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Energy Efficiency and Risk Management in Public Buildings

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List of Acronyms

CHP	Combined Heat and Power
CSS	Cascading Style Sheets
DSS	Decision Support System
EnRiMa	Energy Efficiency and Risk Management in Public Buildings
GUI	Graphical User Interface
HTML	HyperText Markup Language
PV	Photovoltaic
RIA	Rich Internet Application
WP	Work Package

Executive Summary

The goal of this deliverable is to describe the graphical user interface prototype of the EnRiMa decision support system, and to report on its evaluation.
The graphical user interface that has been implemented allows the user to interact with the system via a web browser. Currently the user interface prototype contains the following functionality:

- Screens for the operational optimization model (about 10 screens), for example enabling the user to set demands and energy prices at a per 24 hours basis.
- Screen for the strategic optimization model (about 35 screens), for example enabling the user to configure the current and future technologies, as well as to handle the configuration of long-term energy prices.
- The display of sample result graphs for the operational and strategic model.
- User handling, in the form on login screen, building selection, and authentication via the prototypes kernel module.

To archive this functionality the prototype has been integrated with software modules constructed within the project and by external vendors. Most notable the user interface makes use of the kernel software module as developed within the project, and an open source user interface framework and associated graphs tools developed by external vendors.

The user interface prototype has been evaluated using user tasks and an accompanying questionnaire. While the evaluation shows that the prototype is complex and requires training before use, it also highlights some of the prototypes strengths. Especially the evaluation gives at hand that the prototype got a high potential in the area of usefulness – that is, the prototype was considered to be of high practical importance when it comes to changing the energy efficiency in buildings.

1 Introduction

This deliverable describes the EnRiMa Decision Support System (DSS) graphical user interface (GUI) prototype the evaluation thereof. The GUI prototype is the part of the system that the users interact with in order to enter parameters for optimizations and view the results. The GUI prototype has been implemented as a web application accessible via standard web browsers. In order to provide its functionalities to the user the GUI is interconnected to the DSS Kernel. While the GUI is responsible for presenting the information the kernel is managing the structured storage and retrieval of information.

This deliverable is structured into two main parts; a description of the GUI prototype and a description of its evaluation.

The ***description of the GUI prototype*** gives an overview of the implemented prototype in the form of its implementation architecture (section 2.1) and its user interface screens (section 2.2 to section 2.5). Because of the large number of screens the full list of screens can be found in appendix C.

The ***GUI evaluation*** approach of using user tasks and a questionnaire is described in section 3, while the result and an analysis thereof presented in section 4. The full evaluation questionnaire can be found in Appendix B, while the introduction document used for the evaluation is located in Appendix A.

The GUI prototype has been developed as a part of task 5.3, adaptive GUI for the DSS engine, and task 5.2, service integration in tools. Moreover the prototype has been developed with feedback from task 4.6, implementation of the DSS kernel and task 4.5, stochastic optimisation algorithms and solvers. The GUI prototype software architecture has been developed with input from deliverable D5.1, draft specifications of services and tools (SU et al, 2012).

Note that this deliverable does not contain a full description all software parts in the prototype implementation, only the graphical user interface is described. Most notable the kernel prototype is not described here. For a description of the kernel, please refer to deliverable D4.4 (SU et al, 2013).

2 GUI Prototype

This section provides an overview of a) the software architecture of the prototype and b) the available screens.

2.1 Architecture Overview

The GUI prototype is constructed as a rich internet application (RIA). The user interacts with the system via a web browser that is interpreting HTML and CSS and executing JavaScript that is retrieved from a web server. The web server in turn executes the implemented modules of the GUI prototype. An overview of the GUI prototype is shown in Figure 2-1. As shown in the figure the *Graphical User Interface Server* is containing the implemented modules, and these modules are making use of the DSS kernel. Note that the DSS kernel is implemented in the project, however the kernel prototype implementation is described in deliverable D4.4, kernel prototype implementation (SU et al, 2013).

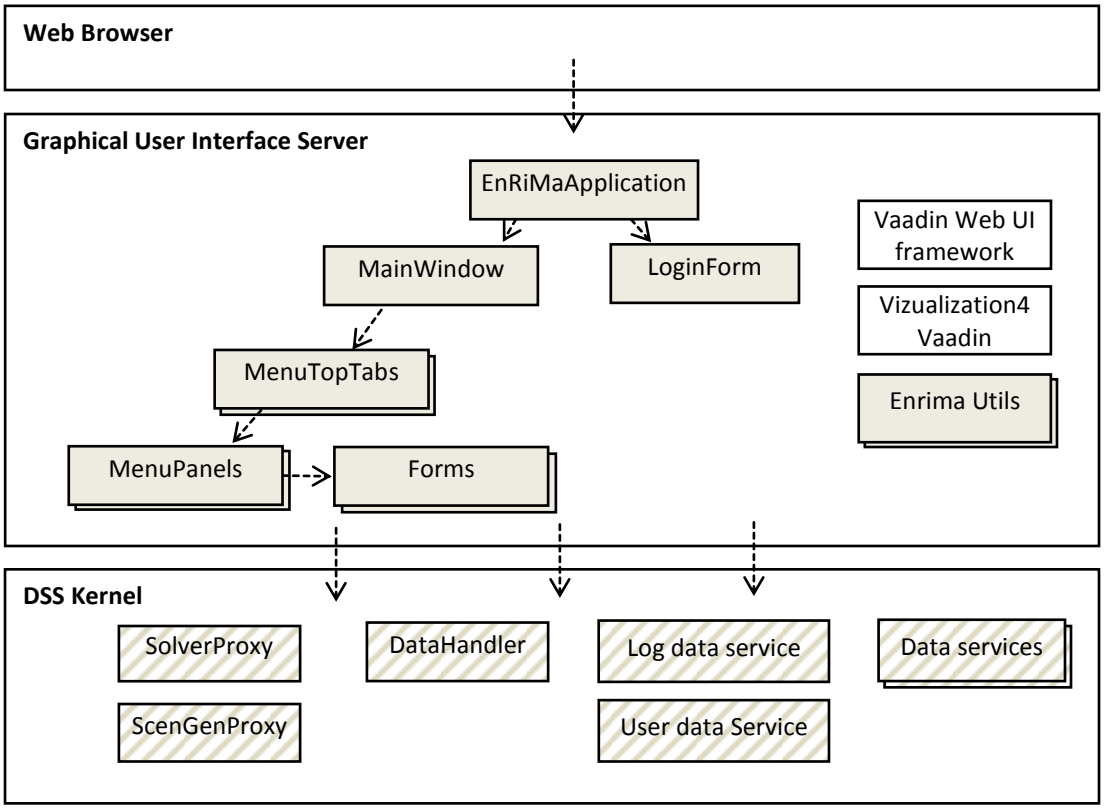

Figure 2-1: Overview of the GUI Prototype Architecture

The main modules of the GUI prototype implementation are described below:

Web Browser. When started, the web browser will request the HTML and CSS that is needed to display the user interface. Moreover the web browser is executing JavaScript code to handle a part of the interaction and the communication with the GUI server. The GUI prototype implementation can be used by any modern web-browser, such as Chrome, Safari, Firefox and mobile browsers for Android and IOS operating systems.

EnRiMaApplication, menues and forms. The main application class, *EnRiMaApplication,* is constructed as a Java Servlet that uses the Vaadin framework. Once requested by a web browser the application will be started and the server will load the *LoginForm* and *MainWindow*. All visual elements (windows, forms etc) and associated logic are implemented as Java classes with the use of the *Vaadin framework*. The Vaadin framework is then responsible for sending the Web browser the appropriate HTML, CSS and JavaScript that the browser can execute. Each of the classes contains separate UI and controller logic, and retrieves data objects via the kernel *Data services*. In Figure 2-1 a simplified structure of the classes for the *MainWindow*, the tabbed top Menu (*MenuTopTabs*) and *MenuPanels* are shown. In total the GUI got about 40 screens.

Vaadin framework and Vizualization4Vaadin. To aid in the creation of the GUI the open-source *Vaadin UI framework* is used. This framework is a server-side Java framework with advanced event handling. Since it is a server-side framework Vaadin allows the user interface to be created without writing much HTML or CSS. To accomplish this Vaadin framework incorporates the well-known Google Web Toolkit (GWT). In total the prototype GUI implementation contains about a page of CSS and a few lines of HTML code. Instead of writing the GUI in HTML the main layout of the UI is drawn in an editor, while the logic is written in Java.

Enrima utilities. Many forms in the user interface share the same visual components and overall logic. To raise the quality and shorten the development time these shared features are reused in the form of utility classes. On example of utility class in the visual tree structure that is used on many menus in the system.

DSS Kernel. The GUI uses the *kernel* to retrieve and store information, as well as to request the start of optimizations. Central for the GUI is the kernel modules as depicted in the figure. The *SolverProxy* and the *ScenGenProxy* are used upon user request to start the scenario generator and the solver respectively. The kernel *DataHandler* is used to copy sets of data, while the *User* and *Log* data services provide authentication and error handling. The general data retrieval is done by the use of the kernel *Data services*. Note that the kernel prototype is described further in deliverable D4.4, kernel prototype implementation (SU et al, 2013).

The user interface implementation and the kernel are deployed in an Apache Tomcat web server. Currently the prototype implementation is running in a Windows server at partner SU.

2.2 GUI Structure Overview

The GUI is a web-based application and is accessed through a standard web browser such as Google Chrome, Microsoft Explorer or Mozilla Firefox. After opening the link to the EnRiMa website a user is asked to login (see Figure 2-1). A user has access only to the buildings and given only the access privileges he or she has been assigned.

Figure 2-2: EnRiMa Login Screen

Once a user is logged in, the EnRiMa main screen is displayed (Figure 2-3). In the upper right hand corner (1) information about the user is displayed and a "Log out" button is provided. Information regarding the building that is currently selected is located at the top in the middle (2). The current building can be changed by pressing the adjacent "Change" button.

The optimization model that is currently selected is displayed just below the current building (3). Two decision making models are supported by the EnRiMa GUI prototype DSS, a operational and a strategic model. The operational model optimizes the usage of on-site and purchased available energy without the installation of any new technologies. The strategic model optimizes the long-term energy fulfilment through the use of new technologies. The selected model can be changed by pressing the "Change" button, located next to the model name.

A set of tabs is provided (4) to organize the input and output screens for both models mentioned above. The screens that are displayed under each tab are dependent on the model that is selected; in Figure 2-3 the "Operational" model and the "Home" tab has been selected.

Id the advent of an error an error message will be shown, and a small button "EMessage" will appear at the bottom right of the page (5). This button opens a window displaying the complete error message. This information can be useful for software developers when resolving the error.

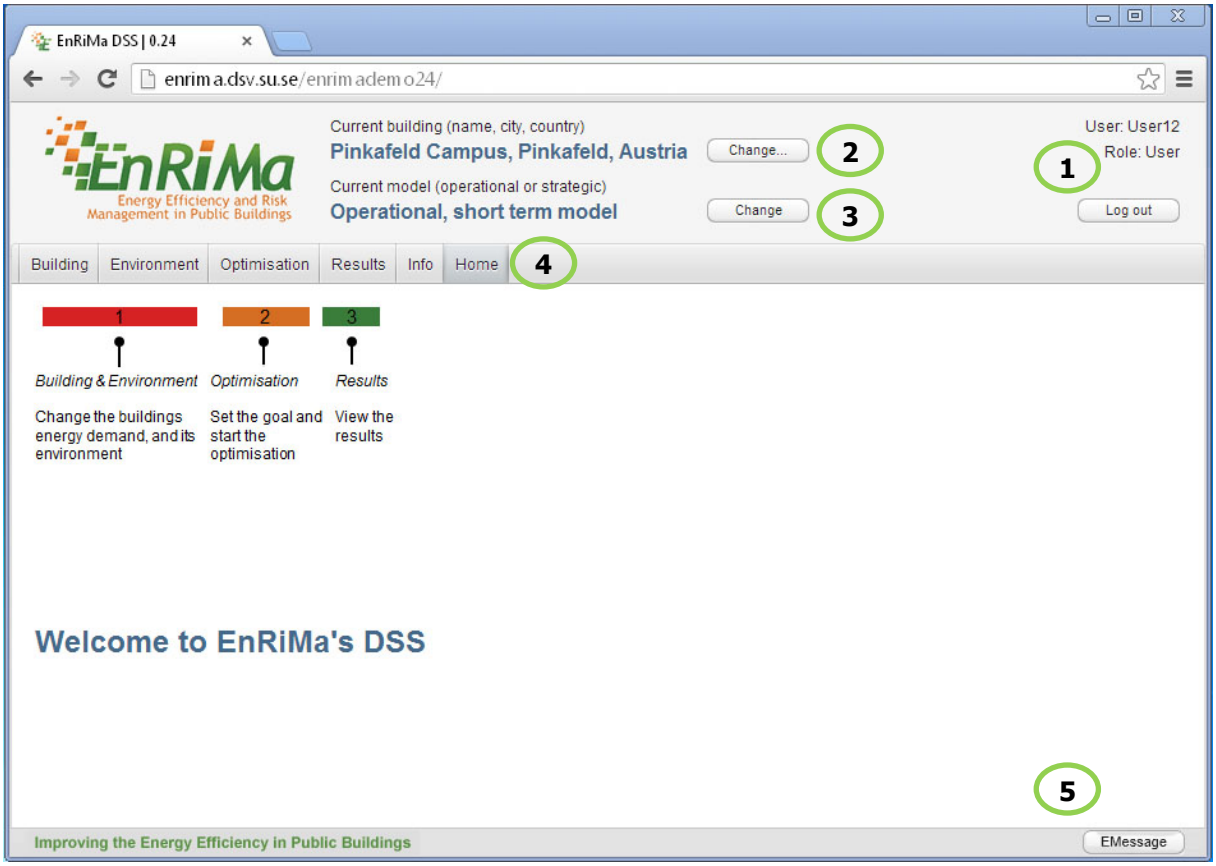

Figure 2-3: EnRiMa Main Screen

2.2.1 General Working Procedure for the UI

As shown in Figure 2-3, the EnRiMa main screen, the GUI gives the user the opportunity to select building and optimization model. However in order to run an optimization the user needs to perform the following steps, as indicated in the home screen (see Figure 2-4):

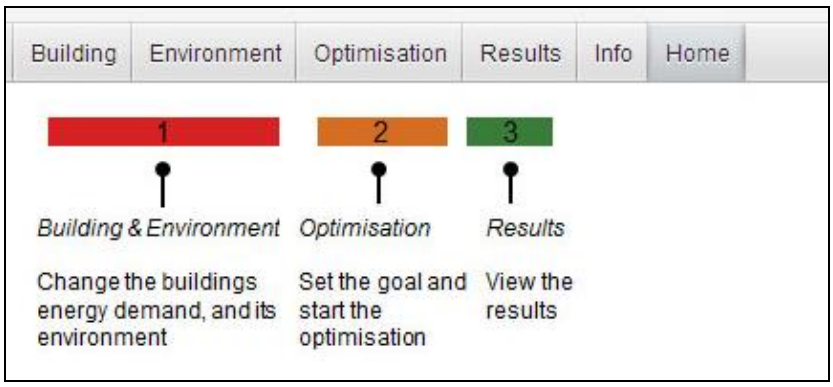

Figure 2-4: Home Screen, indicating the working procedure

Step 1 – Building & environment: This first step is where properties of the building and environment are given and modified.

Step 2 – Optimization: During this step the data the optimization is to be based on can be reviewed, the goal of the optimization chosen and the optimization run.

Step 3 – Results: The last step is to view the results of the optimizations, as will be described later the results for each optimization run is shown as a set of graphs.

The values set during Step 1 is stored for later use, this makes it easy for the user to modify the values and re-run the optimization (Step2). A selection of screens used to carry out these three steps is described in more detail in the following sections. ***A complete listing of all screens included in the GUI prototype is located in the Appendix C – GUI Screens.***

2.3 General User Interface Elements

In order to have a coherent user interface the system employs as set of general user interface elements and behaviours, these will be described in this section.

2.3.1 Saving, and Cancelling Updates

All screens that contain forms where the user can modify data are using the same functionality for saving data. This functionality is represented by "Save" and "Cancel" button in the top of the forms. When data is added, changed or deleted on any building or environment input screen the text "Not saved" is displayed next to the "Save" button in the upper right hand corner of the data input screen (see Figure 2-5). When navigating between screens this data will neither be saved or lost. To prevent the changes from being lost when a session ends, for whatever reason, it must be saved by pushing the "Save" button. Conversely, if desired, the changes can be undone before the data is saved by pushing the "Cancel" button.

Figure 2-5: Save, Cancel, Not Saved

2.3.2 Field Descriptions

Pausing/hovering the mouse pointer over an input label causes a tool tip or description box to appear (see Figure 2-6). A tool tip is provided for many of the more complicated properties. The text that appears is stored in the database and can thus be easily changed. This provides a flexible mean to keep this information up to date.

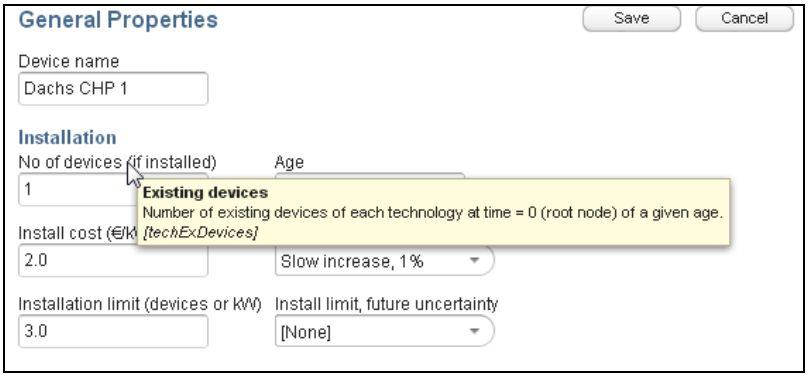

Figure 2-6: Tool Tip on Mouse over Example

2.3.3 Field Validation

Entering invalid values will cause an invalid value warning to be displayed (see Figure 2-7). This warning will disappear as soon as the problem is solved. The validation can be general in nature such, as a character value where an integer is required. It can also be of a more specific nature such, as a value outside a range pre-specified for a specific property.

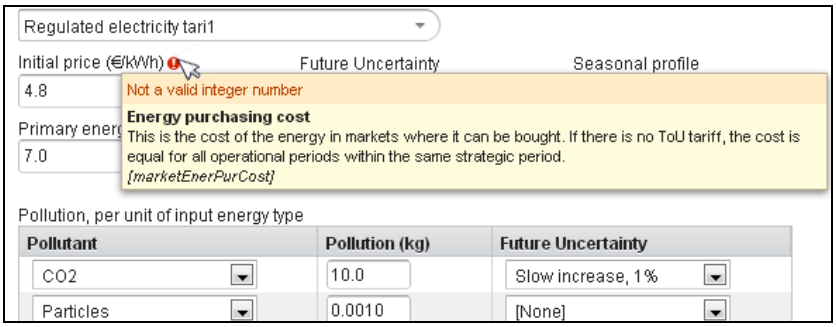

Figure 2-7: Validation Example

2.3.4 Error Handling and Error Messages

In the event that an error is encountered a red box is displayed with a description of the problem and a small "EMessage" button appears in the lower right hand corner (see Figure 2-8). In most cases this signifies that the last action carried out by the user was not performed, and the message explains why it was not performed. More specialised messages are provided for common problems such as a violation of referential integrity constraints in the database and synchronization problems that can arise from multiple users changing the same data. Figure 2-8 shows an example error message shown when the user tries to delete a type of "Pollutant" that is in use in the system.

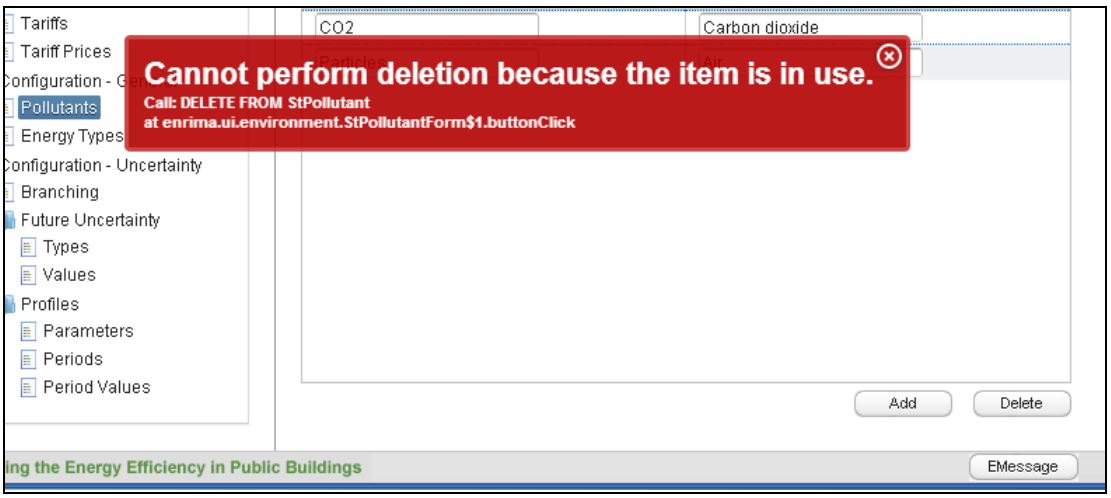

Figure 2-8: Error Message Example

2.3.5 Administrative Tools

When a user is logged in as an administrator a set of tools is available (see Figure 2-9). These tools assist in creating new users, buildings and so called case instances. Without these tools it is a complicated matter to carry out these tasks. When new case instance are created the SQL code to undo the changes is created. This window is accessed by clicking on the "wheel" icon under the user role.

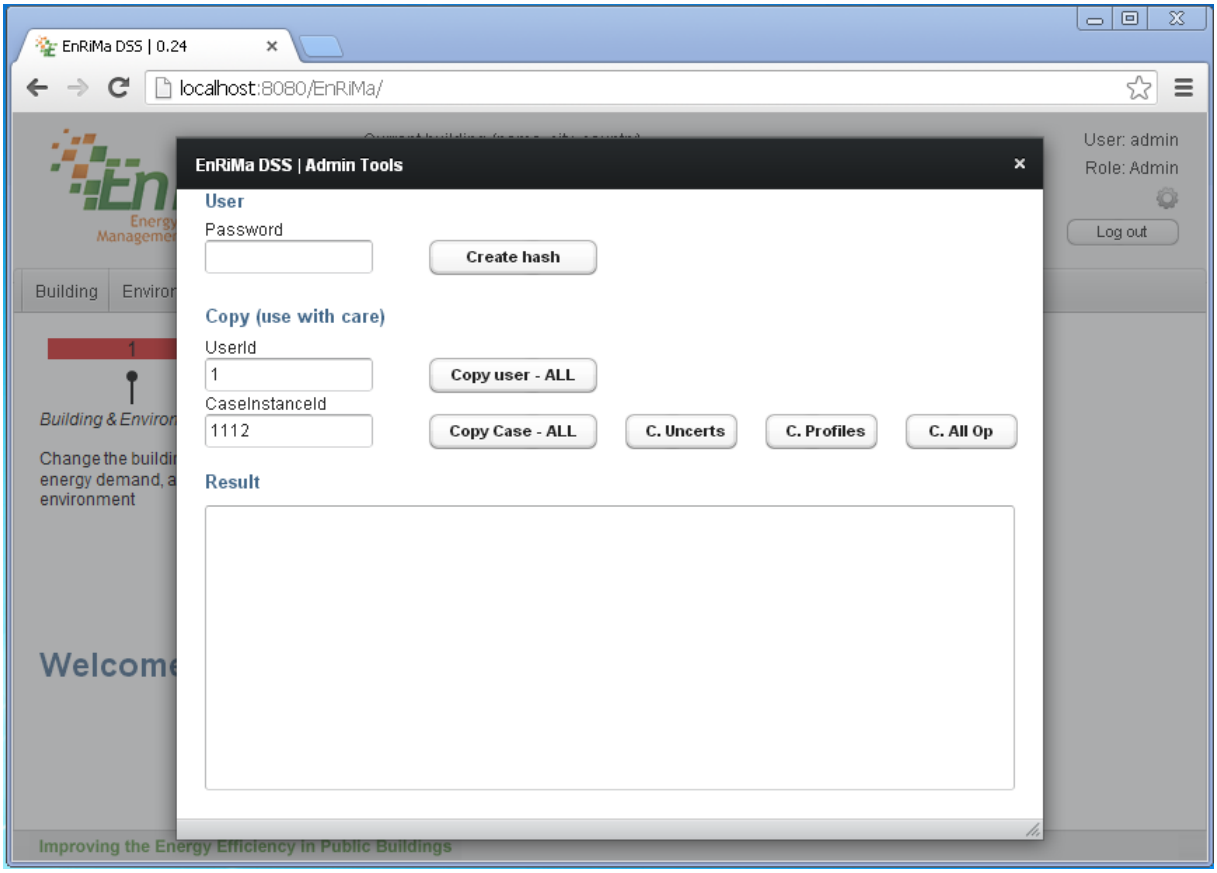

Figure 2-9: Administrative Tools

2.4 Operational DSS GUI Overview

The target of the operational DSS is to minimize the short-term energy costs and emissions for an existing building by considering all available and already installed technologies. The following sub-sections will describe how the required information will be collected within the operational DSS GUI. ***A complete listing of all screens of the GUI prototype is located in Appendix C – GUI Screens***.

At the moment the operational DSS optimization is implemented by use of MatLab®, for more information on this implementation refer to deliverable D4.4.

2.4.1 Building

First of all the building details has to be configured (see Figure 2-10). For the optimization it is important to know the volume, the floor area, the wall area, the glass area, and the available space for solar technologies. Furthermore, heat transfer coefficients for wall, glass, roof and ground are necessary to calculate the heating and cooling demand correctly.

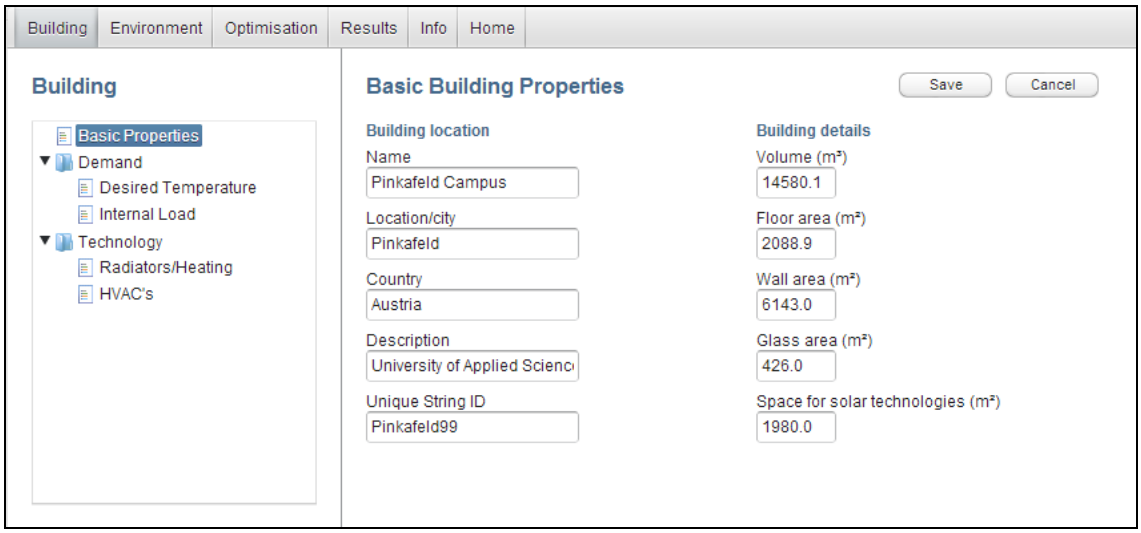

Figure 2-10: Basic Building Properties Screen

After all important building details are available and inserted the next step is to define the indoor temperature bandwidth which should be considered during the optimization approach. The temperature bandwidth allows defining a "window of comfort" where the optimization process can chose the best fitting temperature to minimize cost, emissions, and/or risk (see Figure 2-11). The window of comfort should be defined according to national law.

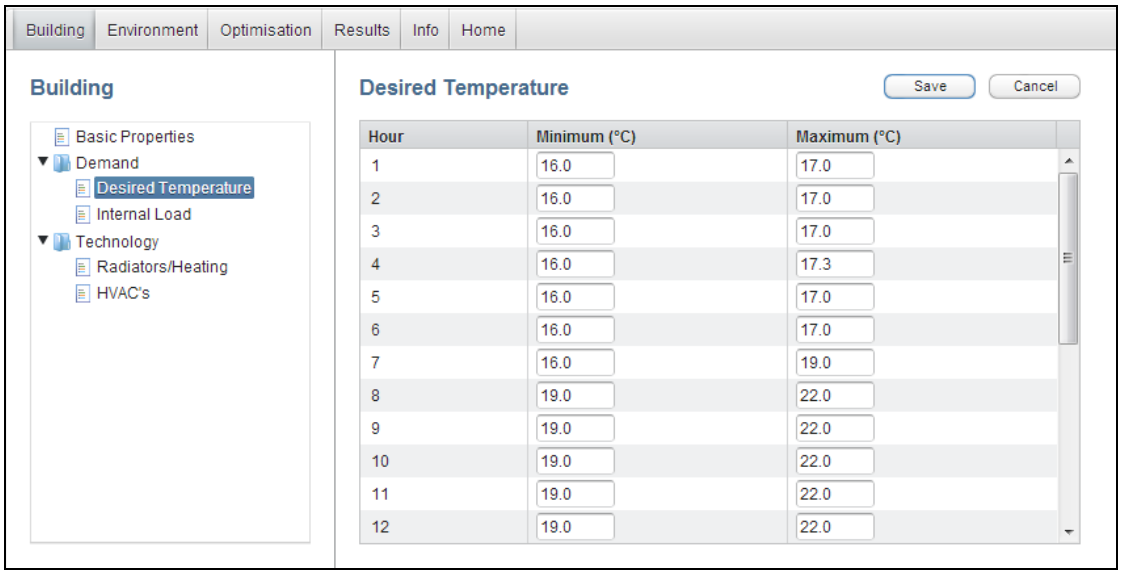

Figure 2-11: Definition of Desired Temperature Band Width

The EnRiMa DSS calculates the cooling and heating load by use of the temperature difference between the desired internal room temperature and the ambient air temperature. Therefore the heating and cooling load is not an input parameter as it is in other tools (e.g. EnergyPLAN, HOMER).

The next step is to define the internal load as well as the required electricity load. The overall electricity load is divided into three different parts to give the DSS the possibility to improve for example lighting parameters. The three parts are: end use, information technology and communication, and lighting (see Figure 2-12).

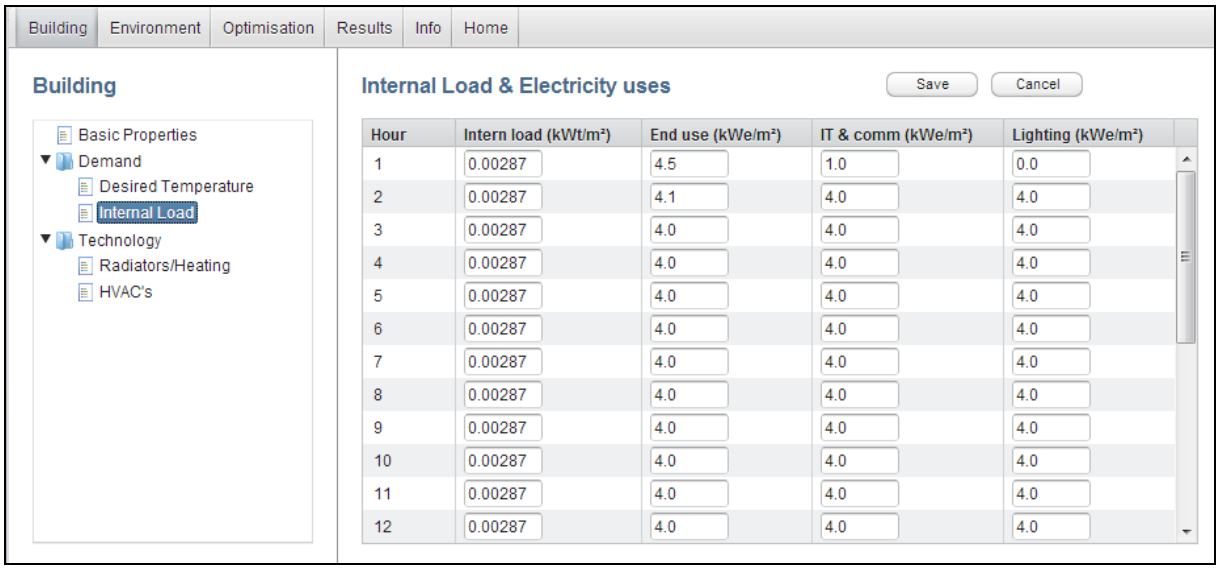

Figure 2-12: Definition of Internal Load & Electricity Use

To use the operational DSS all already installed and available technologies as e.g. PV, CHP, boiler, solar thermal system, electrical storage, and thermal storage has to be setup within the system. At the moment only heating by use of radiators and HVAC systems can be used (see Figure 2-13 and Figure 2-14). In a next version also CHP, thermal and electric storage, PV and heat pumps should be able to be managed.

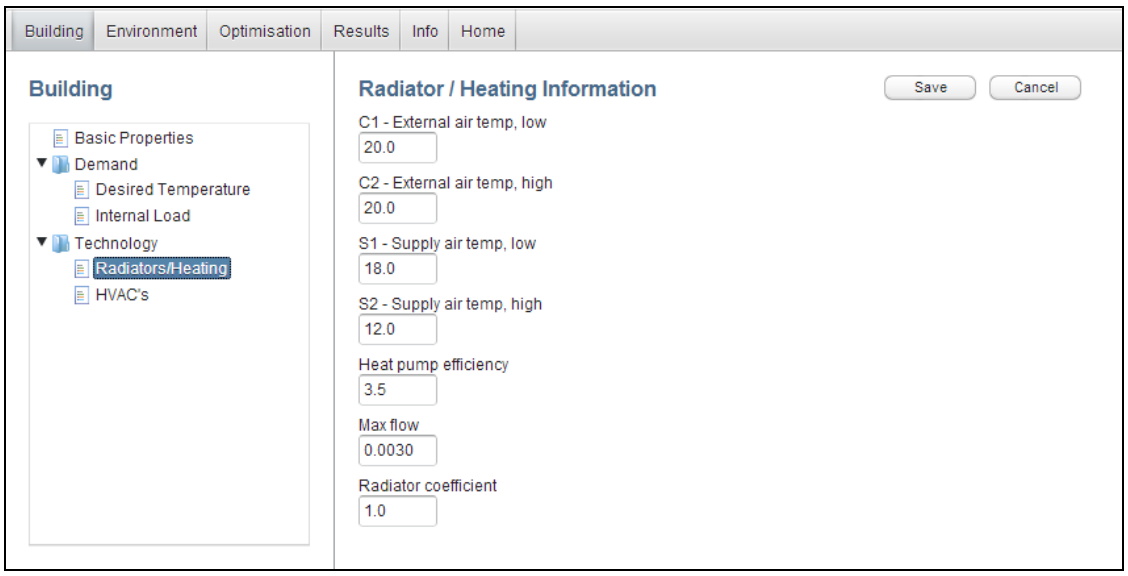

Figure 2-13: Configure Radiator Heating System

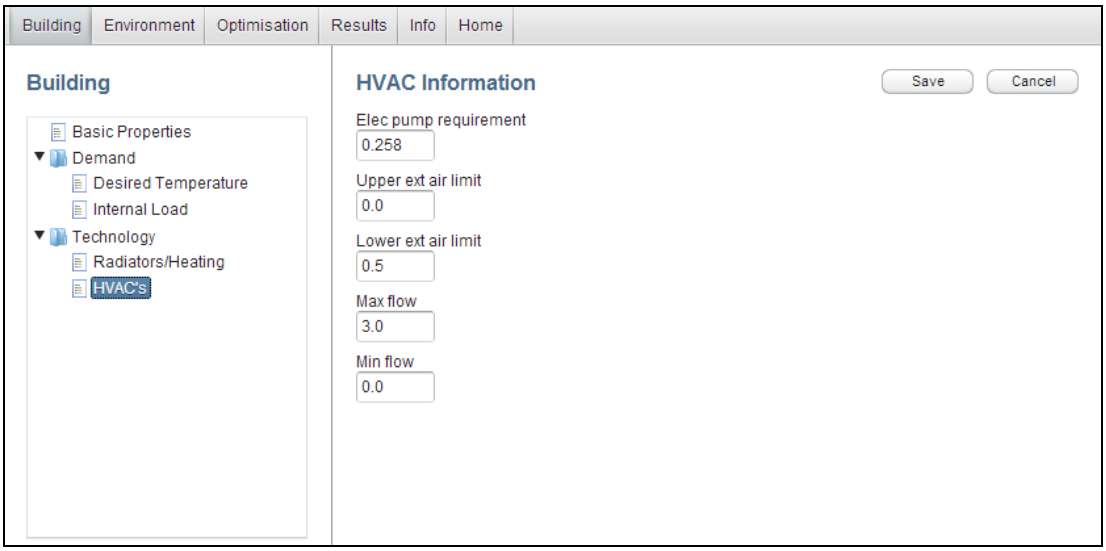

Figure 2-14: Configure HVAC System

2.4.2 Environment

Secondly some environmental parameters as weather details and energy prices are necessary to enable the operational DSS to do the optimization. At first the required weather data are shown (see Figure 2-15). In next version it should be possible to use the weather forecast information from Weather Underground. More details about this weather forecast service is in deliverable D4.4, Appendix II.

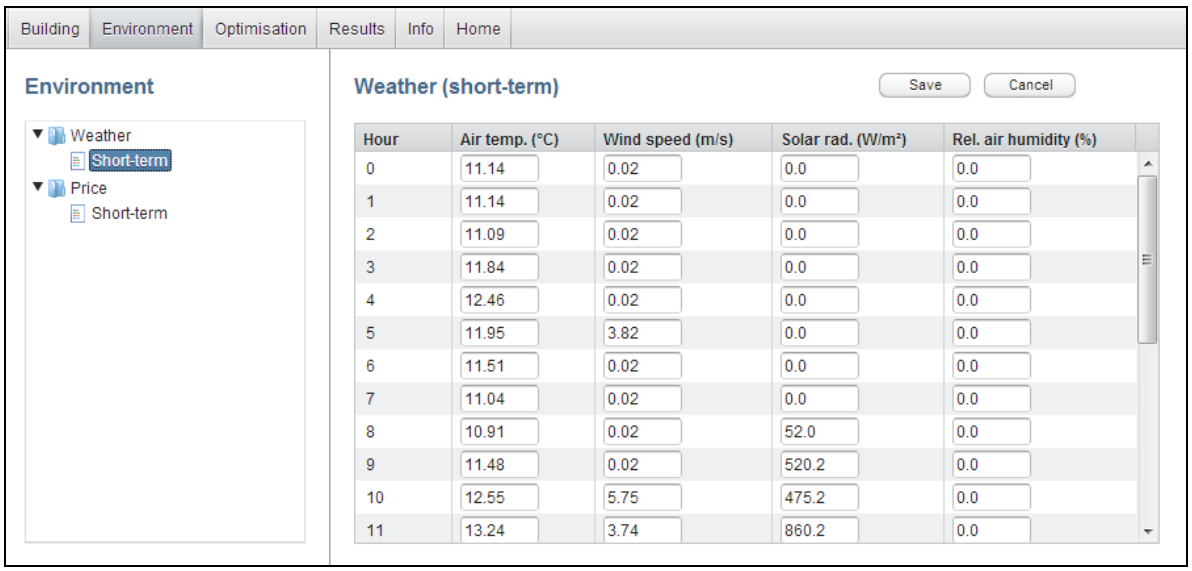

Figure 2-15: Configure Weather Details

After that the energy prices for the following day are required. At the moment the following possibilities are considered: buy and sell electricity, buy natural gas, and buy and sell heat (district heating system) (see Figure 2-16).

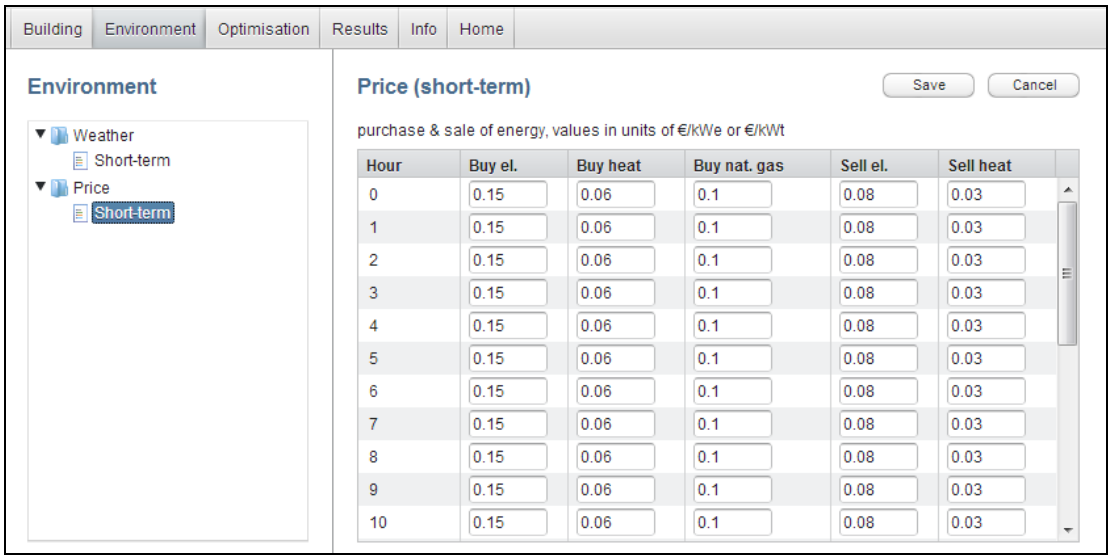

Figure 2-16: Configure Energy Price Details

2.4.3 Optimization

Figure 2-17 shows the entered data to give the user the possibility to check them before the optimization is started (see Figure 2-18).

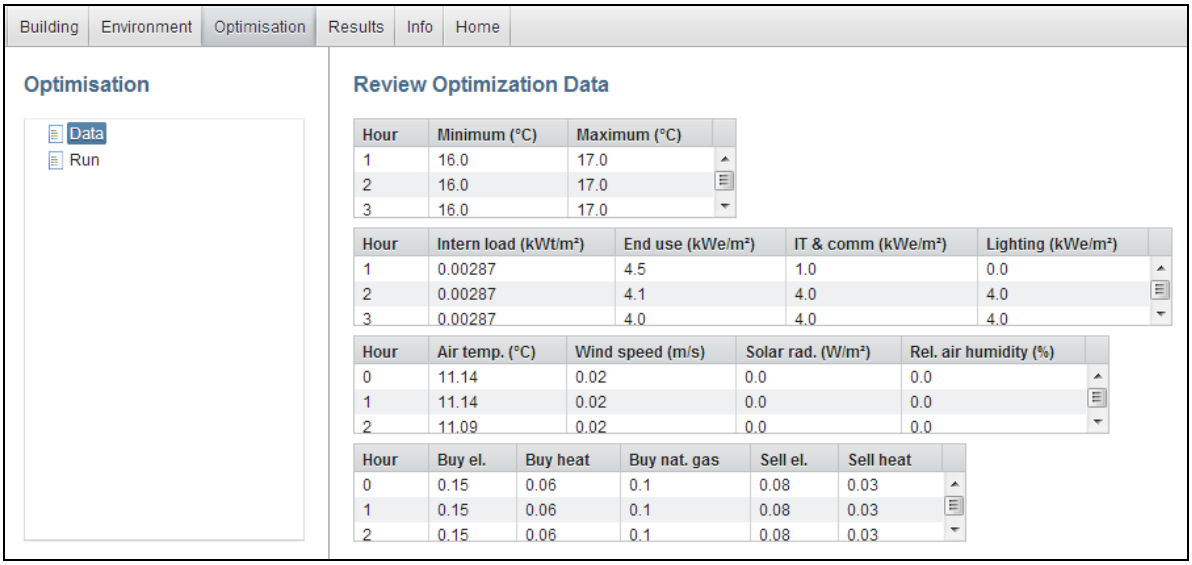

Figure 2-17: Review Operational Optimization Data

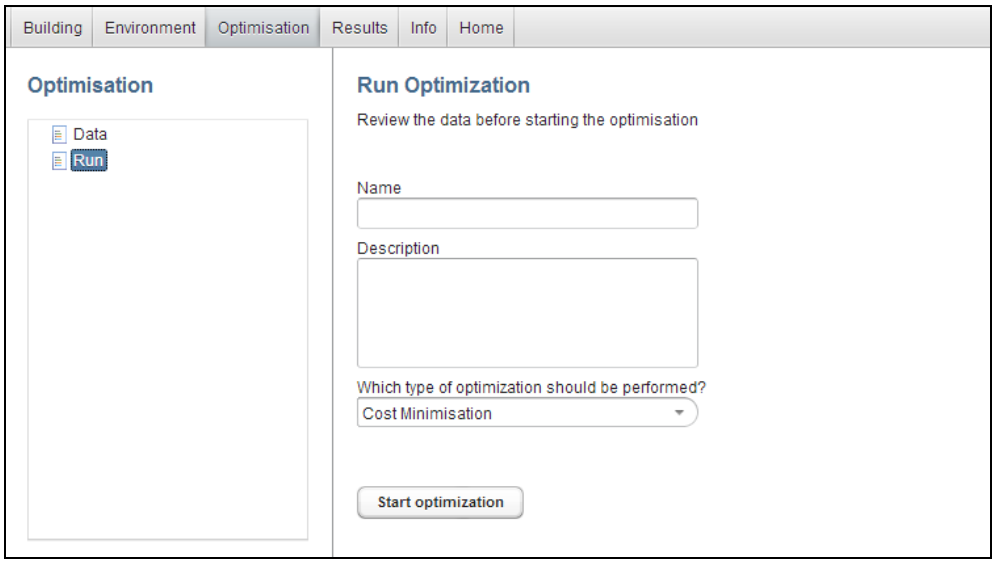

Figure 2-18: Review Operational Optimization Data

2.4.4 Result

The results part of the user interface shows all available optimization runs and their results. Figure 2-19 shows the according screen where the user can chose from the listed optimization results on the left hand side. By clicking on one of them (e.g. “18.01.13 Min. Pollution”) the results are shown (see Figure 2-20 to Figure 2-23). The figures show how the results are presented, and are based on test data rather than real data.

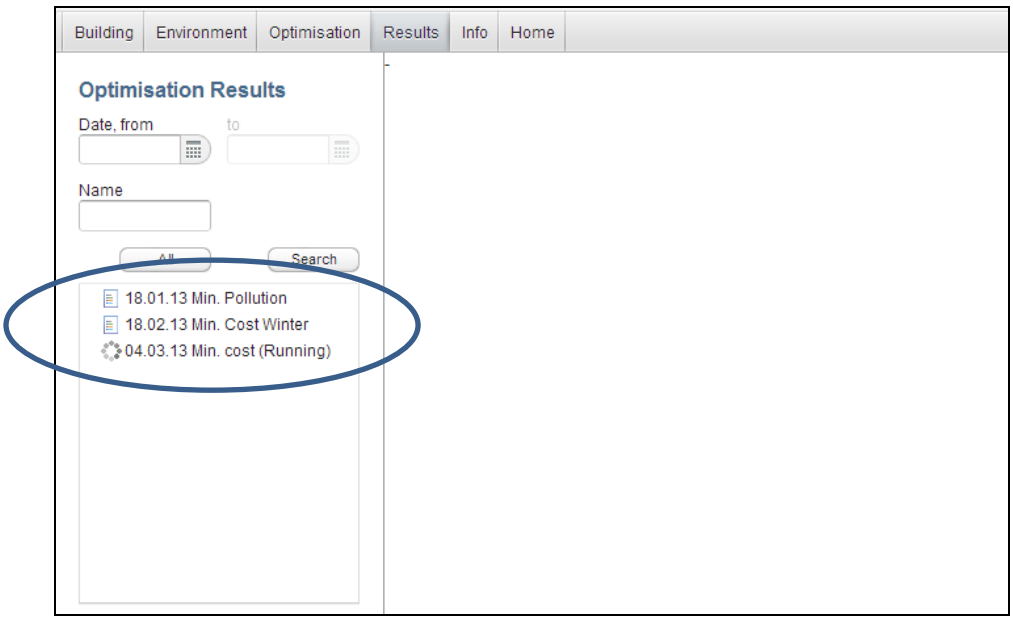

Figure 2-19: Results Overview

The first result diagram shows the “window of comfort”, the ambient temperature, and the optimal zone temperature.

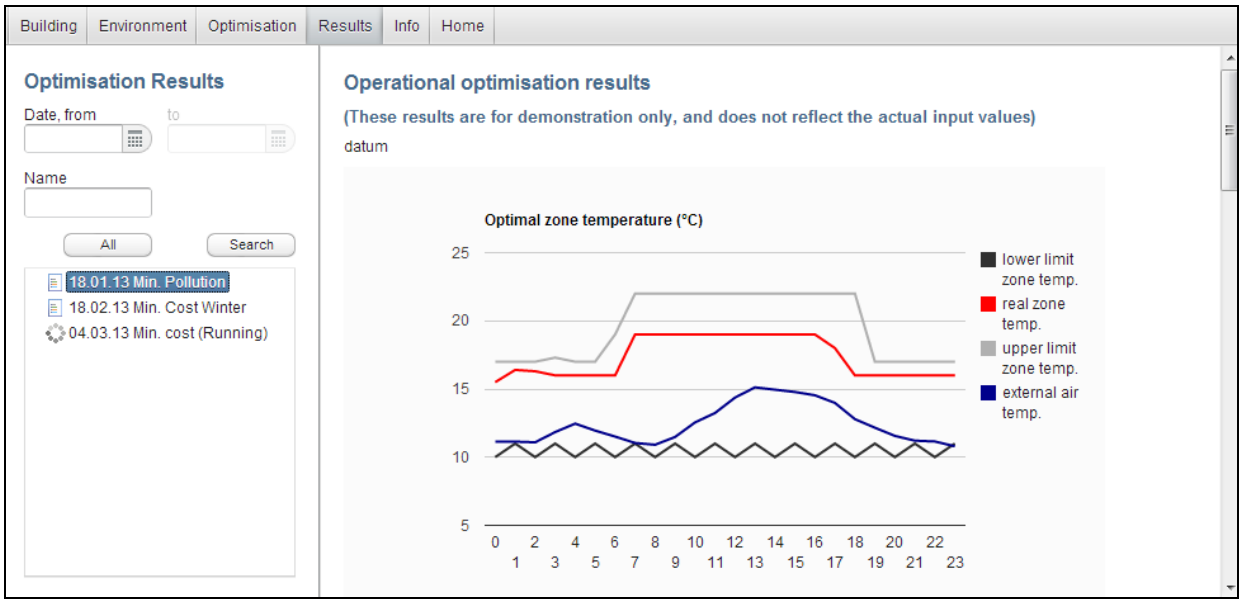

Figure 2-20: Result Details I

The second result diagram shows the energy demand which are divided into electricity (kWh_{el}), heating (kWh_{th}), and cooling (kWh_{th}) energy demand.

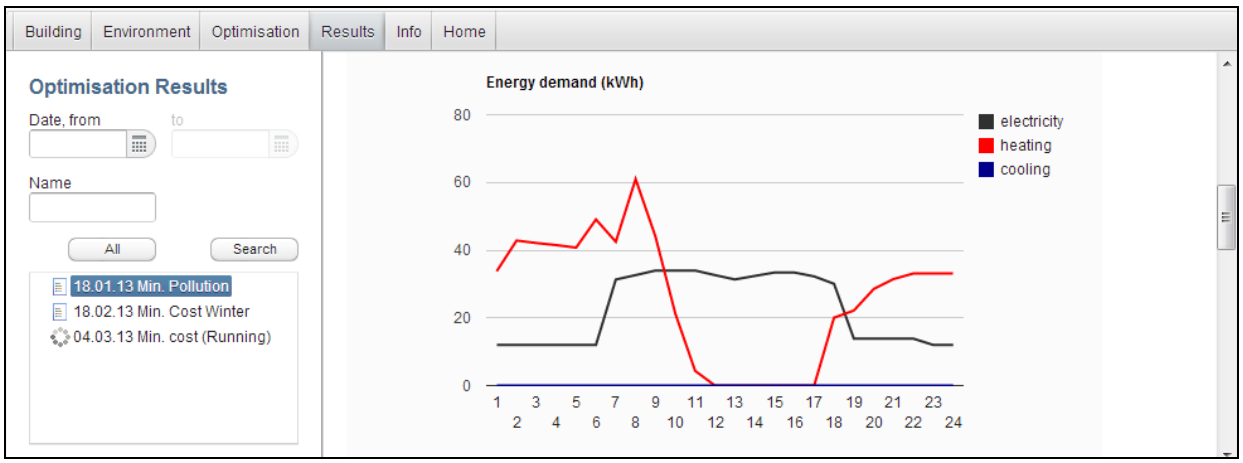

Figure 2-21: Result Details II

The third result diagram shows the costs which are also divided into electricity, heating, cooling, and total costs.

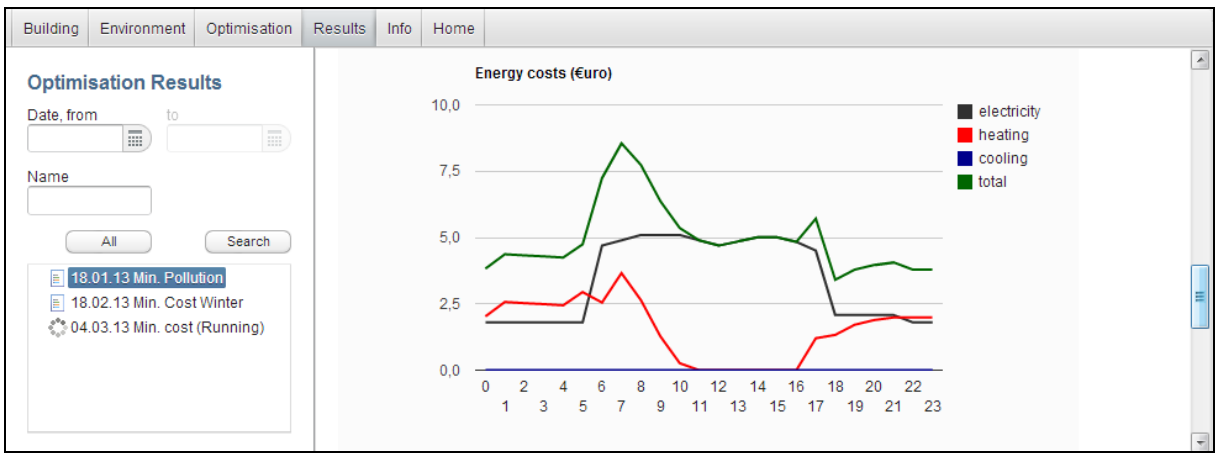

Figure 2-22: Result Details III

The fourth result diagram shows the marginal carbon emissions which are also divided into electricity, heating, cooling, and total emissions.

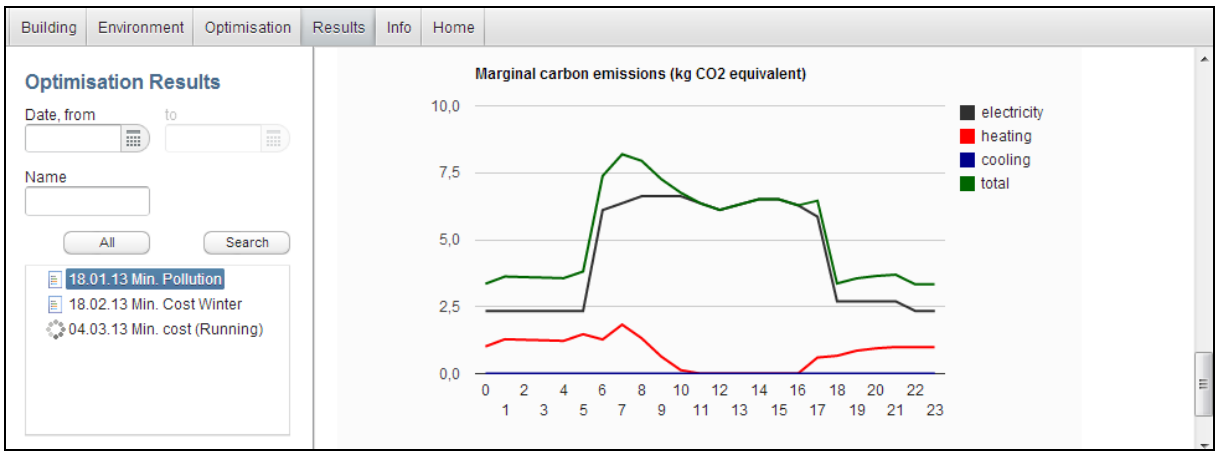

Figure 2-23: Result Details IV

2.5 Strategic DSS GUI Overview

2.5.1 Overview

The target function of the strategic DSS is to minimize the long-term energy costs for an analysed building by considering multi-stage stochastic trees to research the influence of uncertainty into the investment decision. This means that several possible technologies are necessary to be considered within the strategic optimization process. Usually at least PV, solar thermal system, CHP, thermal and electrical storages should be considered to get realistic results for the strategic multi-step investment decision.

The following sections describe some of the more significant screens. ***A complete listing of all screens of the GUI prototype is located in Appendix C – GUI Screens***.

2.5.2 Building

The screens under the Building tab are where the parameters related to the building are displayed and edited. The basic building information screen was discussed briefly in section 2.4.1. The following 3 screens under the building menu contain parameters regarding a buildings demand for the various types of energy, the various pollution limits in place, the total monetary investment limit and the required energy efficiency placed on the building.

Three types of technologies can be included in an optimization and each has a number of screens associated with them:

- Production Technology (Also referred to as generating technologies)
    - General Properties Screen
    - Energy Production Properties Screen
    - Pollution Properties Screen
    - Maintenance & decommission Cost Screen

- Storage Technology
  - General Properties Screen
  - Maintenance & Decommission Cost Screen
  - Storage Properties Screen
- Passive Technology
  - General Properties Screen
  - Passive Properties Screen

Figure 2-24 shows the "Dachs CHP 1" technologies' general properties screen. The "Dachs CHP 1" is of type production as can be observed in the building menu. Because it's of type it has all the screens associated with a production type of technology. Its icon in the menu is darker and more complete then the icon for the Siemens PV2 technology. This indicates at least one device is installed, a lighter icon indicates a device is planned but not installed.

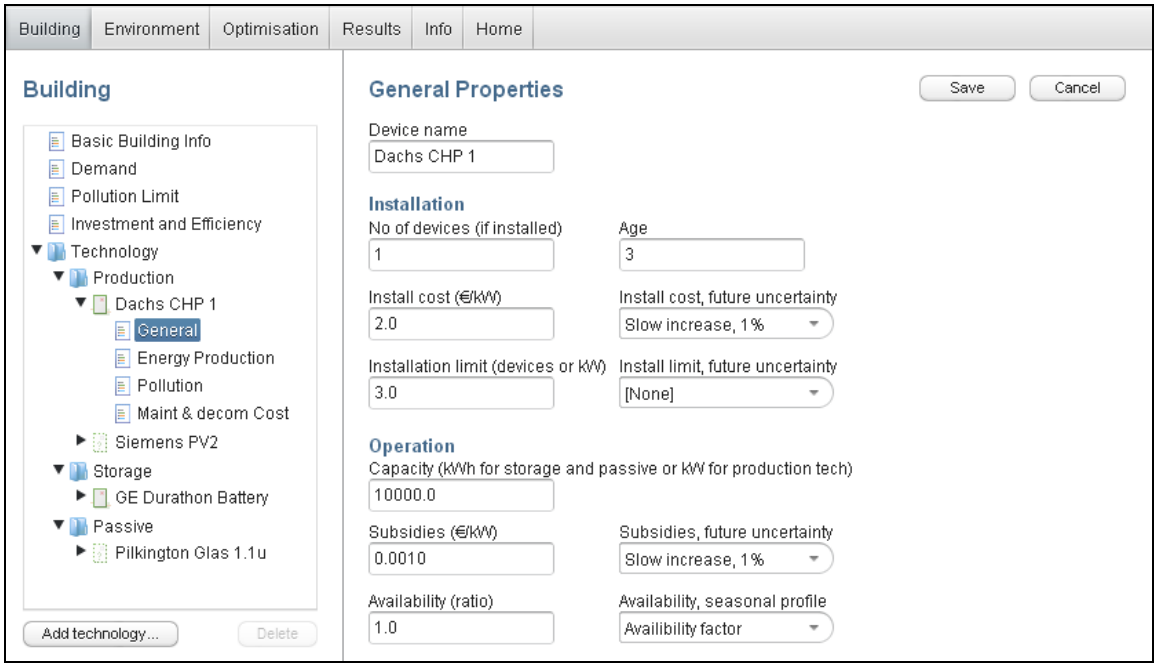

Figure 2-24: Technology General Screen

Technologies can be added or removed. When a user presses the add technology button the add technology window will appear (see Figure 2-25). The user then chooses a name and the type of technology and then presses the Add button. The new technology is added to the building menu under the heading of the correct type of technology and all required screens are created. A technology can also be removed by selecting the technology and pressing the delete button next to the Add technology button.

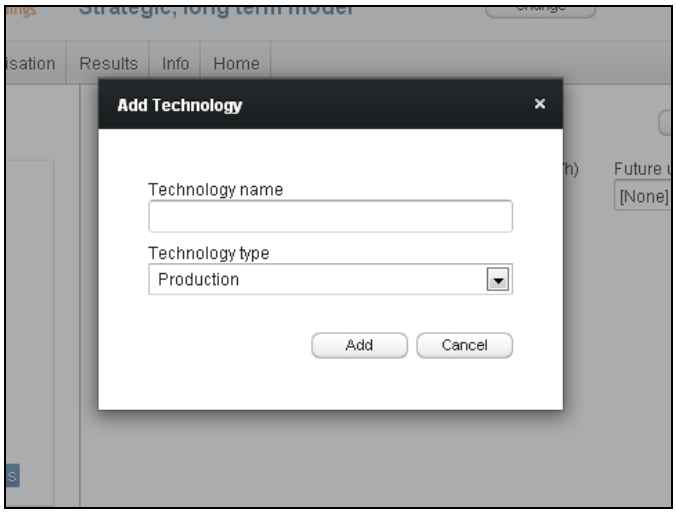

Figure 2-25: Add Technology Window

2.5.3 Environment

The screens under the Environment tab are used to: configure values that are components of stochastic parameters defined elsewhere in the GUI and to define the tariffs related to the purchase or sale of the different forms of energy.

Tariffs are for the most part defined on the Tariff Prices screen (see Figure 2-26). Tariff prices can be of a monetary value and in the form of pollutions. Thus a tariff contains both information about the prices (for example the field Initial price), and how much pollution that is caused by using one unit of the energy. Each pollutant is defined in terms of the type and amount of pollution along with its future uncertainty.

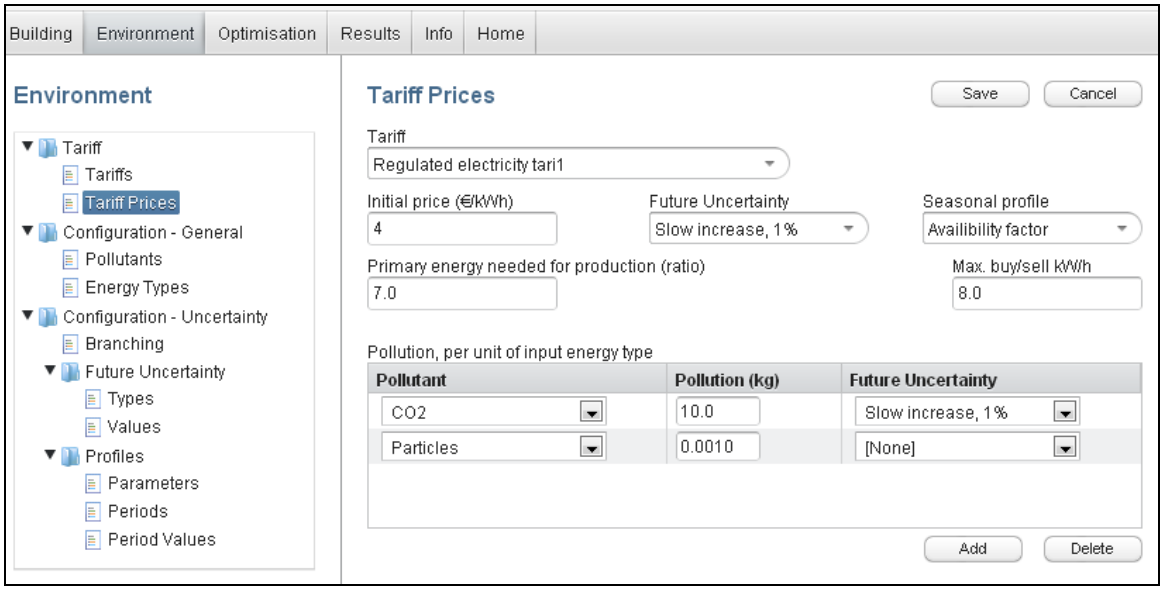

Figure 2-26: Tariff Prices Screen

The Branches per Year Screen (see Figure 2-27) allows a user to choose how many decision alternatives that are considered each year. A scenario generator tool is used to generate the possible decisions scenarios based on this information. As an input the scenario generator requires one row per branch and a probability for each branch. If the value 1 is entered for a given year it implies no branching for that year. When the optimizer is run, in this case, one row with the probability of 100% is provided for the scenario generator. In the prototype

design, each decision alternative will have the same probability. The total number of scenarios indicates the total number scenarios that will be generated.

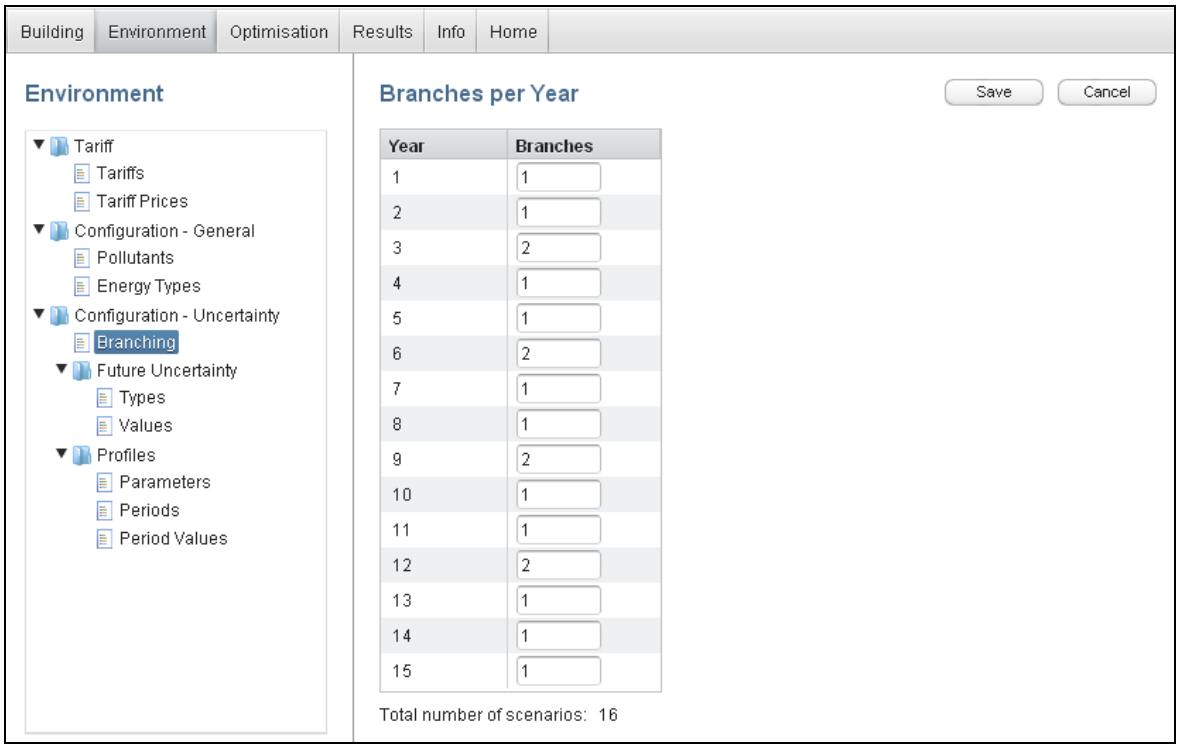

Figure 2-27: Branches per Year Screen

Many stochastic parameters in the GUI are represented by a start value and an uncertainty type. Uncertainty types are associated with a set of distribution values (see Figure 2-28). Each distribution value contains a mean % increase/decrease and standard deviation for each year of the optimization. Once an uncertainty type is defined it can be shared by multiple parameters. In Figure 2-28 it is shown how an uncertainty type with an annual increase of 5% is defined. Note that this uncertainty types can be used when entering values. For example in Figure 2-26 the initial energy price is associated with a Future Uncertainty referred to as "Slow increase, 1%".

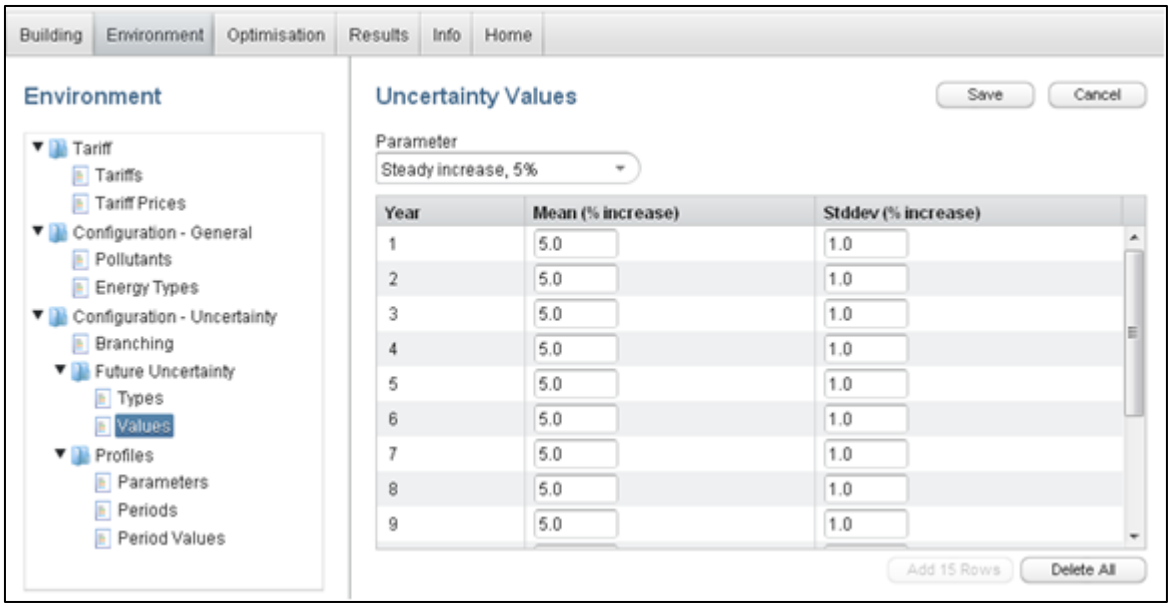

Figure 2-28: Uncertainty Values Screen

Some stochastic parameters have distributions that include a seasonal component. An example of what this seasonal component can be based on is the amount of sunlight throughout an average day. These values would be quite different based on a given season.

On the Profile Values screen (see Figure 2-29) a set of hourly values can be defined for each parameter, period/season combination. The unit for these values are relative (%) or absolute (kWh) based on the parameter chosen. A profile is a parameter along with all the period/seasonal values associated with it. A profile can be associated to the stochastic parameters that are affected by this type of distribution.

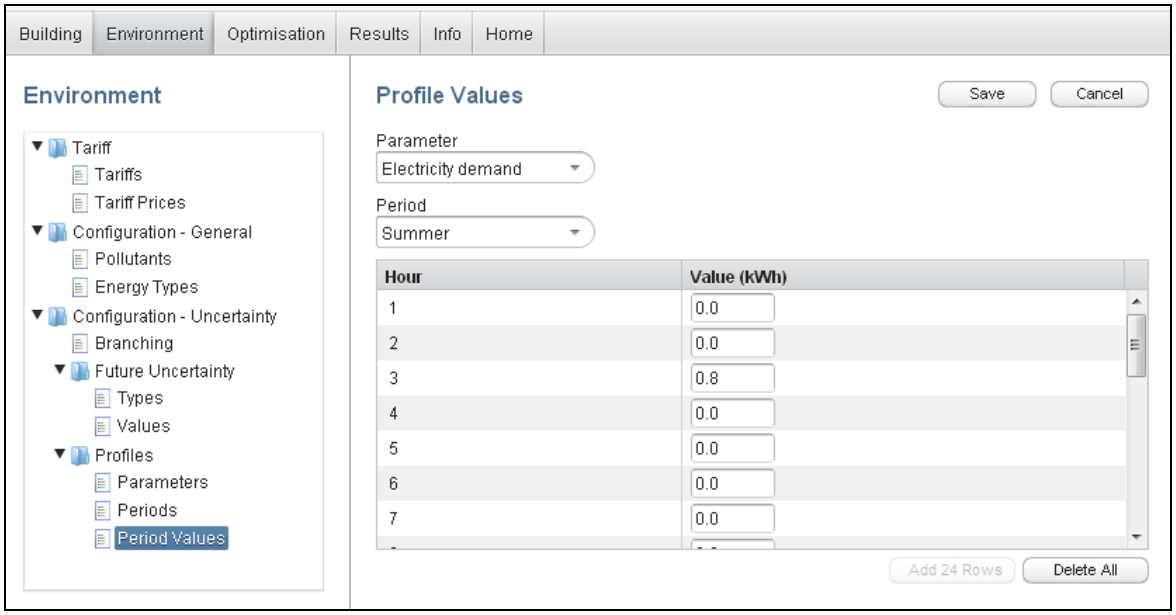

Figure 2-29: Profile Values Screen

2.5.4 Optimization

The screens under the strategic optimization tab are similar to the screens discussed in section 2.4.3 so they are not discussed here.

2.5.5 Result

The results screen (see Figure 2-30 and Figure 2-31) lists all completed optimizations along with optimizations that are still running. When an optimization is selected the results are displayed on the right hand side of the screen. The optimizations that are listed can be filtered by date and or name.

As the software-link to the stochastic tree as well as to the strategic solver manager is not in action at the time of writing this deliverable. Thus only example values are of the of the first strategic results can be shown.

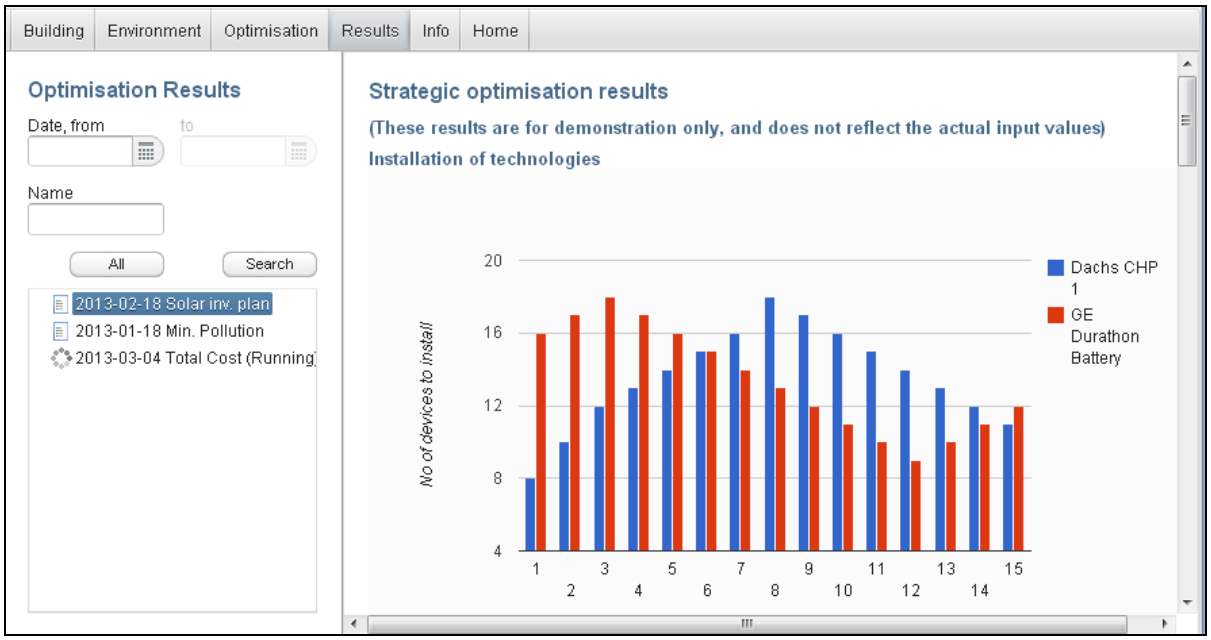

Figure 2-30: Result Example 1

Figure 2-31: Result Example 2

Note that the above screens a subset of the ones implemented in the prototype. A complete listing of all screens included in the GUI prototype is located in Appendix C – GUI Screens.

3 Evaluation Approach

The purpose of the evaluation was to identify points of improvements in the EnRiMa DSS prototype. The subject of the evaluation was the EnRiMa DSS GUI prototype implementation. While the main subject of the evaluation was the GUI, it is inevitable that that the evaluation also touches on issues related to other parts of the implementation, such as the DSS kernel. The GUI is simply not a standalone part, it is thus affected of the underlying data structures and services provided by the rest of the system. Prior to the evaluation early prototype versions had been tested and discussed within the project group, but the evaluation provided the possibility to get more in-depth comments on the overall design.

The execution of the evaluation was done by letting users perform pre-defined tasks and then participate in a survey utilising an on-line questionnaire. Using a questionnaire gave us the benefit of allowing the user to perform the user test at any time during the evaluation period. Moreover, the on-line questionnaire made it easy to perform the evaluation even though the users were dispersed in several countries. Alternative evaluation approaches, such as observations, sometimes referred to as exploratory tests (Rubin and Chrisnell, 2008), does not give these benefits. Likewise tests using user-interface experts rather than domain experts, referred to as heuristic testing (Dumas and Redish, 1999), would not give us any feedback related to the actual domain of energy efficiency of buildings.

In the following sections the questionnaire design, user selection and evaluation execution will be described.

3.1 Questionnaire Design

In order to have a structured approach to the evaluation the well-established technology acceptance model (TAM) was used to identify the main evaluation criteria's. TAM is describing the factors that influence user uptake and use of a technology (Davies, 1989) (Venkatesh and Davies, 2000). The core concepts of the model are to measure ease of use, usefulness and intention to use the technology under study. These can concepts be categorized as subjective in DSS evaluations (Rhee and Rao, 2008). Since the DSS is a data intensive application we complemented the core concepts with measurements of information and functional completeness.

To summarize, the following areas was thus selected for evaluation; *information and functional completeness*, *ease of use*, *usefulness* and *intention to use*. For each of the areas we identified statements that were used in the questionnaire. Each of the areas and their statements is further described below.

3.1.1 Evaluation Areas

Information and functional completeness. Based on the criteria defined in (Hong, 2006), this area was further subdivided into four questions related to information completeness, information relevance, information granularity and functional completeness to give the four evaluation statements below:

1. *Completeness*: The system provides all the information necessary for performing the task.

2. *Relevance*: The system contains relevant information for performing the task.

3. *Granularity*. The system contains information on a sufficient level of detail for performing the task.

4. *Completeness*: The system has all the functions and capabilities I expect it to have.

Ease of use. Ease of use is the user's perception of how/if using a particular system is free from effort. This area was evaluated by seven questions related to the sub areas structure, interaction and understanding. This lead to the following questions:

5. *Structure*: It is easy to find information in the system by using its menus.

6. *Structure*: The organization of information on the individual screens is clear.

7. *Interaction*: The system's response times are satisfactory.

8. *Interaction*: The system informs me when I do mistakes, and allows me to correct them.

9. *Understanding*: The system uses terminology that is consistent with the domain.

10. *Understanding*: It is easy to interpret the information the system presents.

11. *Understanding*: It is easy to learn how to use the system.

Usefullness. Usefullness is the user's perception of how the system is of practical use. We here subdivide this area into the two sub areas of efficiency and effectiveness. We include three statements for this area.

12. *Efficiency*: The system helps accomplishing the tasks quicker and easier compared to not using the system.

13. *Effectiveness:* The result of using the system will have an impact on energy efficiency of the building.

14. *Effectiveness*: The use of the system makes it easier to understand the factors that affect short-term building energy efficiency and the long term investments.

Intention to use. Intention to use measures the users perception of how/if they would use the system in the future. Tis subarea is represented by the following evaluation statements:

15. Would you use system the system in the future?

16. Would you recommend this system to your colleagues?

Each of the above statements was evaluated bases on a Likert scale. A Likert scale is a scale that is independent of the formulated question, and where the participants register their agreement or disagreement (Rubin and Chrisnell, 2008). The following scale was used for all statements:

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Besides the statements described above, the evaluation questionnaire also included text fields where the users could provide comments for each of the sub areas. Furthermore, background questions about the users were included. The current role/position was asked for as well as the number of years working with issues relating to energy efficiency in buildings and which building management systems that the user uses. These questions were asked to discern the overall background knowledge of the user.

3.1.2 Evaluation Tasks

To drive the evaluation the users were asked to perform two tasks before filling in the evaluations form:

Task A: Short-term, operational energy optimization

Use the system to calculate the optimal indoor temperature for a building by performing the following subtasks.

1 Log into the system, select a building and the short-term operational model.

2 Review the building information, and change if desired:

- a Overall building properties, such as the building area
- b Desired temperature
- c HVAC system properties
- d Radiator system properties

3 Review building environment information, and if desired change the values for the forthcoming 24 hours:

- a Outdoor weather, such as temperature
- b Energy prices

4 Run the optimization

5 Review the result.

Task B: Long-term, strategic investment optimization

Use the system to calculate the best way to invest and use the building technologies the forthcoming 15 years.

1 Log into the system, select a building and the long-term strategic model.

2 Review the building information, and change if desired:

- a Energy demand
- b Pollution and investment limits

3 Review the installed and desired technologies for the building. This includes Production, Storage and passive Technologies. For each technology review:

- a General properties - Such as installation cost, installation limit.
- b Production properties - Such as input and output energy types, pollutions and efficiencies.
- c Storage properties - Such as availability and storage limits.

d Maintenance and decom cost - Such as maintenance cost for old technologies.
4 Review building environment information, and if desired change the values:
a Energy prices
5 Review the configuration of Uncertainties. The future development of for example energy prices can be set using an yearly increase or decrease.
6 Run the optimization
7 Review the result.

3.2 Evaluation Execution

The following steps were performed as part of the evaluation:

1. User selection
2. Test data preparation
3. Introduce the user to the system.
4. Presentation of the tasks to be performed (A: short-term optimization, B: long-term optimization)
5. Users complete task A ("Short-term, operational energy optimization") and fill in the evaluation form once, online.
6. Evaluators/users complete task B ("Long-term, strategic investment optimization") and fill in the evaluation form once, online.
7. Analysis of the result

The first step, user selection is described below, while the last step, analysis is described in a separate section in this deliverable. The second step, test data preparation, consisted of creating data for 15 test-users in the system. 15 sets of data were created, each containing two buildings pre-configured with values. The users testing in Step 3-6 was performed during the period of March 6 to March 19, 2013.

The cover sheet for introducing the evaluation to the users is found in Appendix A, while the full questionnaire is located in Appendix B. The users were informed that the evaluation was done anonymously, but that the collected data would be presented in public reports.

3.2.1 User Properties and Selection

The types of potential stakeholders and users for the DSS are defined in deliverable D4.1, requirement assessment. Users refer to the persons that are directly using the system via its user interface, while stakeholders refer to those roles/persons that have a general interest in the system. Thus to evaluate the user interface we focus on the potential direct users, rather than the full list of stakeholders. Based on the user description in deliverable D4.1, we conclude that the users targeted in the evaluation should have the following properties:

- Knowledge within the field of building management and building management systems.
- Knowledge in the field of building technologies for heating, cooling, energy storage etc.
- General knowledge about a building energy demands, and possible energy supplies.

The selection of users to participate in the evaluation was done by partner HCE and CET. HCE selected five users that could participate, while CET selected three. Through their respective contacts users that exhibited the above mentioned properties was identified. CET used its university and consultancy contacts to identify users, while HCE had experts in-house that could participate in the evaluation.

4 Evaluation Results

4.1 Results

The following sub-section shows the result of the evaluation.

4.1.1 Information and Functional Completeness

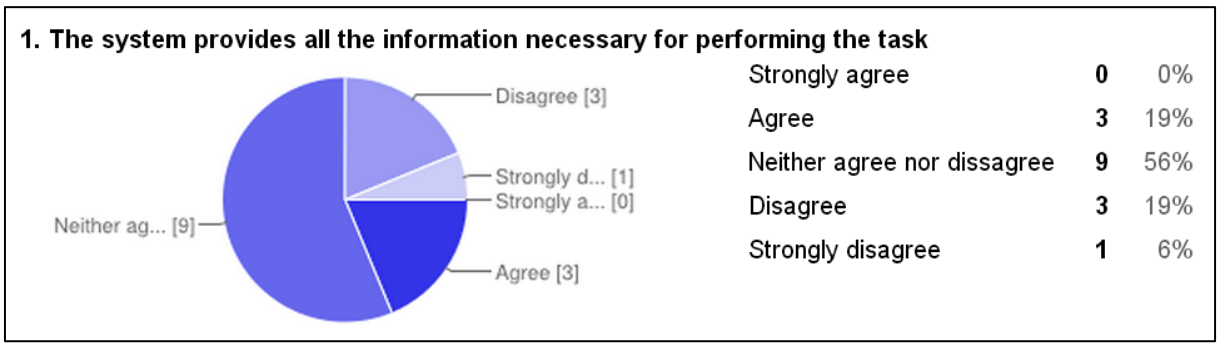

Figure 4-1: Result, Question 1

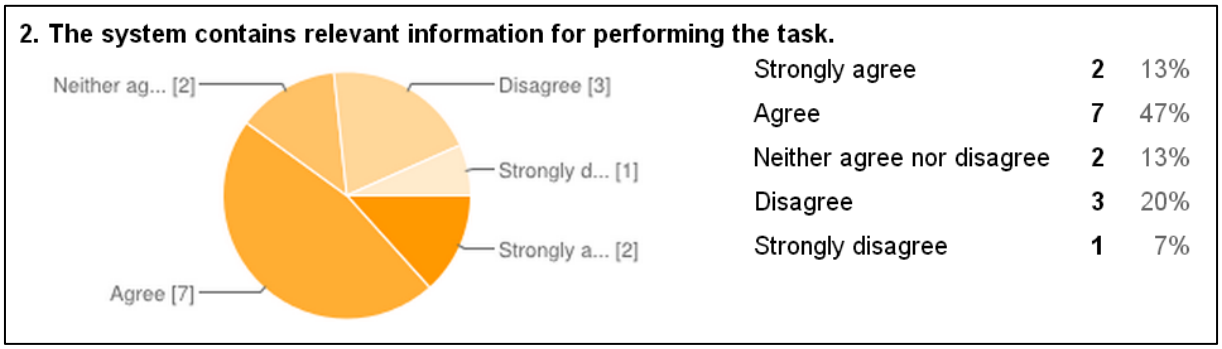

Figure 4-2: Result, Question 2

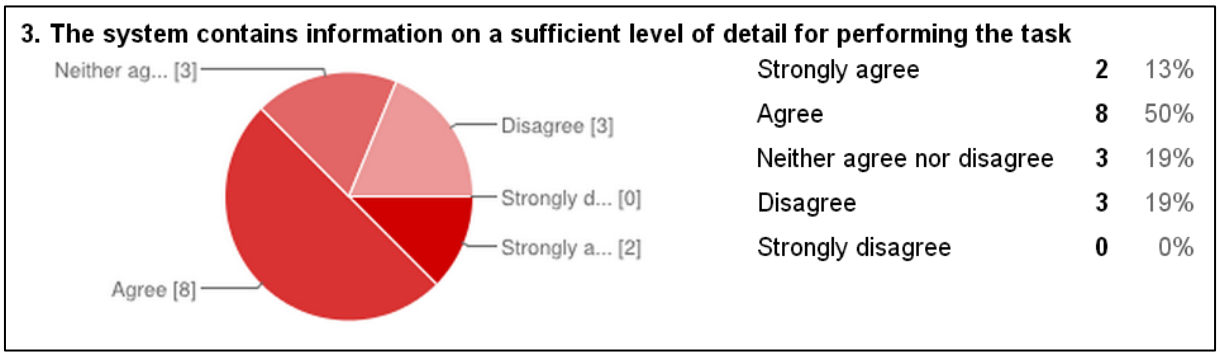

Figure 4-3: Result, Question 3

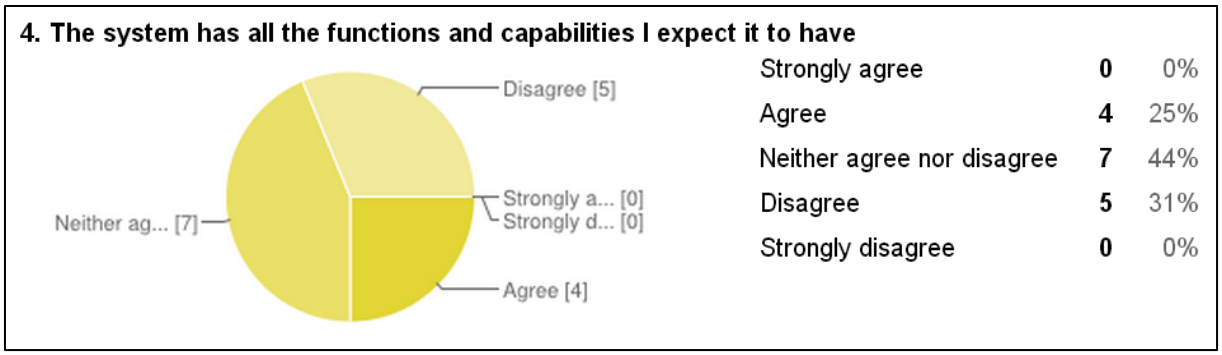

Figure 4-4: Result, Question 4

4.1.2 Ease of Use

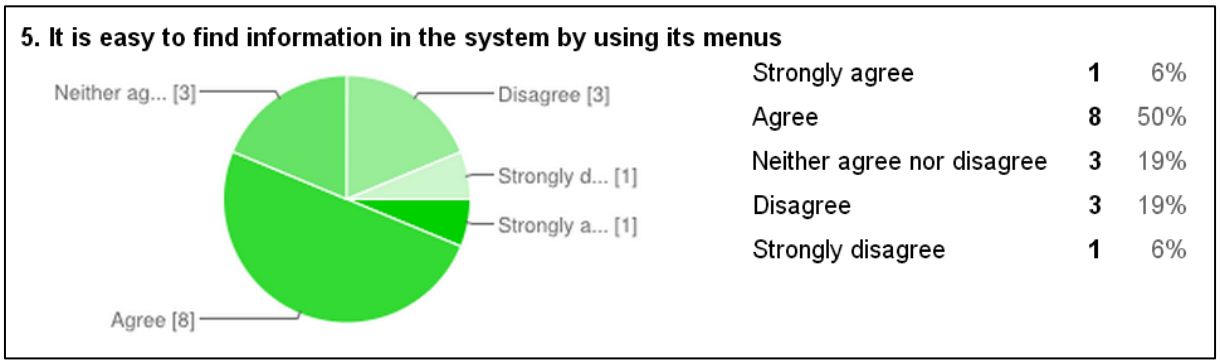

Figure 4-5: Result, Question 5

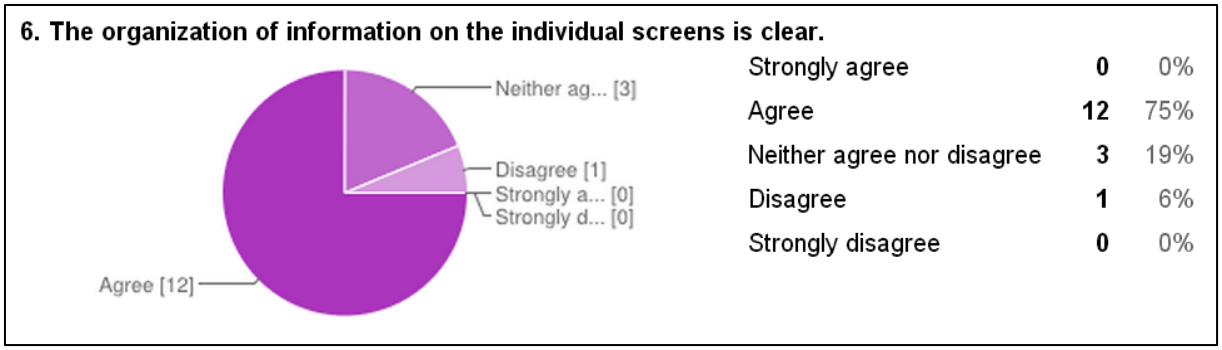

Figure 4-6: Result, Question 6

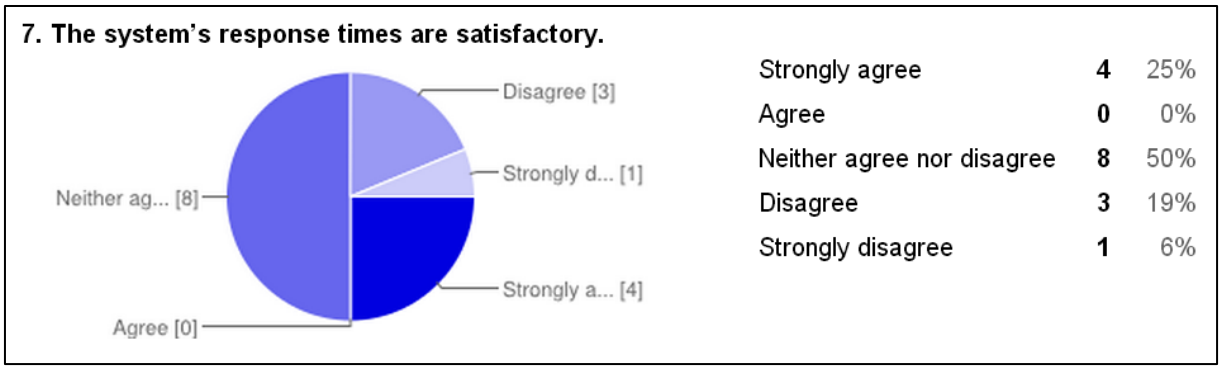

Figure 4-7: Result, Question 7

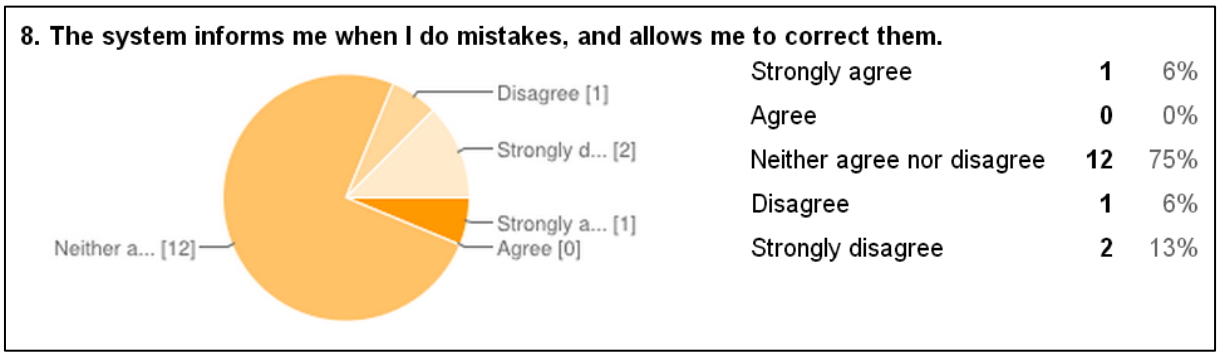

Figure 4-8: Result, Question 8

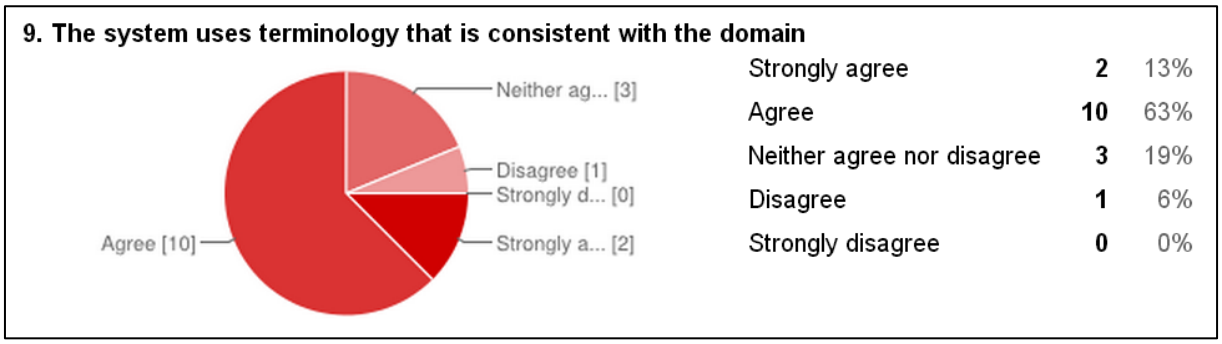

Figure 4-9: Result, Question 9

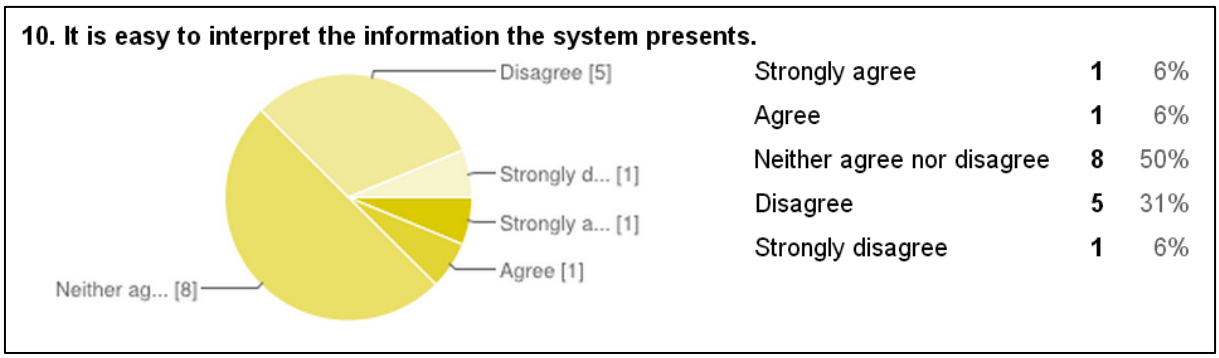

Figure 4-10: Result, Question 10

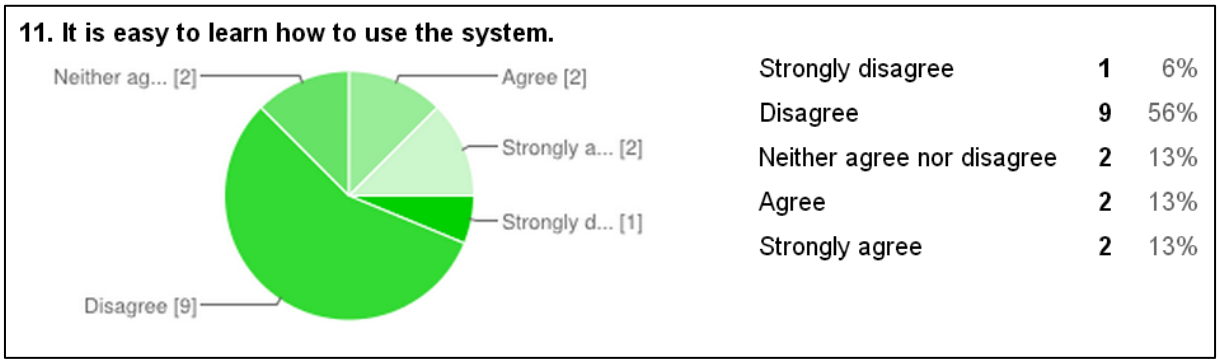

Figure 4-11: Result, Question 11

4.1.3 Usefulness

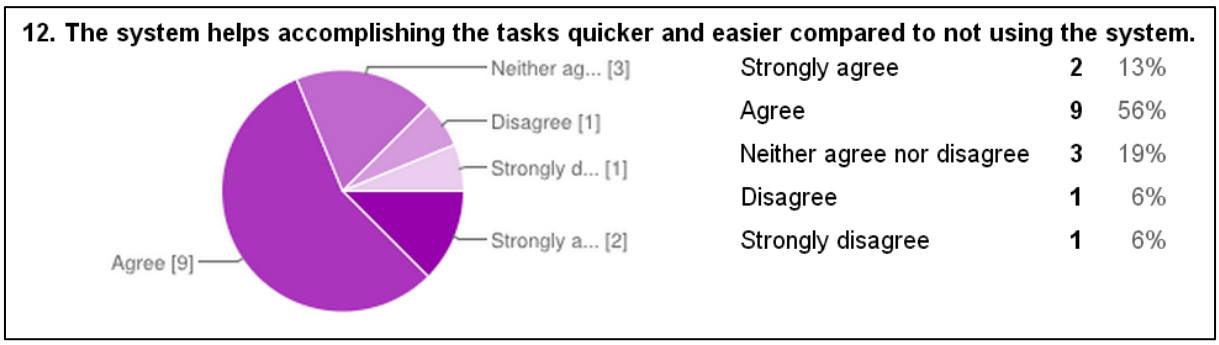

Figure 4-12: Result, Question 12

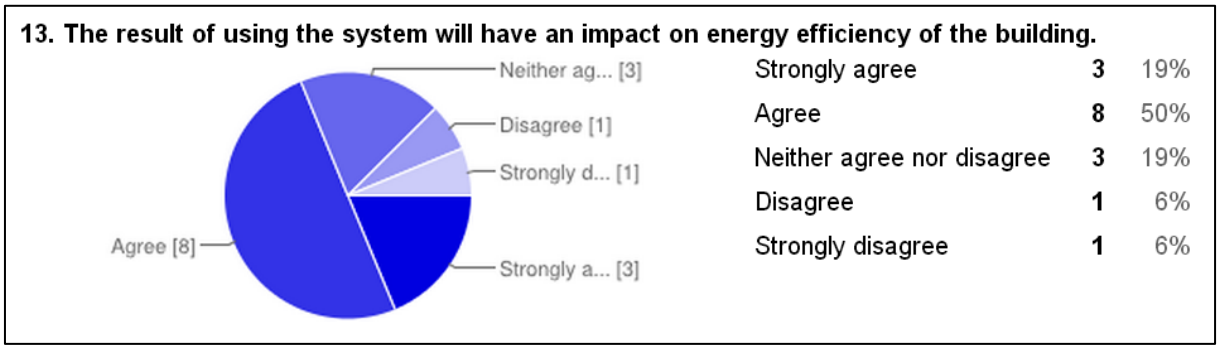

Figure 4-13: Result, Question 13

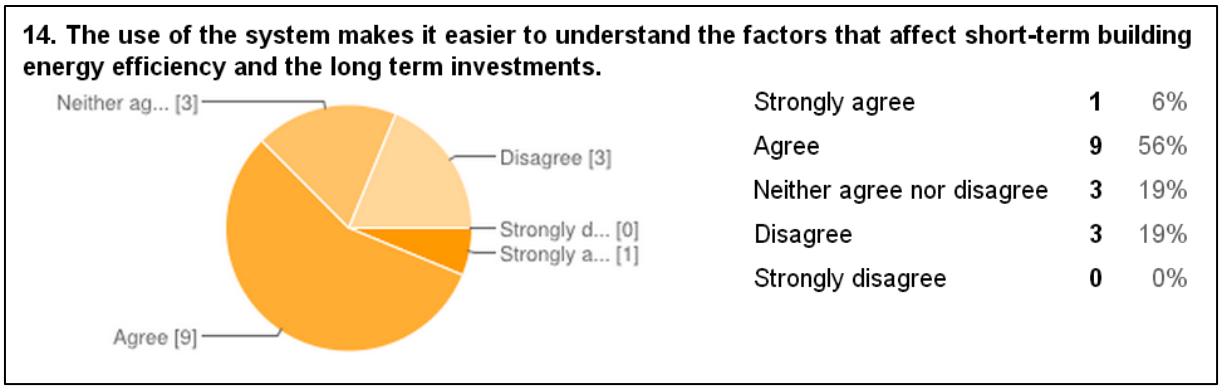

Figure 4-14: Result, Question 14

4.1.4 Intention to use

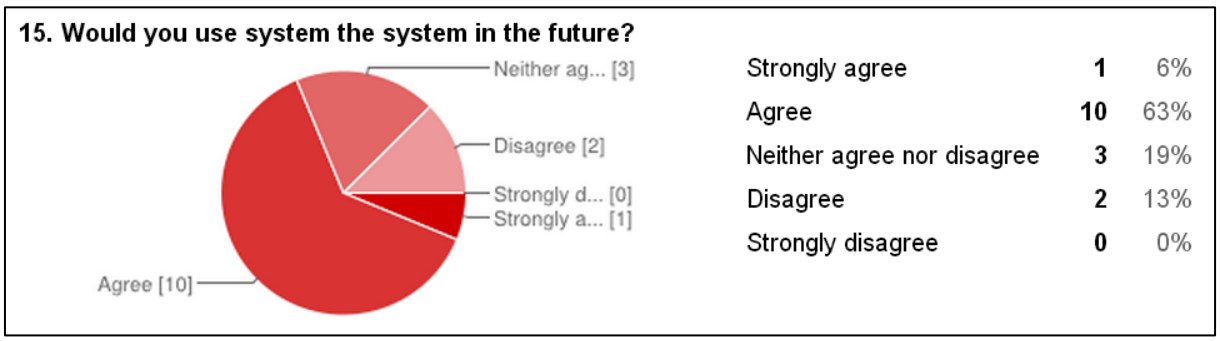

Figure 4-15: Result, Question 15

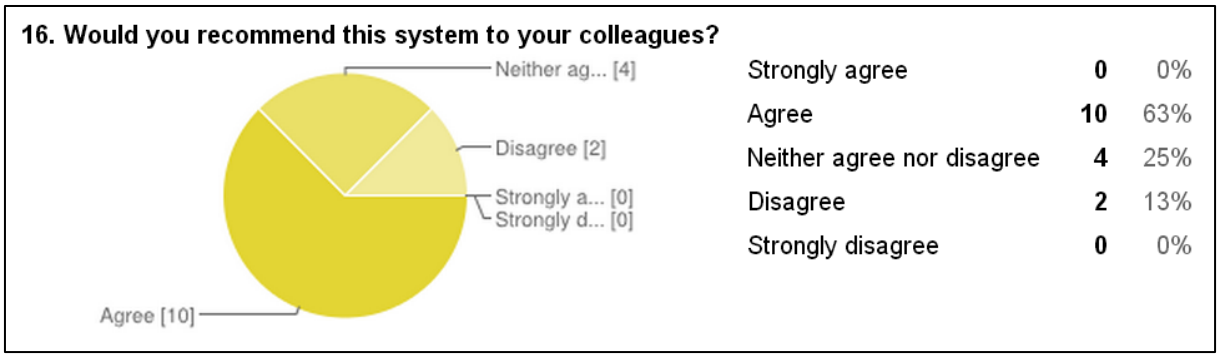

Figure 4-16: Result, Question 16

4.2 Analysis

In total 16 responses to the questionnaire were sent in from eight users. As described before each user filled in the form twice, one time for the operational model and one for the strategic. The average number of years of experience of using building management systems was 7½ years, however only five users filled in that information.

In the following sections the result for each of the evaluation areas will be discussed.

4.2.1 Information and Functional Completeness

As described before this area evaluated how *complete*, *relevant* and *detailed* the information and functions are in the system.

The questions gave slightly different result. The strongest agreement was indicated for information relevance (Q2), and information detail (Q3). For these two statements between 60% and 63 % agreed to that the information relevance and detail was satisfactory. Out of these users, 13% indicated a strong agreement with the statements.

Out of the statements on information and functional completeness the statement related to functional completeness (Q4) was given the lowest level of agreement. 31% of the users disagreed; while 44% neither disagreed nor agreed to that the system had all functions they expected.

The open question about information and functional completeness gave 12 separate comments. Half of the comments related to the lack of description of the fields in the user interface, and three comments related to the need to explain how to handle future uncertainties. A direct comment was made on the lack of units for some fields, and that the "info" tab was not of much use.

Overall the system information and functional completeness was deemed as neither perfect nor unsatisfying. The results simply point towards that the system are deemed to be average in this respect, which is not unexpected for a prototype. This is especially true for the statements related to functional completeness, which was given comparatively low scores. The prototype simple do not have all the functionality implemented yet.

The user interface can concretely be changed to address the comments in the following ways:

- All fields should be described using the systems tooltips. In the prototype only a subset of the fields were described.
- The info tab can be removed, or need to contain relevant documentation.
- It should be clear that the prototype is a prototype and not a finished system.

The next version of the prototype will be more features complete, and this will address the functional completeness. Furthermore, it must be more evident that the system is a prototype and not a ready commercial tool.

4.2.2 Ease of Use

The evaluation area ease of use address the needed effort needed in order to use the system. It was targeted by statement 5-11 in the evaluation. In the evaluation *structure* (Q5, Q6), *interaction* (Q7, Q8) and *understanding* (Q9-Q11) was evaluated.

Both the statements related to structure (Q5, Q6) scored fairly well, with 56% and 75% agreement. Particularly, the organization of elements within a screen was deemed satisfactory, while the overall navigation structure was slightly less satisfactory.

Regarding interaction, the system response times (Q7) was given mediocre scores, with 25% disagreeing with the statement. That could be explained by that the system is built as a modern rich internet application (RIA), making heavy use of JavaScript that the browser needs to execute. From the system log from the evaluation period it is shown that three users used very old web browsers that are not capable to handle advanced web applications. These browsers were Internet Explorer 6 (one user) and Internet Explorer 7 (two users). Modern web browsers are much faster when running web applications compared to these browsers. For example, it has been shown in tests that Internet Explorer 9 is more than four times faster than

Internet Explorer 8 (Niyogi, 2010). More recent web browsers, such as Internet Explorer 10 and Chrome 25 are even faster. Even though the system log shows that 19% of the users did run old web browsers, these users cannot be related to the 25% that gave low evaluation scores, since the evaluation was done anonymously.

The evaluation of understanding (Q9-Q11) shows that the system uses the right terminology (Q9), while it was deemed partially difficult to interpret the information the system presented (Q10). Moreover, the system was deemed difficult to learn (Q11). The issues regarding interpreting information can be tributed to the same issues as discussed in connection to the comments given to information and functional completeness. Some field in the system simply lacks a description. Moreover the system is working in a complex domain, and the result from the statements, mostly Q11, shows that the user need appropriate training before using the system.

The evaluation area ease of use was given 15 comments. Six of these related to that the users were not given good enough instructions on how to use the system. Direct comments were given for that the use of profiles were unclear, and that the environment tab was misleading.

The user interface, and user introduction can concretely be changed to address the comments in the following ways:

- There is a need to better explain how the system can be used before starting the evaluation, alternatively to provide a user's guide.
- The environment tab needs to be re-designed. For example the tab contains both information about configuration and environment.
- The user could be warned when they are using an old web browser that will decrease the performance of the system. For example a warning could be issued for browsers older than 4 years.

4.2.3 Usefulness

Usefulness concerns the user's perception on how practically useful the system is. This was targeted in statements related to efficiency (Q12) and effectiveness (Q13, Q14).

Overall the usefulness in terms of efficiency (Q12) was rated fairly high, with 69% of the users indicating an agreement or strong agreement. The usefulness in terms of effectiveness was rated lower, with 62% to 69% of the users indicating an agreement or strong agreement. Lowest score was given for one of the statements on effectiveness (Q14) referring to the prototypes ability to make it easier to understand the domain, where 19% disagreed.

Based on these figures, the prototype fared well when it comes to usefulness. Thus, the user sees the tool as being of practical use. However, the prototypes ability to work as a pedagogical tool could be questioned, at least 19% of the users do not see the prototype as a value full tool for understanding the domain.

In total, the area of the evaluation that is concerned with usefulness was given 12 comments. Out of these three mentioned that the system needs to include more instructions before it is used. These comments are similar to the ones given before, and can be attributed to how the users were introduced to the system and its status as being a prototype, not a fully working system. Moreover four of the comments related to that the prototype could not run optimizations as expected. Since it is a prototype, the integration with the systems solver was not done at the time of the evaluation. This was clearly indicated to the users when an optimization started, and the results screens were clearly marked as being test data. However, even with these measures taken, the users still expected a fully working system. It is clear that

it need to be even more evident what is currently implemented in the system and what is not. Two comments related to the desire to include Sankey diagrams for showing the effect of the optimization.

Based on the evaluation scores and the comments on the usefulness area of the evaluation the prototype can concretely be improved in the following ways:

- Make it even more clear what kind of functionality that is working, and what is not.
- Investigate if Sankey diagrams can be included to visualize the result of the strategic model.

4.2.4 Intention to use

The evaluation area intention to use evaluated the users desire to use the system in the future. This evaluation area was measured by the two last statements in the questionnaire, Q15 and Q16. For both the statements, 63% agreed. It can however be noted that 13% of the users did not agree, and thus indicated that based on the current state of the prototype they would not use the system nor recommend it to a colleague for use.

The intension to use area of the evaluation was given seven comments. Four of these pointed out that the system needs to be completed before any judgements about use can be done. Two comments were related to the business model of use, that is, the cost and available expertise when using the system.

5 Future Outlook and Feedback to Development Tasks

This deliverable describes the EnRiMa DSS graphical user interface and its evaluation. In this section we conclude with a short description of the main features that has been implemented, and what need to be implemented in future versions. We also draw on the results of the evaluation to indicate areas where improvements can be done to the current prototype.

5.1 Implemented and Future Features

In the current prototype a GUI that works for both the operational and strategic part of the system has been implemented. The GUI stores and retrieves information via the DSS kernel, which implementation is described in deliverable D4.4, DSS kernel prototype implementation (SU et al, 2013). Key features of the GUI prototype implementation include:

- Input screens for the operational model (about 10 screens), for example enabling the user to set demands and energy prices at a per 24 hours basis.
- Input screen for the strategic model (about 35 screens), for example enabling the user to configure the current and future technologies, as well as to handle the configuration of long-term energy prices.
- User handling, in the form on login screen, building selection, and authentication via the DSS Kernel.
- The display of sample result graphs for the operational and strategic model.
- Tool integration in the form of the DSS kernel, the VaadinUI framework and associated graphs tools.

The GUI prototype implementation also contains a robust set of utilities that makes future extensions easier. For the upcoming development effort the following main features need to be considered:

- Full integration with the solvers as provided by the DSS kernel. This means that the users can start optimizations and view (real) results.
- Extended results graphs, to cover visualisation of the results from the strategic optimization. Investigate if Sankey diagrams can be included to visualize part of the data.
- Add additional screens to add all operative parameters (e.g. U values and areas for wall, window, ground and roof) and additional available technologies (e.g. thermal ene electrical storage).

The current GUI prototype follows the capabilities of the current strategic and operational optimization model, and as such need to be evolved when these two models are changed. For example the operational model is in need of handling more technologies (e.g. PV, CHP, electricity and thermal storage). When this is addresses in the operational model the GUI will be affected. Upcoming versions also need to cover the aspects of improvements as covered in the evaluations analysis, this is described in the next section.

5.2 Features Affected by the Evaluation Results

As pointed out the evaluation analysis section of this deliverable several aspects of the GUI need to be addressed. The full list of concrete changes are listed in section 4.2, however we summarize a few concrete changes here:

- The system was deemed complex, and thus need proper introduction before use.
- Use of the system could be simplified by the inclusion of more build-in help, such as field descriptions.
- The system created high expectations, and it was not clear that it was a prototype system. This need to be clearer.

The evaluation gave us a good metrics of the prototypes information and functional completeness, its ease of use, its usefulness and the user's intension to using it in the future. However it should be noted that the concrete actions for implements was given as a part of the comments given in the questionnaire.

Acknowledgements

The GUI prototype description and implementation are created in a joint effort of several partners, most notably SU and CET. In this deliverable Martin Henkel (SU), Wayne Westmoreland (SU) and Markus Groissböck (CET) described the user interface. Martin Henkel (SU) and Janis Stirna (SU) designed the evaluation and performed the result analysis. The user selection and prototype introduction for the evaluation was performed by Michael Stadler (CET), Markus Groissböck (CET), Luis Manuel Santos Moro (HCE) and Angel Luis Alvarez Iglesias (HCE).

In the course of the internal review of this document Angel Luis Alvarez Iglesias (HCE), Eugenio Perea (TECNALIA) provided valuable comments.

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Appendix A – Evaluation Cover Sheet

Evaluation of the web-based user interface

The overall goal of EnRiMa is to develop a decision support system (DSS) for operator of public buildings. By using a multi-objective optimization approach comfort, financial risks and efficiency improvements are covered in a most economical way.

Goal of the evaluation is a further improvement of the graphical user interface (GUI) by using assessment and feedback of stakeholders from EnRiMa's test sites and some additional experts in the field of facility management.

Part of the evaluation is a demonstration of the EnRiMa DSS as well as an explanation of the overall system (components of EnRiMa server, web services, user interface, integration of building management system). After that all involved people should fill in an evaluation form.

For the demonstration, evaluation and add additional discussion we estimate the time exposure will be about one to two hours.

Evaluation procedure

The evaluation is anonymous, however the (anonymous) data will be made public in the project deliverables.

1 Introduce the project and objectives, and role of your organization
2 Introduction to the EnRiMa DSS and its main parts (main window, menu, tabs). Use the assigned username to login at <link to system>. Each evaluator/user should use their own username, see instruction in the end of this document.

Present the tasks (A: short-term optimization, B: long-term optimization)

3 Evaluators/users complete task A ("Short-term, operational energy optimization") and fill in the form once, online
4 Evaluators/users complete task B ("Long-term, strategic investment optimization") and fill in the form once, online

Tasks

Perform each of the following tasks using the system, then fill in the evaluation for each of the two tasks.

Task A: Short-term, operational energy optimization

Use the system to calculate the optimal indoor temperature for a building by performing the following subtasks.

1. Log into the system, select a building and the short-term operational model.
2. Review the building information, and change if desired:
   a. Overall building properties, such as the building area
   b. Desired temperature
   c. HVAC system properties
   d. Radiator system properties
3. Review building environment information, and if desired change the values for the forthcoming 24 hours:
   a. Outdoor weather, such as temperature
   b. Energy prices
4. Run the optimization
5. Review the result.

Task B: Long-term, strategic investment optimization

Use the system to calculate the best way to invest and use the building technologies the forthcoming 15 years.

1. Log into the system, select a building and the long-term strategic model.
2. Review the building information, and change if desired:
   a. Energy demand
   b. Pollution and investment limits
3. Review the installed and desired technologies for the building. This includes Production, Storage and passive Technologies. For each technology review:
   a. General properties - Such as installation cost, installation limit.
   b. Production properties - Such as input and output energy types, pollutions and efficiencies.
   c. Storage properties - Such as availability and storage limits.
   d. Maintenance and decom cost - Such as maintenance cost for old technologies.
4. Review building environment information, and if desired change the values:
   a. Energy prices
5. Review the configuration of Uncertainties. The future development of for example energy prices can be set using an yearly increase or decrease.
6. Run the optimization
7. Review the result.

The system is available here:

<*link to system*> (use the most recent version)

Each User has his own set of data. Use the following users for the login (the password is the same as the username):
Evaluators contacted by CET: User1 - User9
Evaluators contacted by HCE: User10 – User19

Evaluation form is available here:

<*link to evaluation form*>

Appendix B – Evaluation Form

EnRiMa GUI Evaluation Questionnaire

This evaluation is based on
(If you are evaluating both the operational and strategic module, please fill in this form twice)

- ◯ Operational, short-term module
- ◯ Strategic, long-term module

Current role/position (text):

Number of years working with issues relating to energy efficiency in buildings (number):

I have prior experience with using building management systems (BMS)

	1	2	3	4	5	
No prior experience	◯	◯	◯	◯	◯	Extensive prior experience

Which Building Management System (BMS) do you know/respectively use?

Information and functional completeness

1. The system provides all the information necessary for performing the task

- Strongly agree
- Agree
- Neither agree nor dissagree
- Disagree
- Strongly disagree

2. The system contains relevant information for performing the task.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

3. The system contains information on a sufficient level of detail for performing the task

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

4. The system has all the functions and capabilities I expect it to have

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Open comments about Information and functional completeness

Ease of use

5. It is easy to find information in the system by using its menus

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

6. The organization of information on the individual screens is clear.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

7. The system's response times are satisfactory.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

8. The system informs me when I do mistakes, and allows me to correct them.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

9. The system uses terminology that is consistent with the domain

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

10. It is easy to interpret the information the system presents.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

11. It is easy to learn how to use the system.

- Strongly disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

Open comments about ease of use

Usefulness

12. The system helps accomplishing the tasks quicker and easier compared to not using the system.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

13. The result of using the system will have an impact on energy efficiency of the building.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

14. The use of the system makes it easier to understand the factors that affect short-term building energy efficiency and the long term investments.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Open comments about usefullness

Intention to use

15. Would you use system the system in the future?

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

16. Would you recommend this system to your colleagues?

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Open comments about intention to use

Final comments

How can the system be improved?

Appendix C – GUI Screens

Common

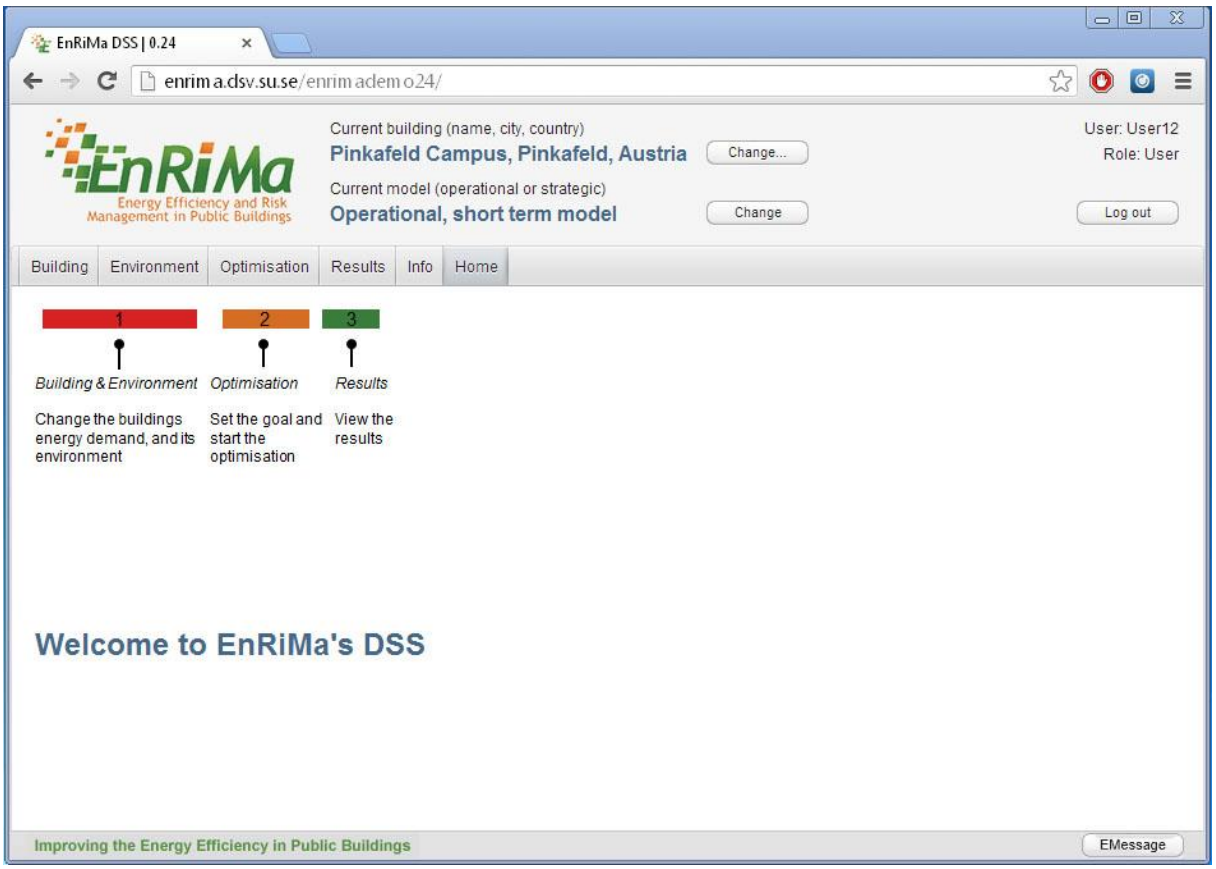

Figure A1 1: EnRiMa Main

Building

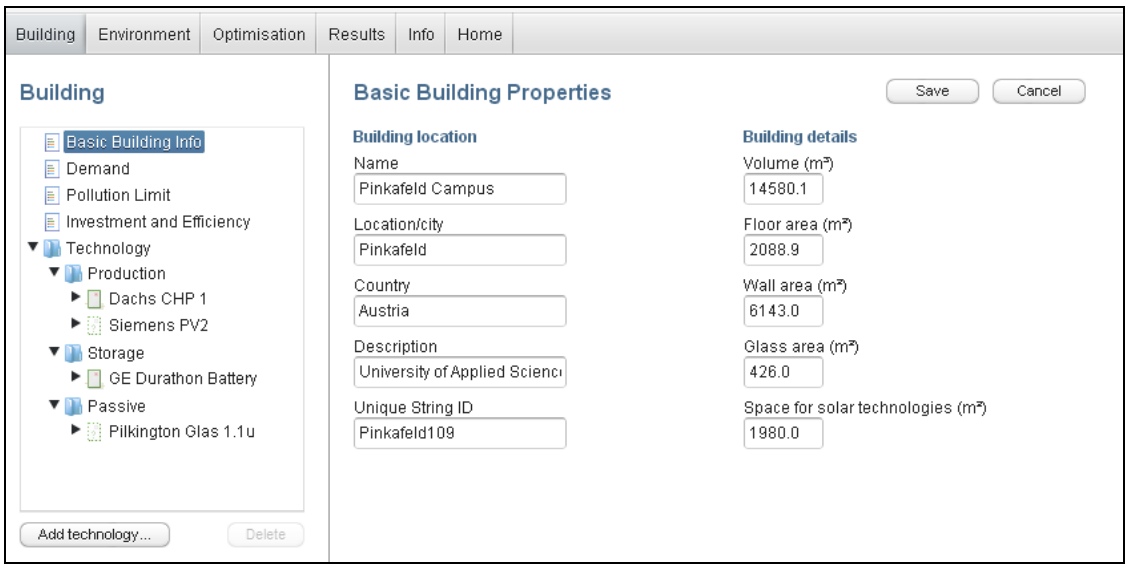

Figure A1-2: Basic Building Properties

Optimization & Result

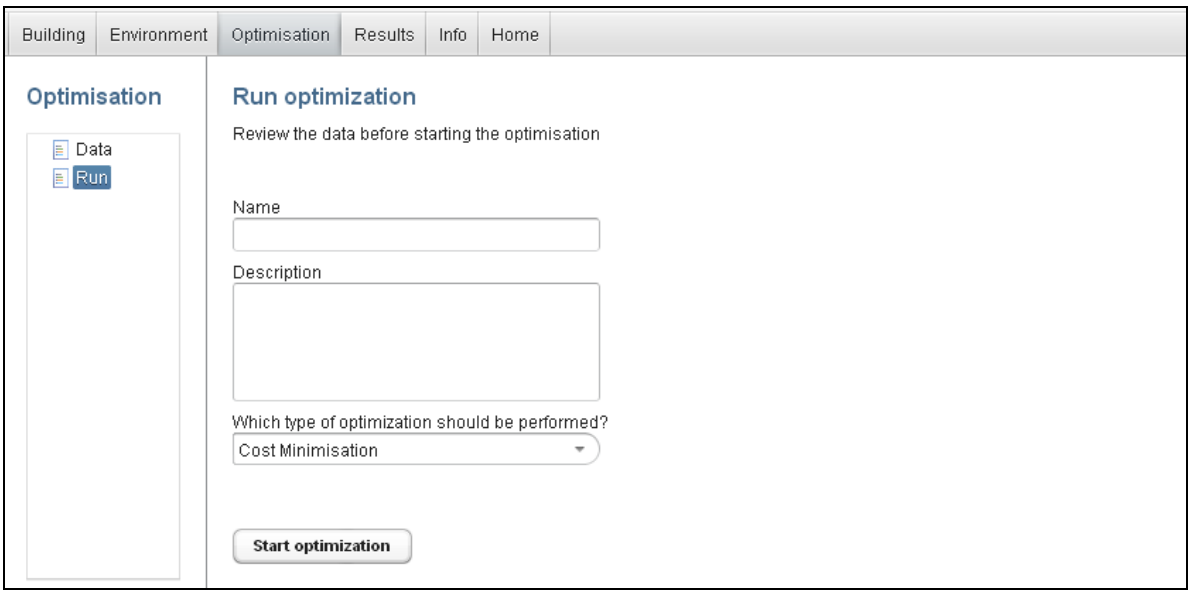

Figure A1-3: Optimization Run

Operational

Building

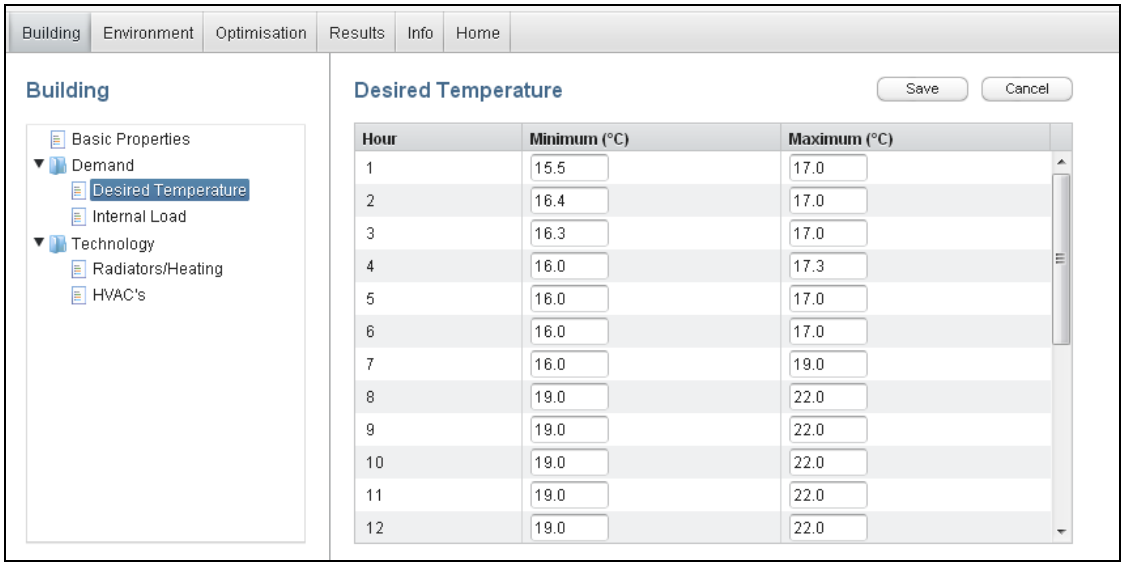

Figure A1-4: Building Technology Demand Desired Temperature

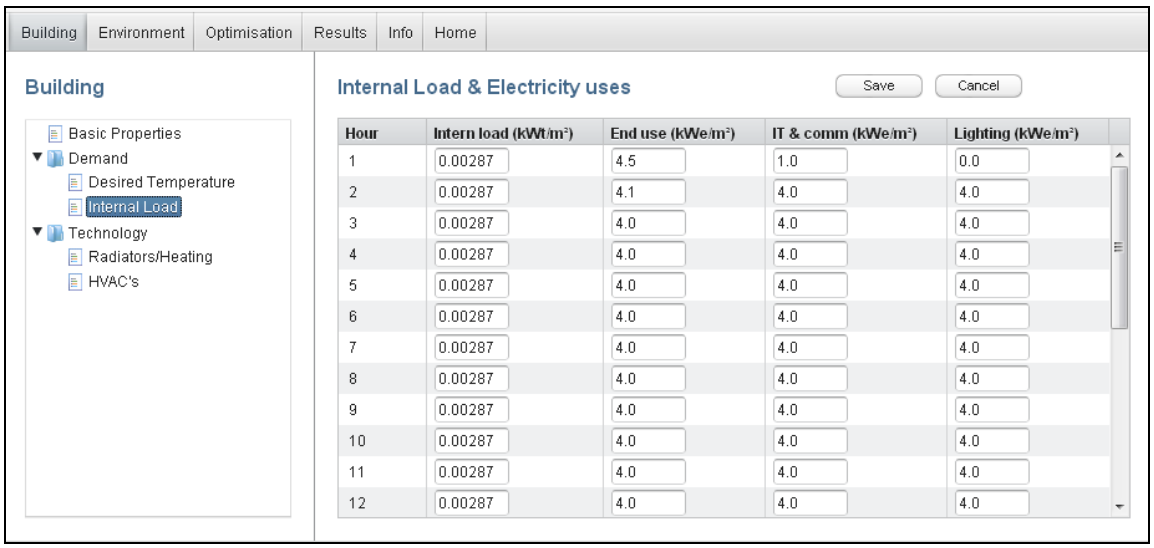

Figure A1-5: Building Technology Demand Internal Load

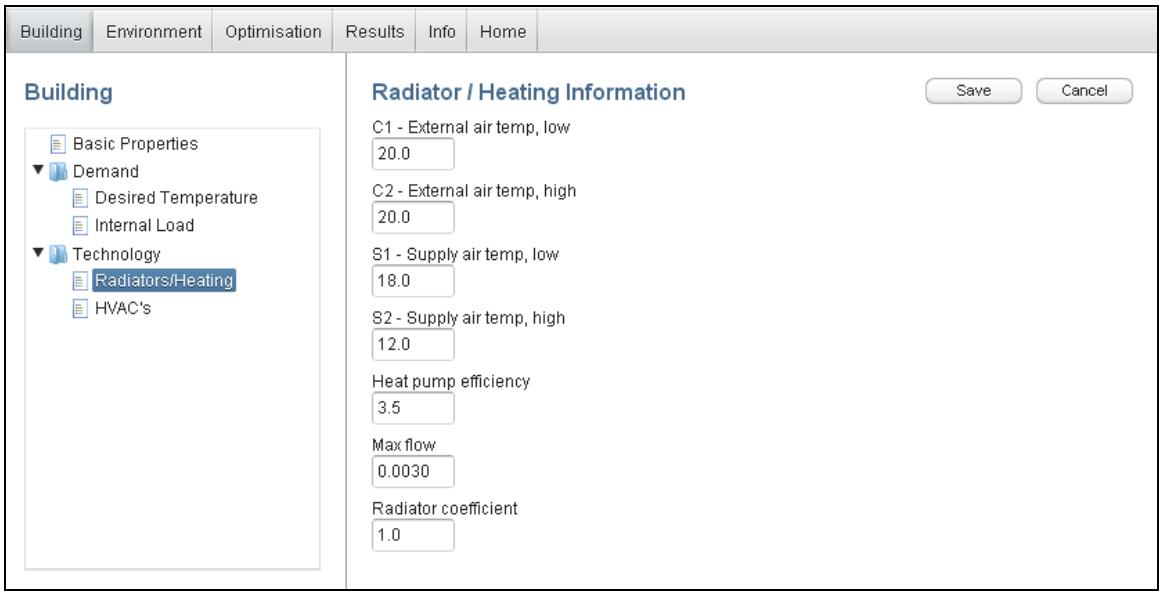

Figure A1-6: Building Technology Radiators/Heating

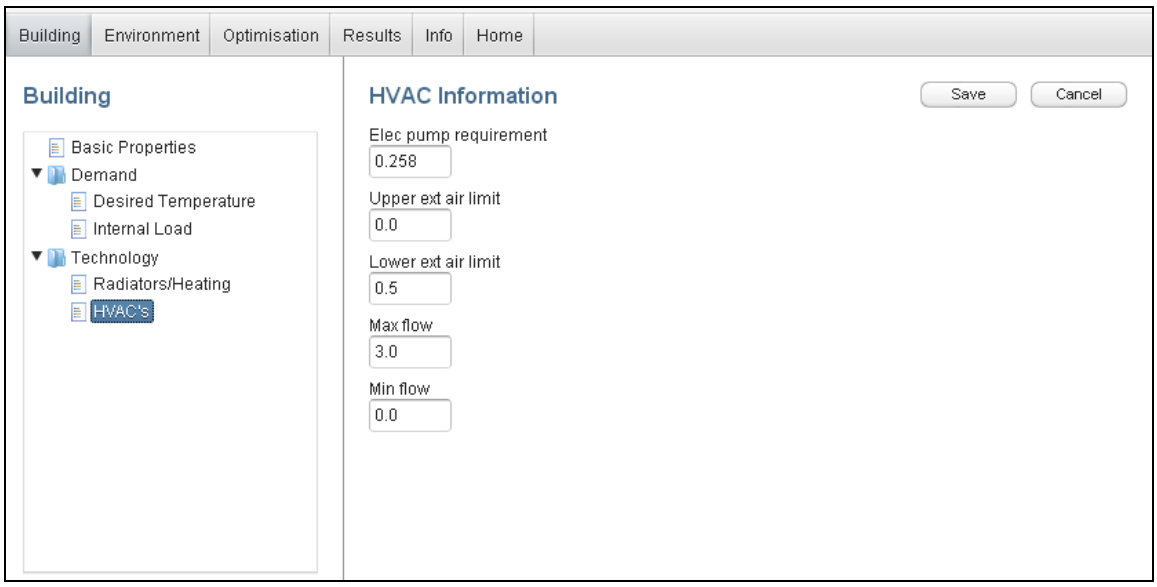

Figure A1-7: Building Technology HAVC's

Environment

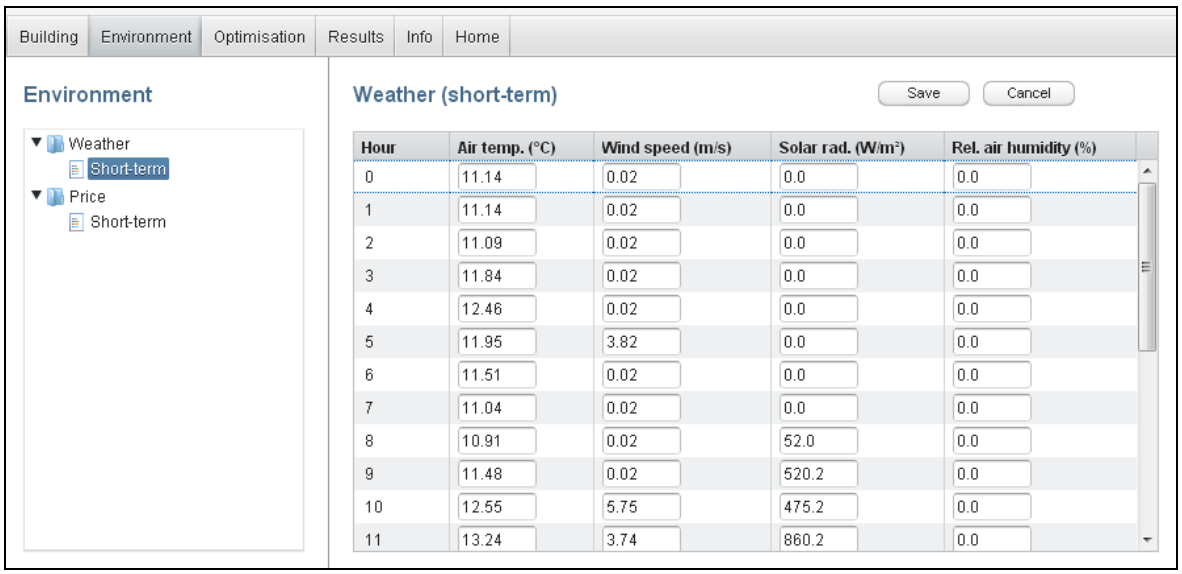

Figure A1-8: Environment Weather Short-Term

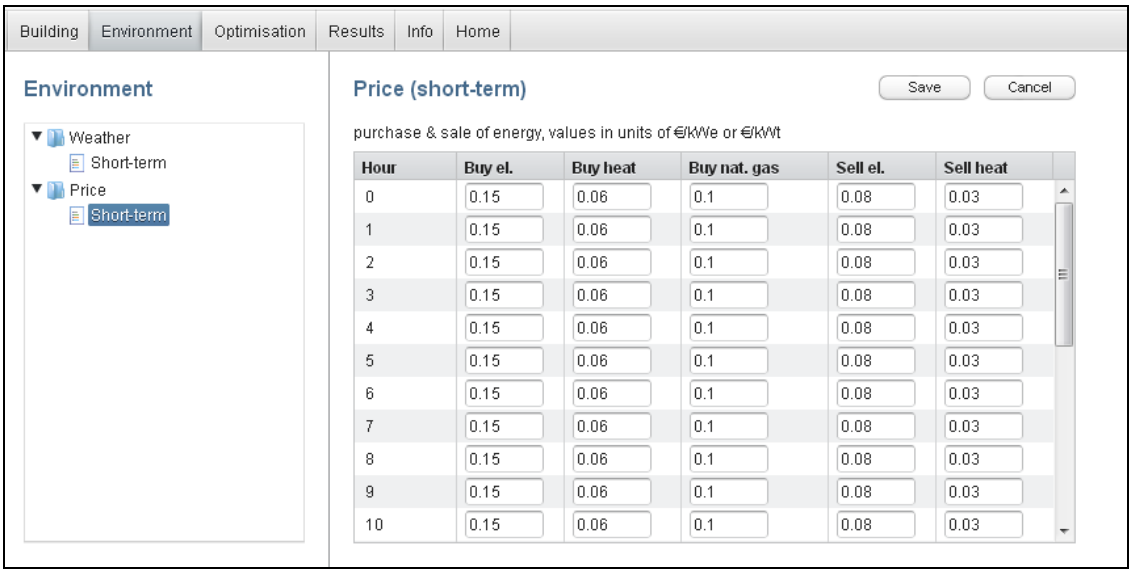

Figure A1-9: Environment Price Short-Term

Optimization & Result

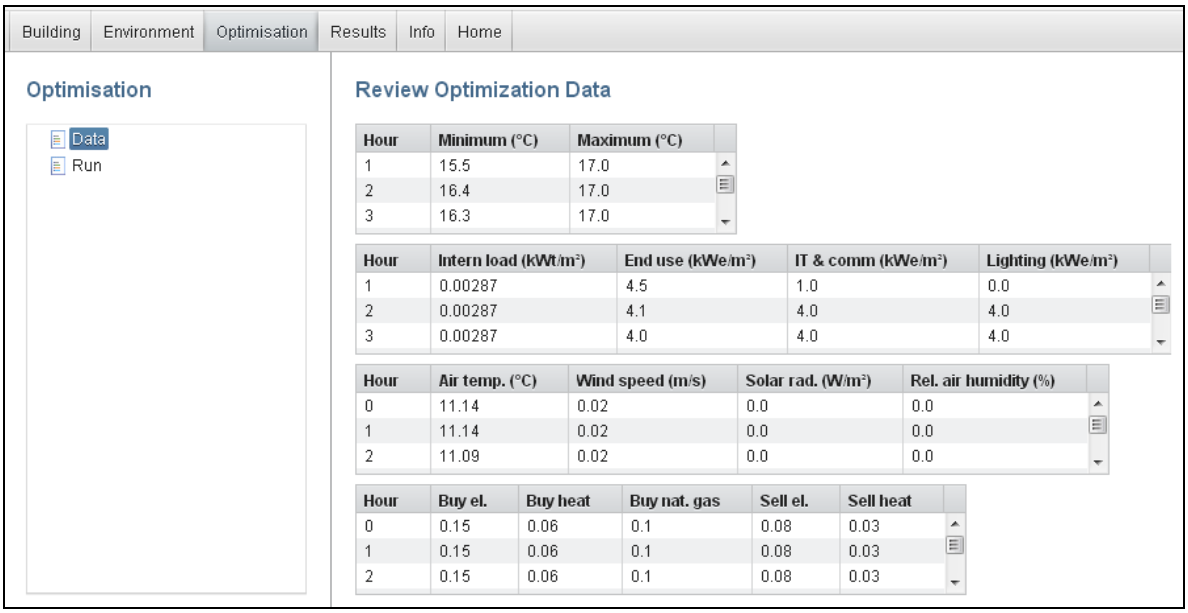

Figure A1-10: Optimization Data

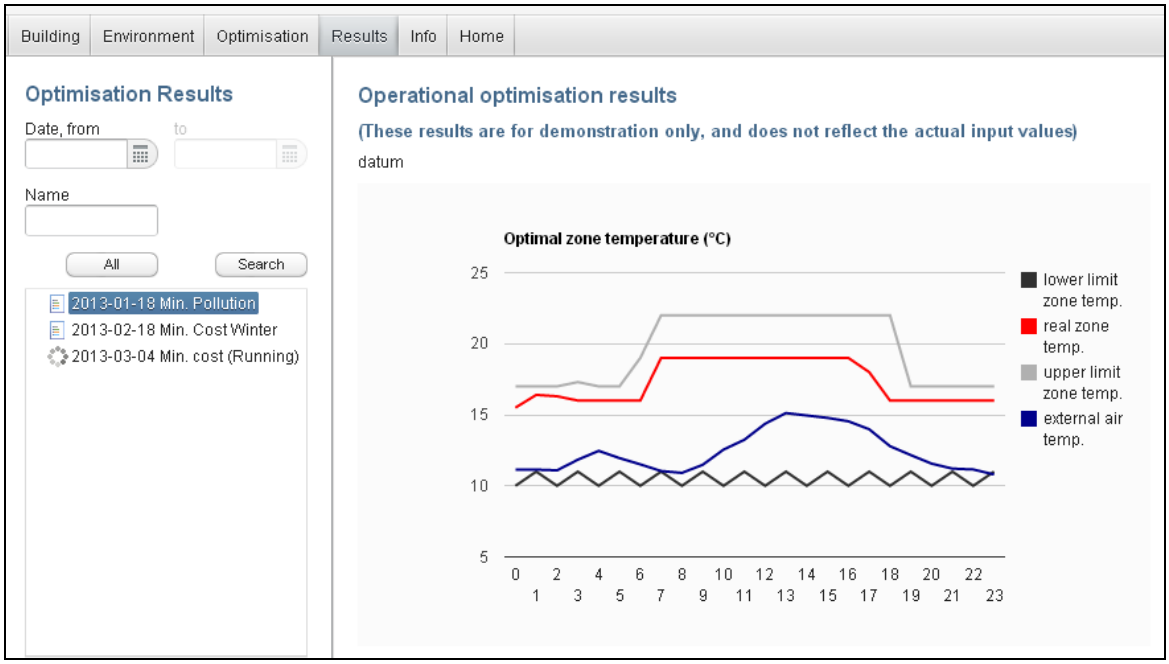

Figure A1-11: Results

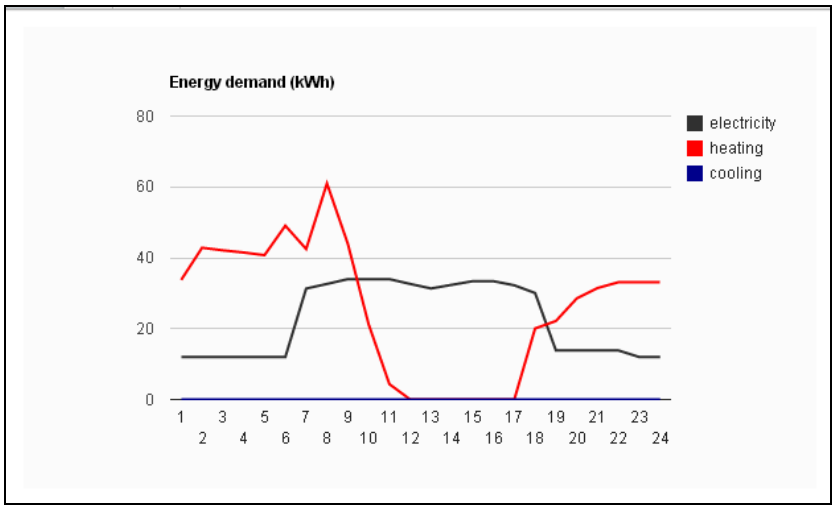

Figure A1-12: Result Example 2

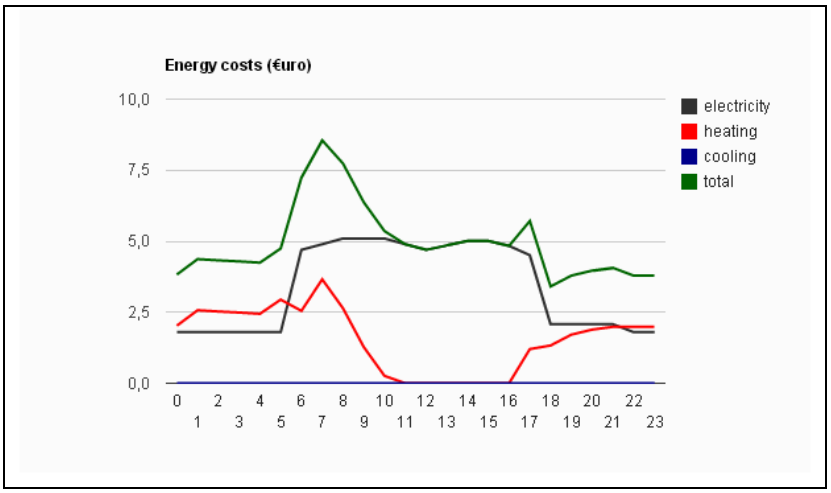

Figure A1-13: Result Example 3

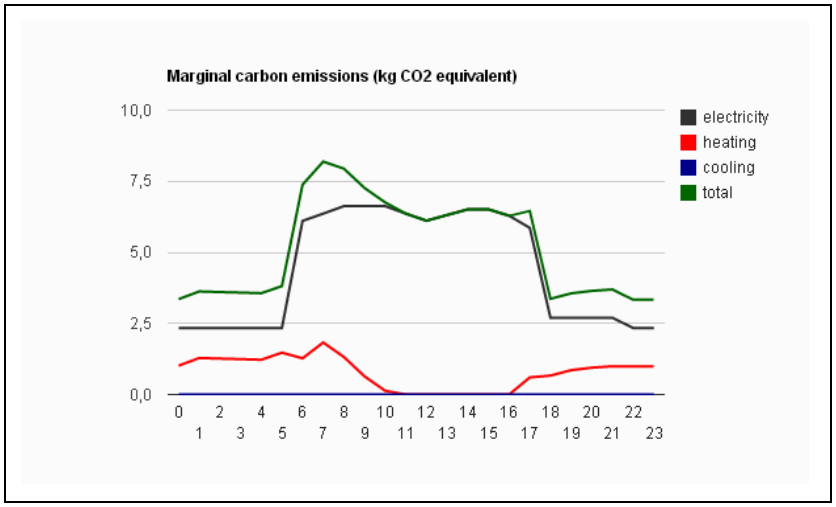

Figure A1-14: Result Example 4

Strategic

Building

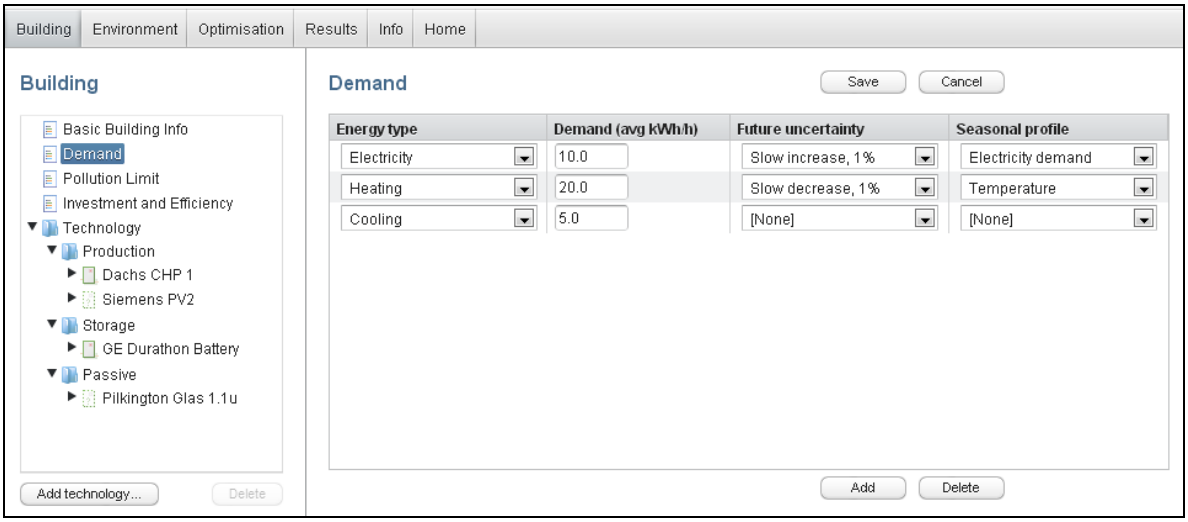

Figure A1-15: Demand

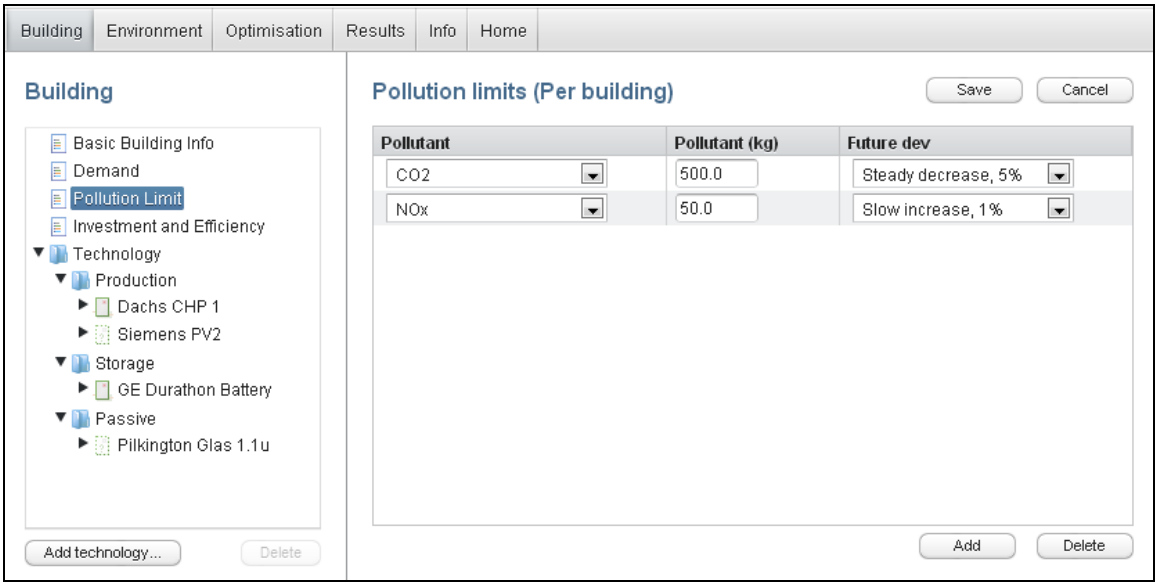

Figure A1-16: Pollution Limit

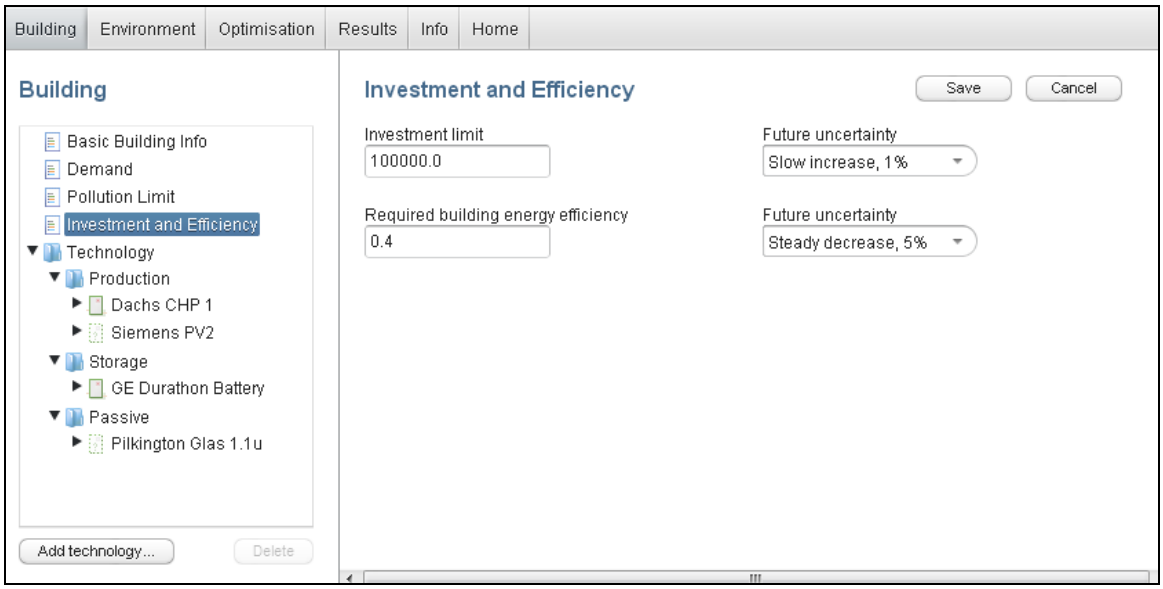

Figure A1-17: Investment and Efficiency

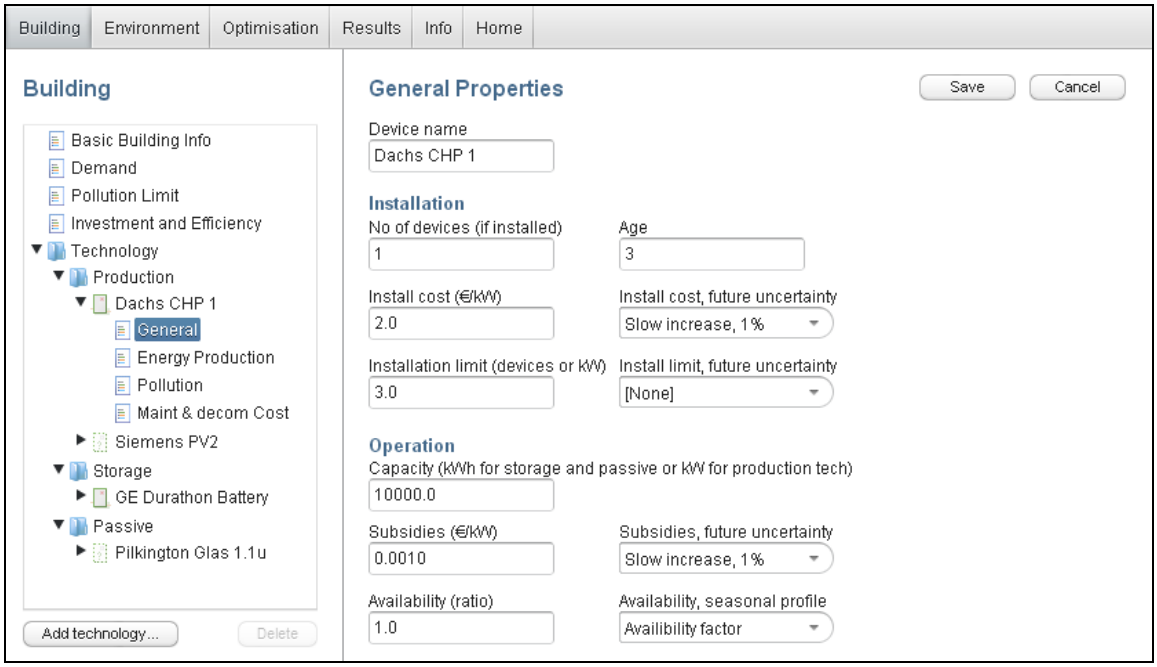

Figure A1-18: Technology General

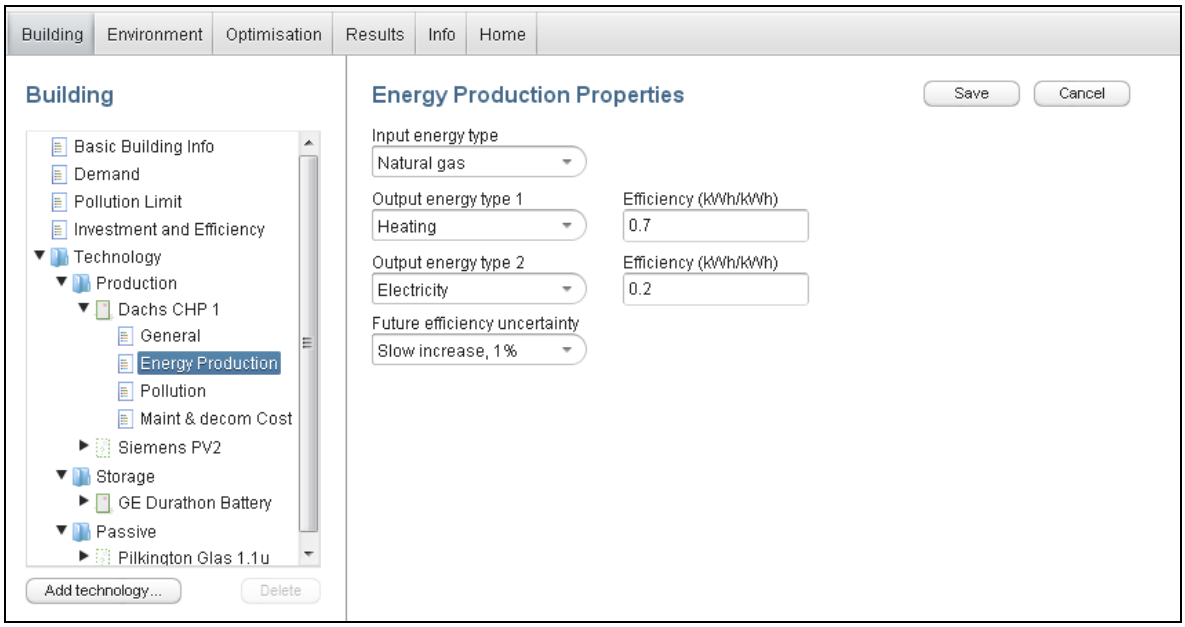

Figure A1-19: Technology Energy Production

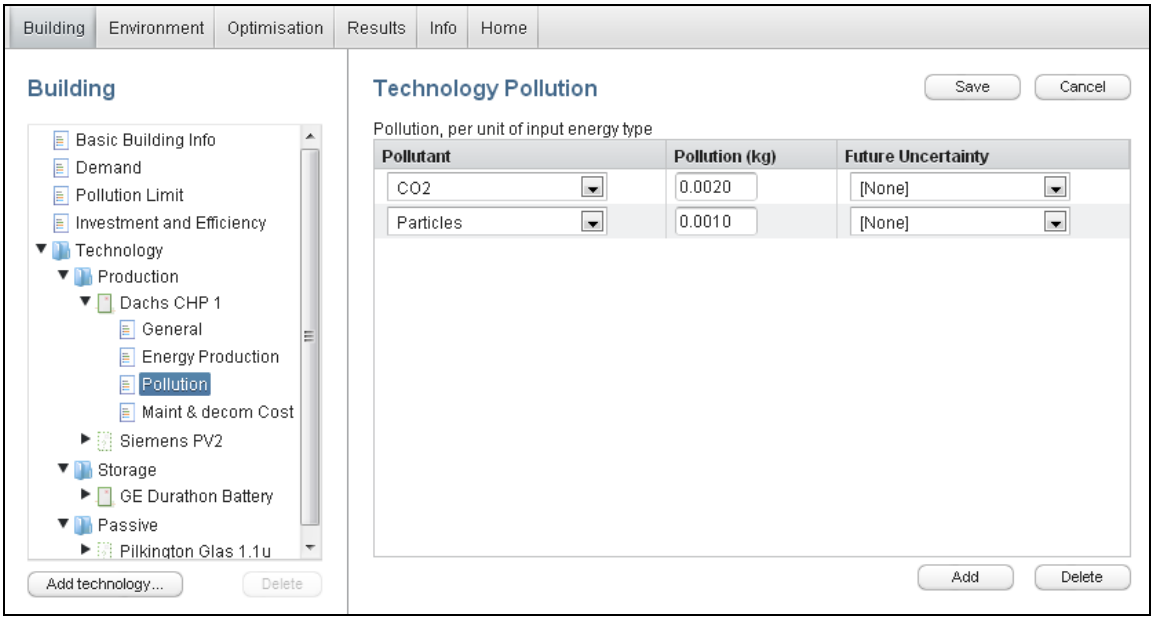

Figure A1-20: Technology Pollution

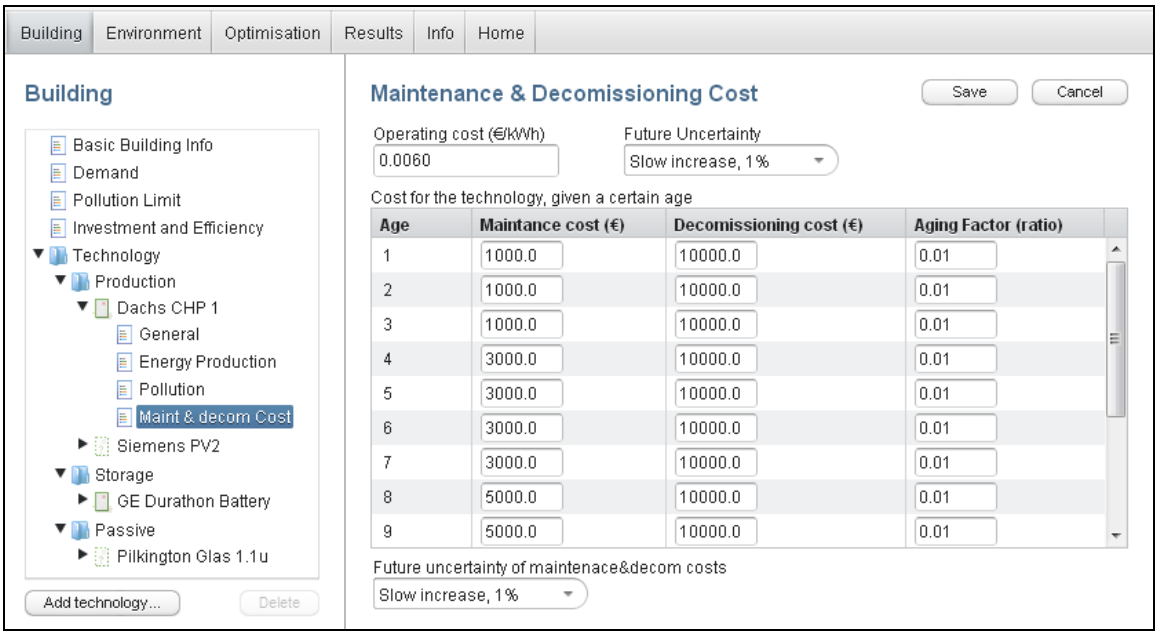

Figure A1-21: Technology Maintenance and Decommission Cost

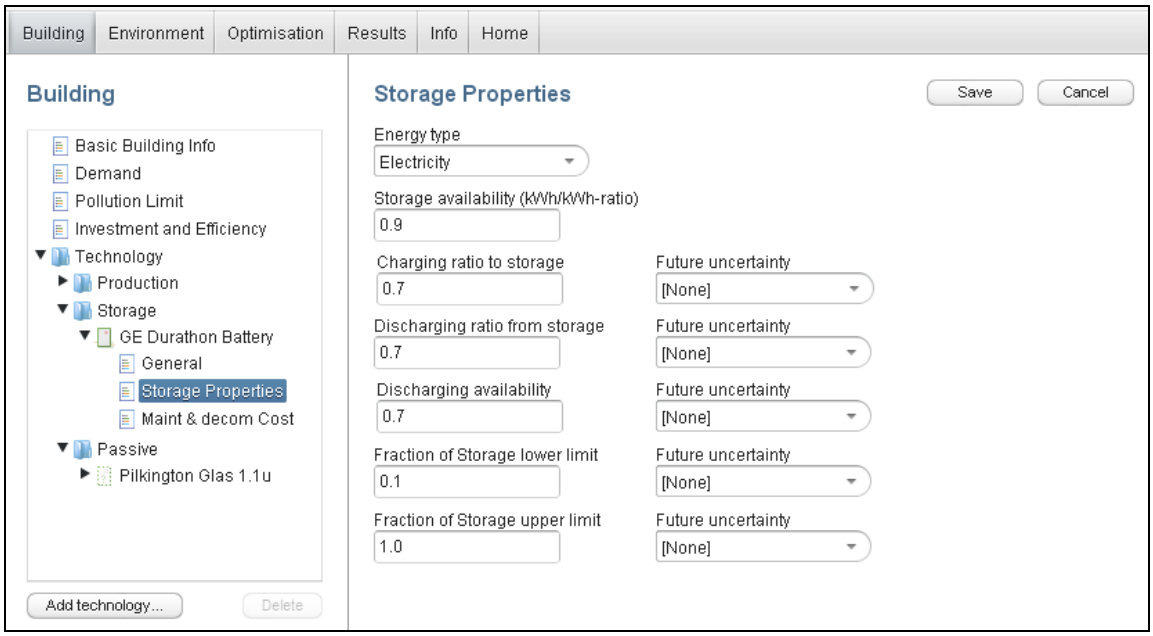

Figure A1-22: Technology Storage Properties

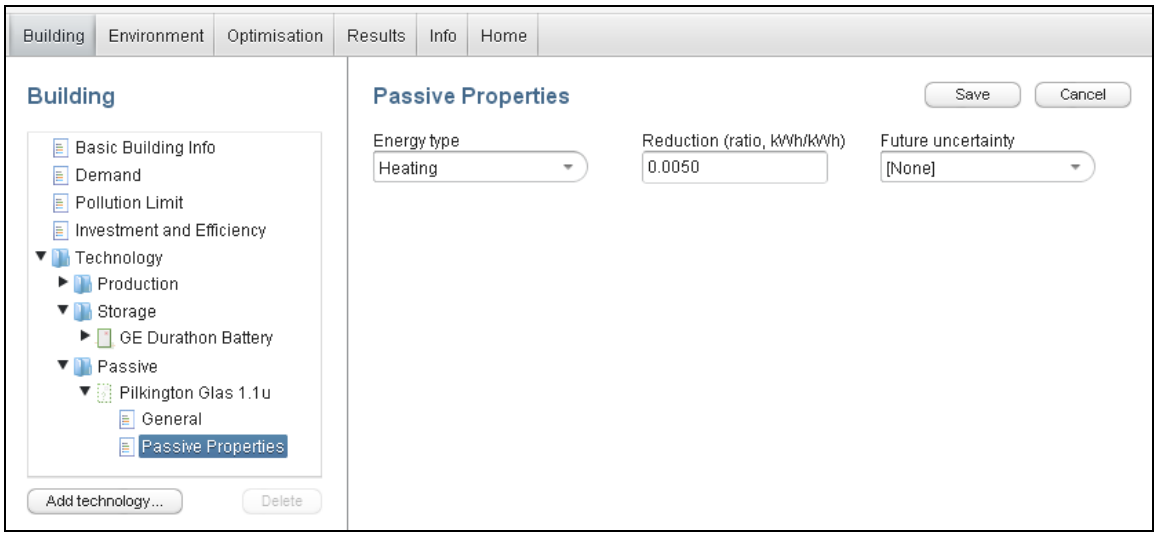

Figure A1-23: Technology Passive Properties

Environment

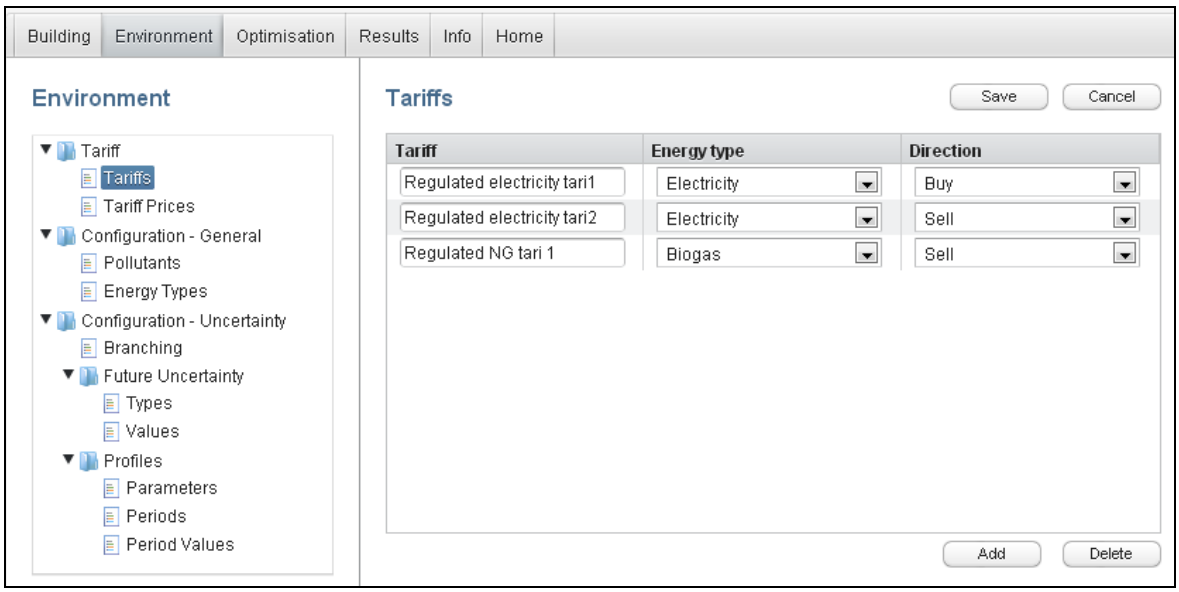

Figure A1-24: Tariffs

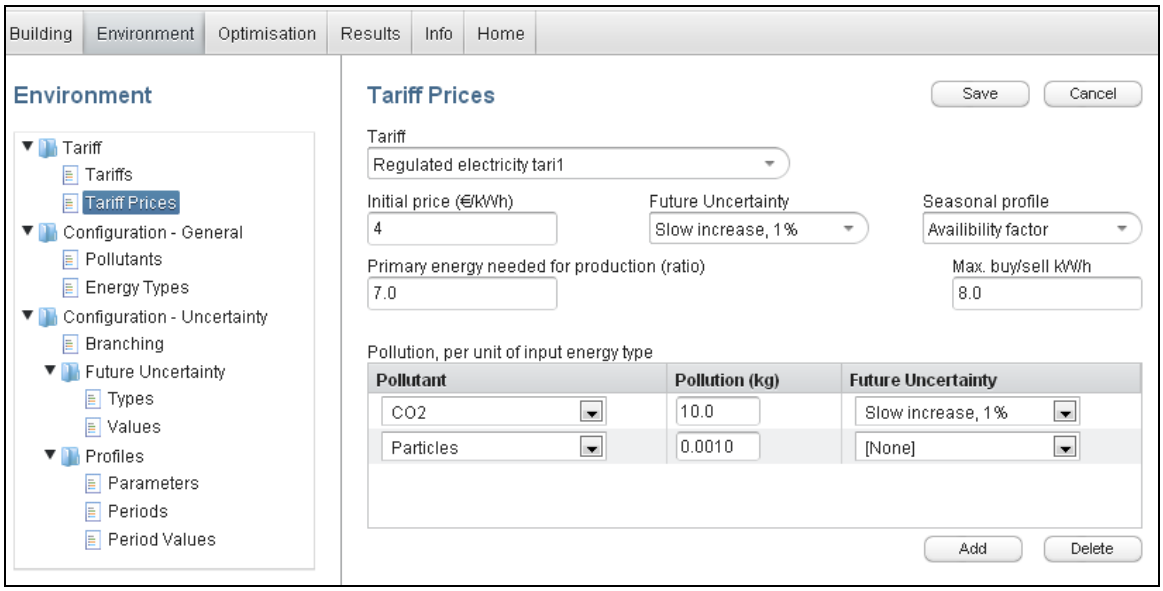

Figure A1-25: Tariff Prices

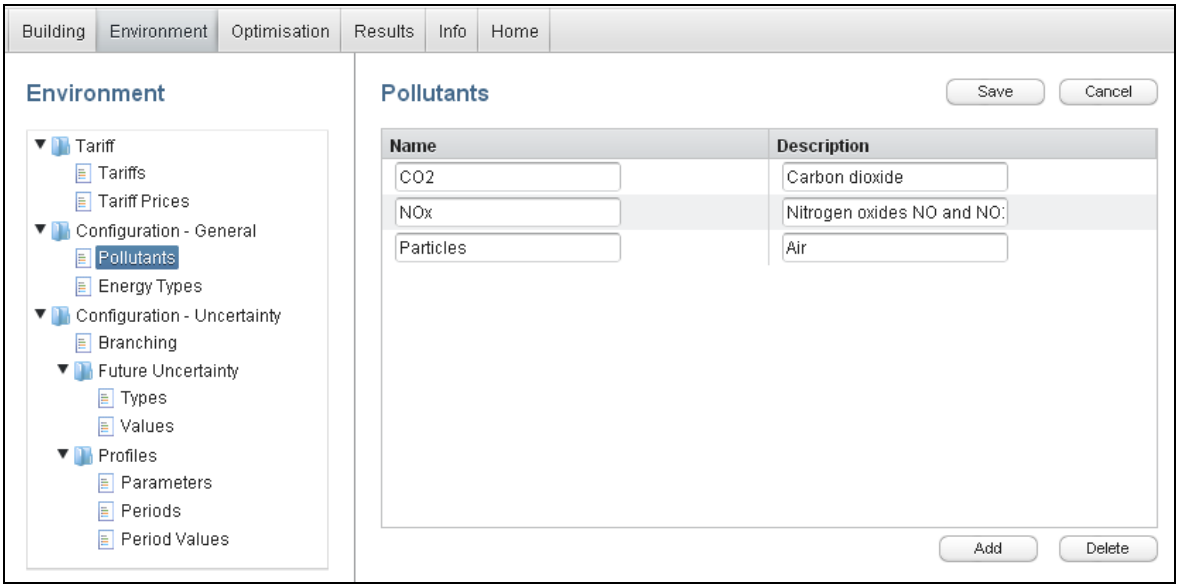

Figure A1-26: Pollutants

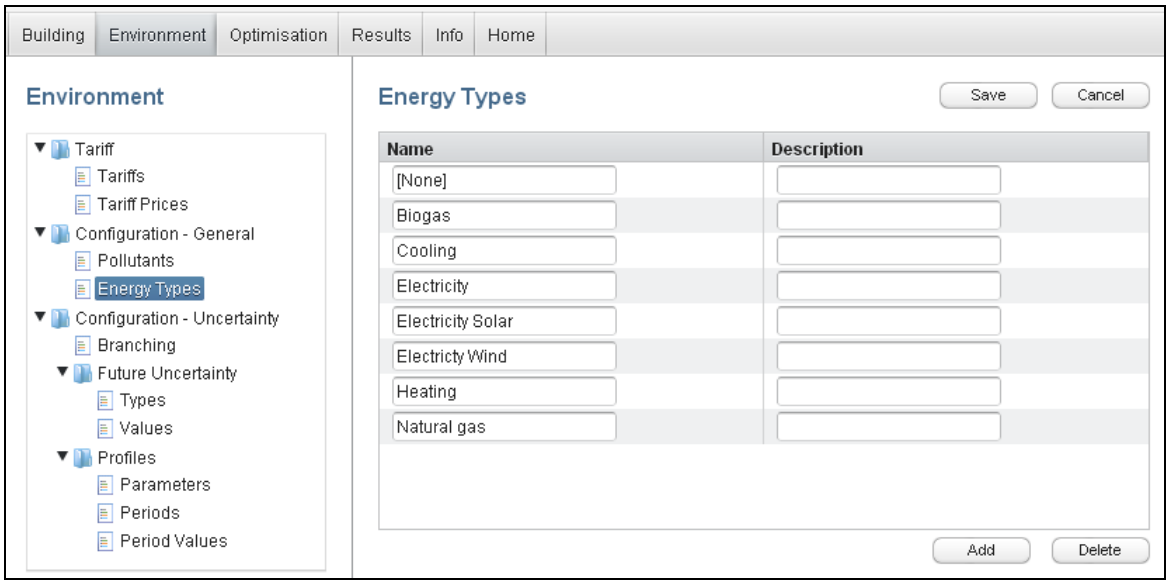

Figure A1-27: Energy Types

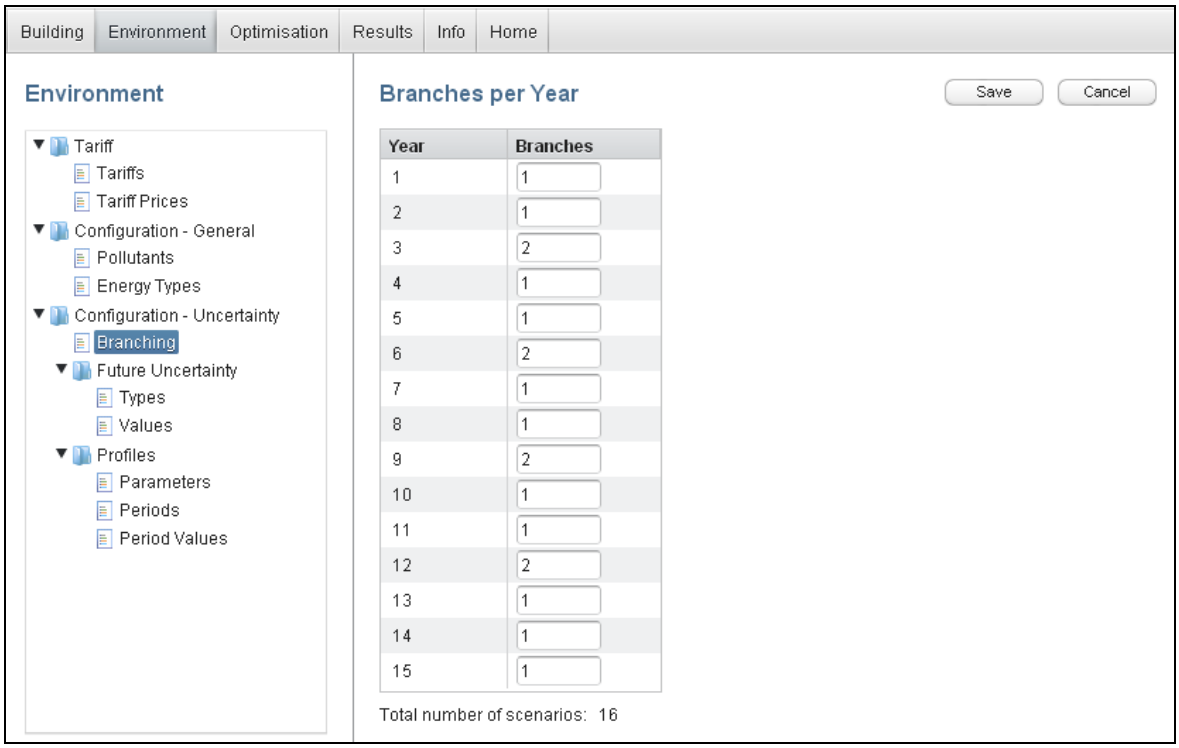

Figure A1-28: Branches per Year

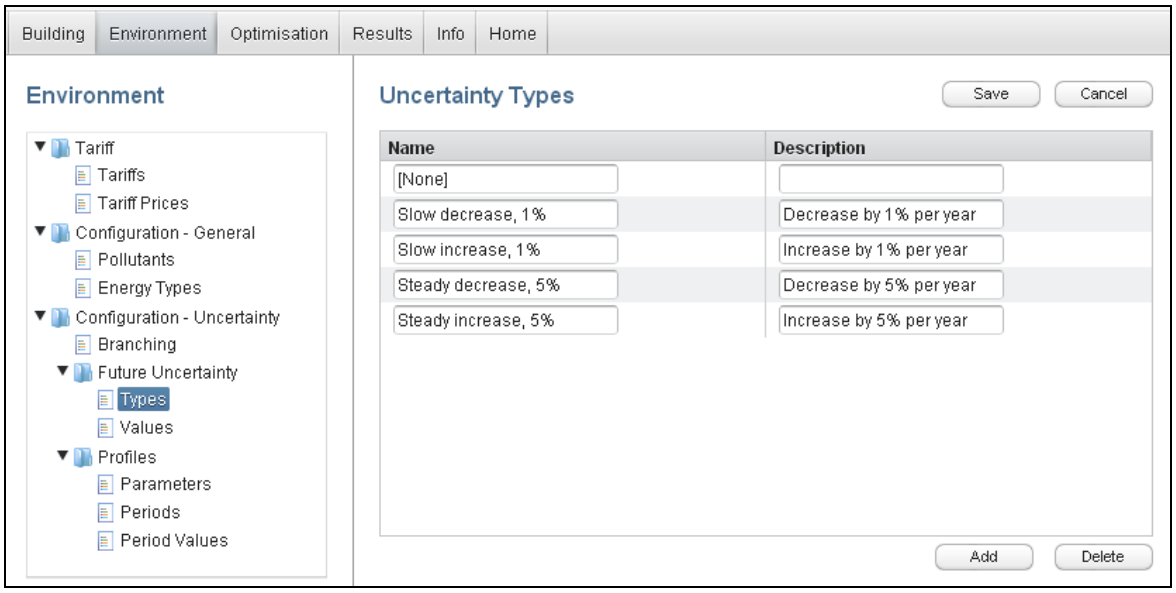

Figure A1-29: Uncertainty Types

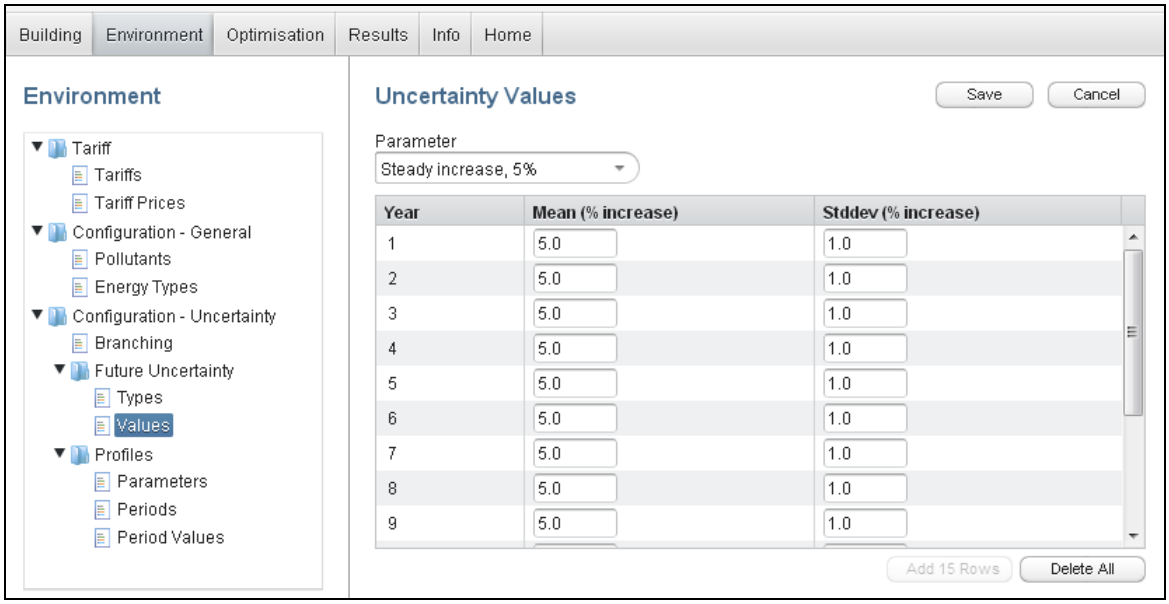

Figure A1-30: Uncertainty Values

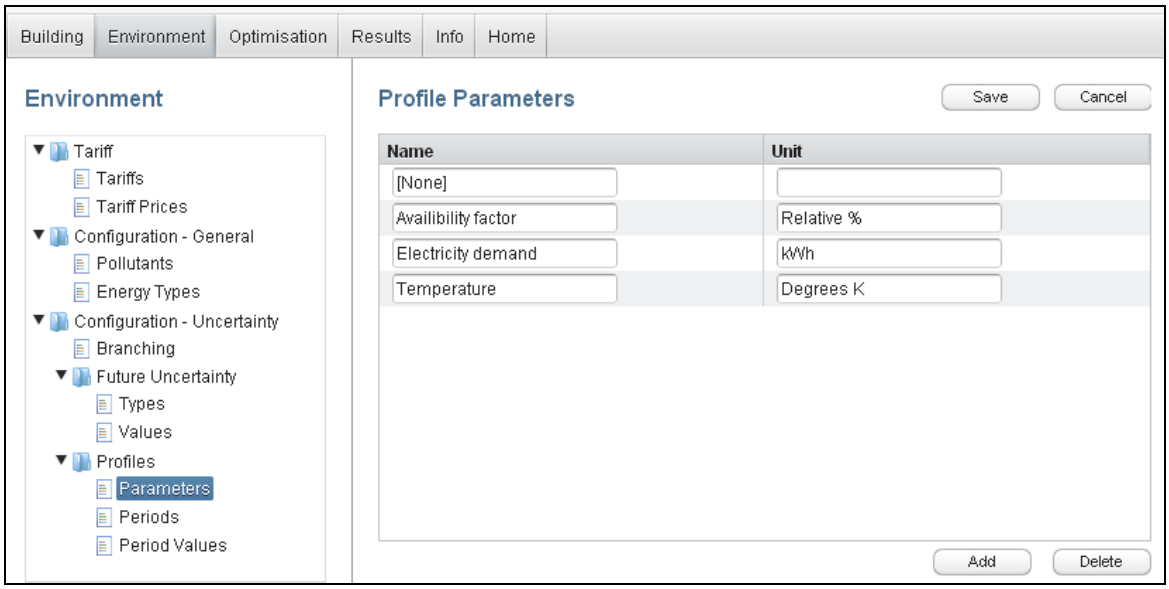

Figure A1-31: Profile Parameters

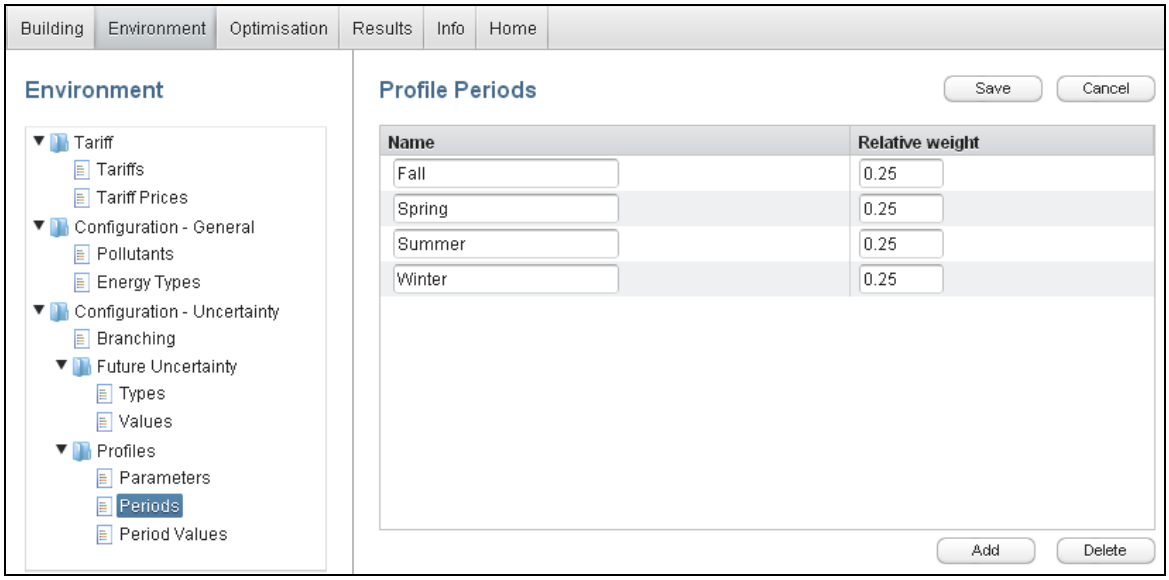

Figure A1-32: Profile Periods

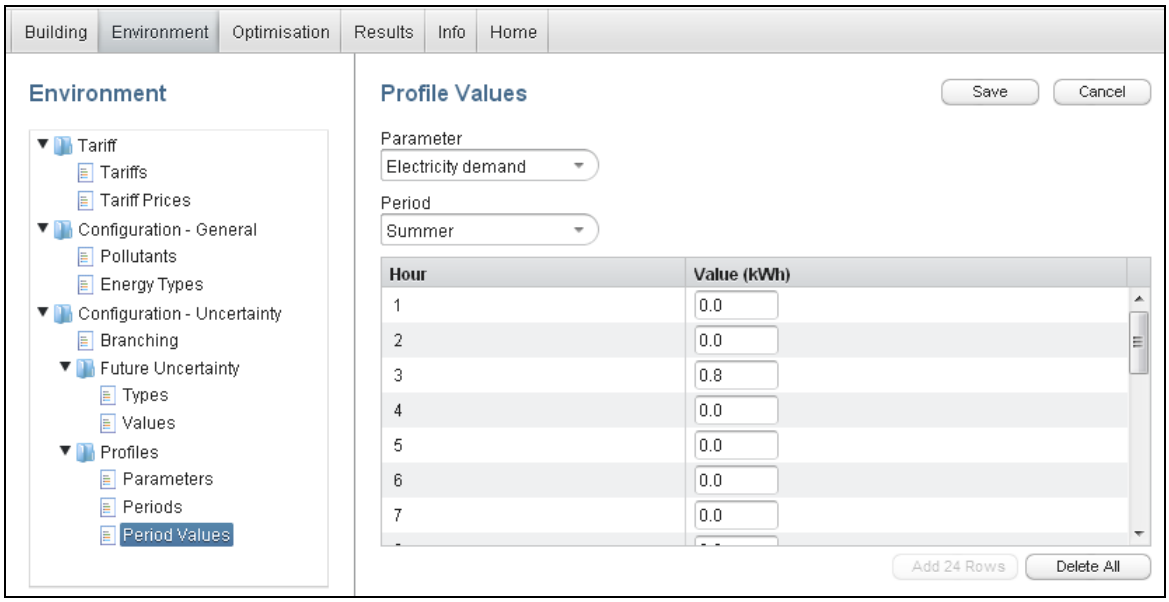

Figure A1-33: Profile Values

Optimization & Result

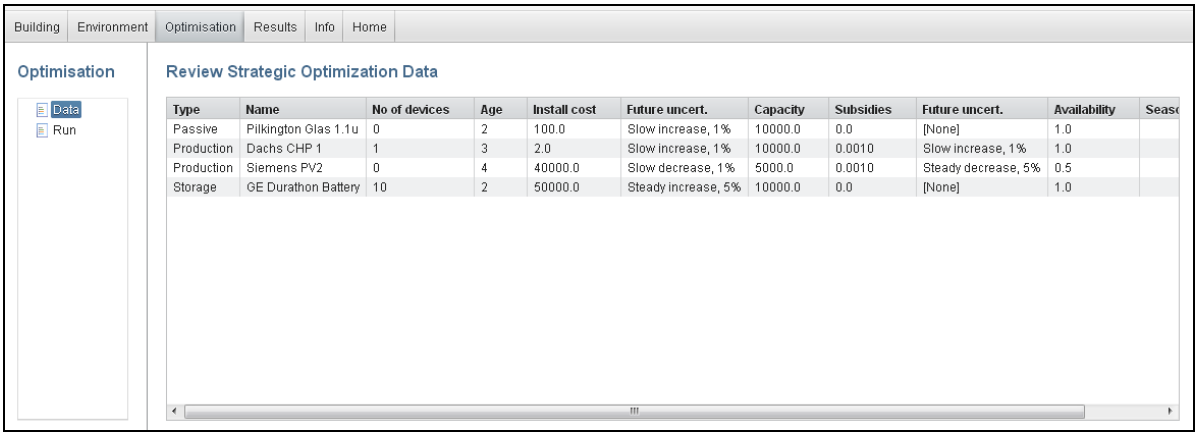

Figure A1-34: Optimization Data

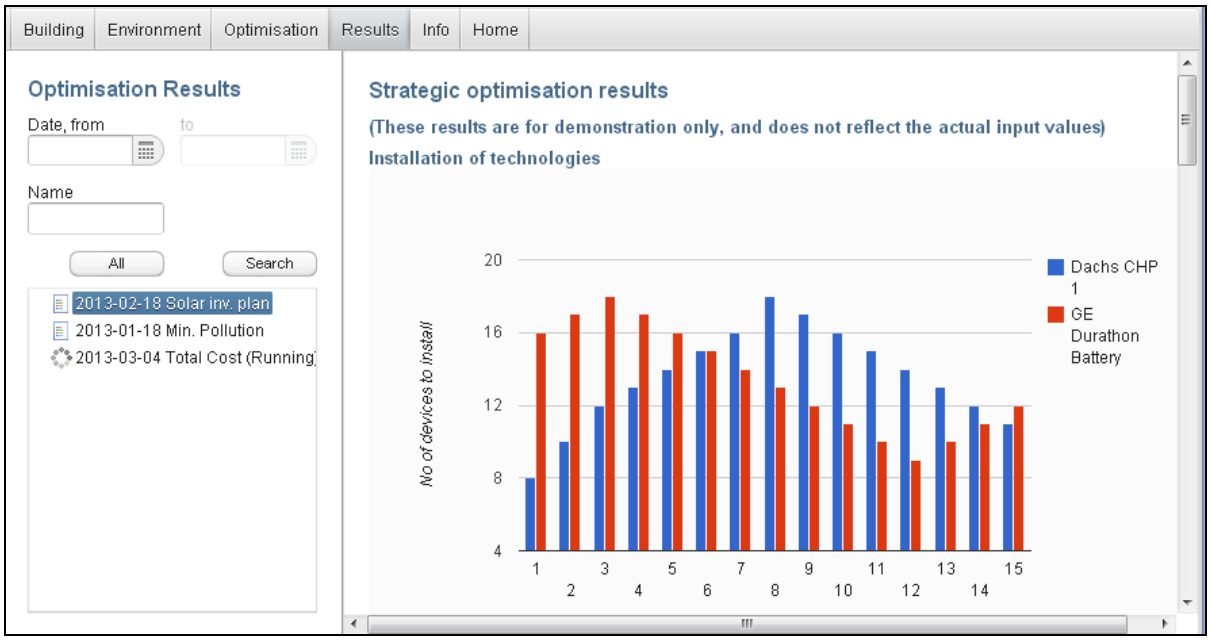

Figure A1-35: Results

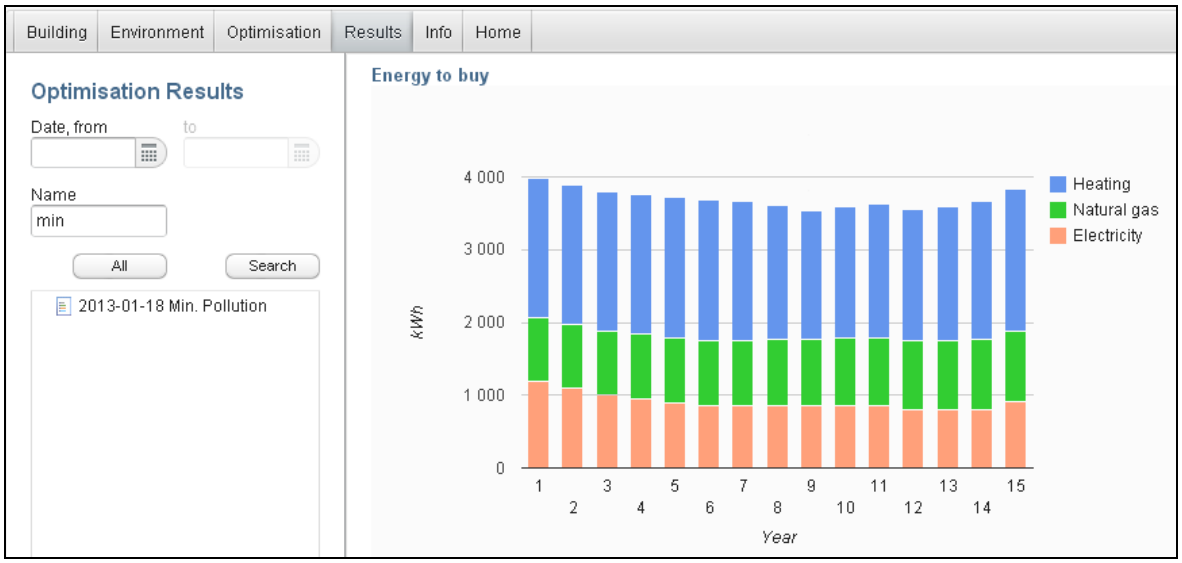

Figure A1-36: Result Example 1

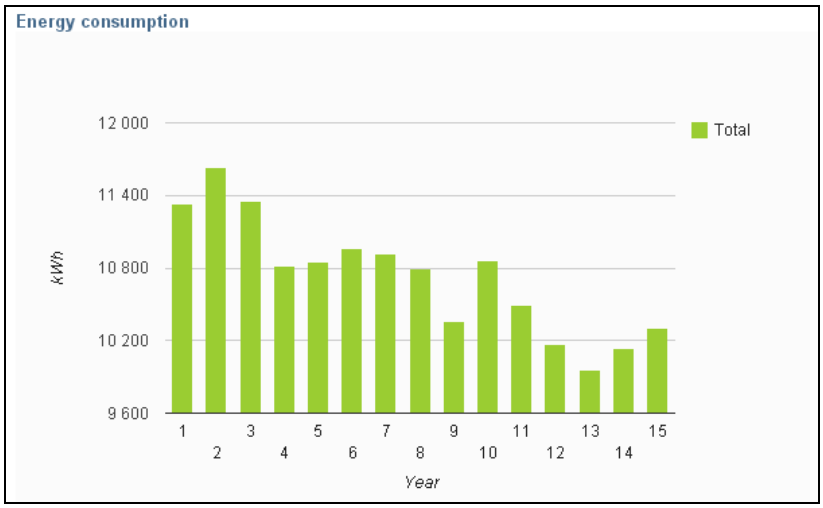

Figure A1-37: Result Example 2

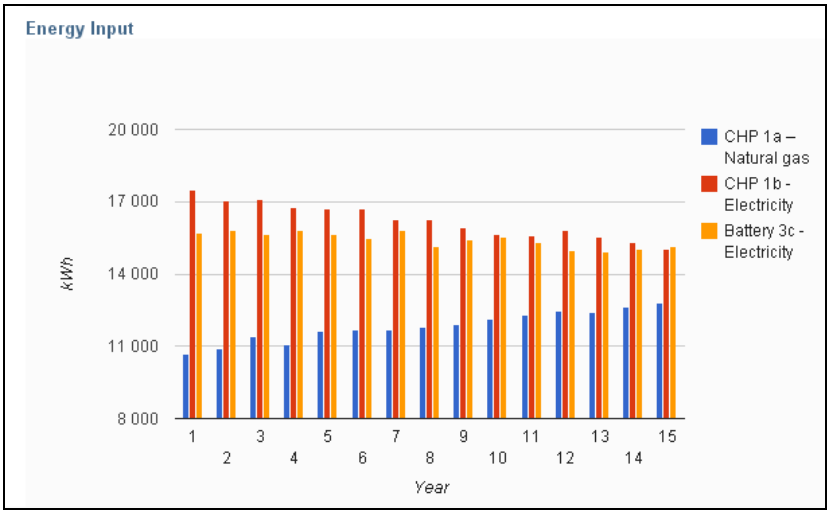

Figure A1-38: Result Example 4

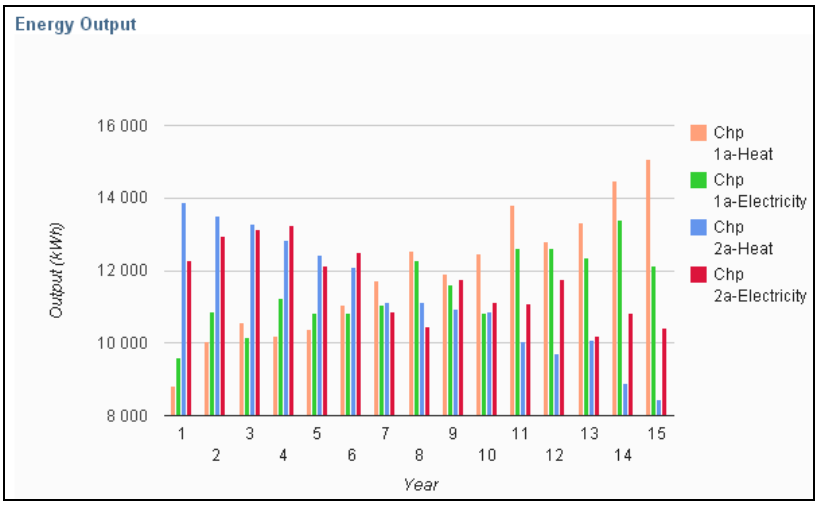

Figure A1-39: Result Example 4

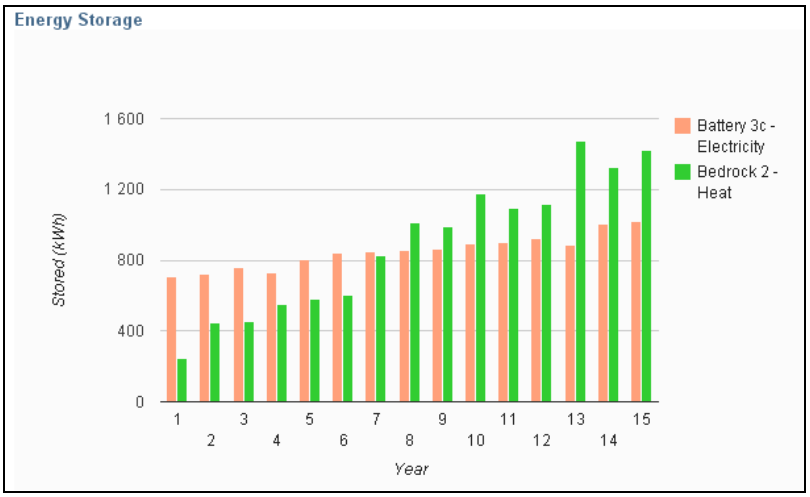

Figure A1-40: Result Example 5