with feedback on the energy efficiency of their current structure but the aim of the software is to allow the user to identify where improvements to the energy efficiency of their greenhouse may be made. At a basic level this can be as 'simple' as allowing the user to make changes to the greenhouse, to run the analysis again with these changes and then compare the outputs to the baseline greenhouse analysis. This effectively provides the user with a 'what if' facility, to explore different greenhouse permutations. Once the user has their baseline profile, some 'what if' profiles, a means of comparing and ranking the greenhouses is required. Presenting the scenarios in a table, which is then sorted by one or more of the output parameters, allows this (Figure 4). The user is able to select the parameters by which the table is sorted, e.g. overall energy consumption, highest heating requirement, highest yield, lowest net energy flow, lowest energy input per tonne of yield, etc. The data for each greenhouse profile is displayed on the

Figure 4. Comparison screen showing greenhouse profiles output and (inset) weekly input data display 'Comparison' screen that ranks the structure with respect to the chosen output (for example fuel consumption) other greenhouse profiles. It highlights to the user how their baseline greenhouse compares to other greenhouses and may be sorted according to the chosen variable. The user can then view these greenhouses to establish any differences relative to the baseline structure, in terms of components, management or both. The user is presented with options to improve the energy efficiency of their greenhouse.

3.3.3. Backing up greenhouse profiles and databases

The greenhouse profile, alterations to the materials database and comparisons between greenhouse profiles may be saved to the user's PC and re-instated as required. Each greenhouse constructed as a 'what if' scenario may be added to the saved greenhouse profiles while selected for viewing in the 'Comparisons' screen. The saved profiles may be transferred to other users with the Energy Auditing Tool installed on their PC through, for example, email.