ECBCS Annex 49

Low Exergy Systems for High-Performance Buildings and Communities

Newsletter No. 6 September 2009

TOOLS FOR EXERGY PERFORMANCE EVALUATION

THE DESIGN PERFORMANCE VIEWER

Forrest Meggers, Arno Schlüter and Frank Thesseling[1]

For the first time a building exergy calculation has been implemented in a Building Information Modeling (BIM) tool. A new energy and exergy tool called the Design Performance Viewer (DPV) has been developed in the Building Systems Group at the ETH in Zurich based on the Excel tool developed in the IEA ECBCS Annex 37 and currently being expanded in the Annex 49. The tool integrates with the Autodesk Revit software allowing planners, designers, and architects to obtain an easy-to-understand graphical display of the energetic and exergetic performance of their building. The tool can be implemented in all phases of design and most importantly, allows the user to observe potential impacts of changes during the earliest and most influential phases of the design process. This facilitates an awareness of energy and exergy performance throughout a project, instead of energy analysis just being an afterthought.

It is not easy to design a modern building, and as buildings have become more complex so have the tools used to design them. Nearly all buildings today rely on some form of Computer Aided Design (CAD) tool in their creation. The need for higher performance buildings has led to the development of energy simulation tools that show not just the construction of a building, but also its operation. But often these simulation systems require complicated inputs making analysis of various constructions or multiple design possibilities very difficult. The development of object orientated CAD models has facilitated the growth of more accessible energy analysis systems. These Building Information Models (BIM) include both geometric data as well as other information about various components of the building such as wall thermal resistance and room orientations. The information stored in the BIM can be used directly to do calculations about the design such as shading and lighting as well as energy calculations.

The DPV tool takes information by using an API from a Revit building model and uses it to determine performance factors for a building and display them in a simple graphical interface. The first version of the

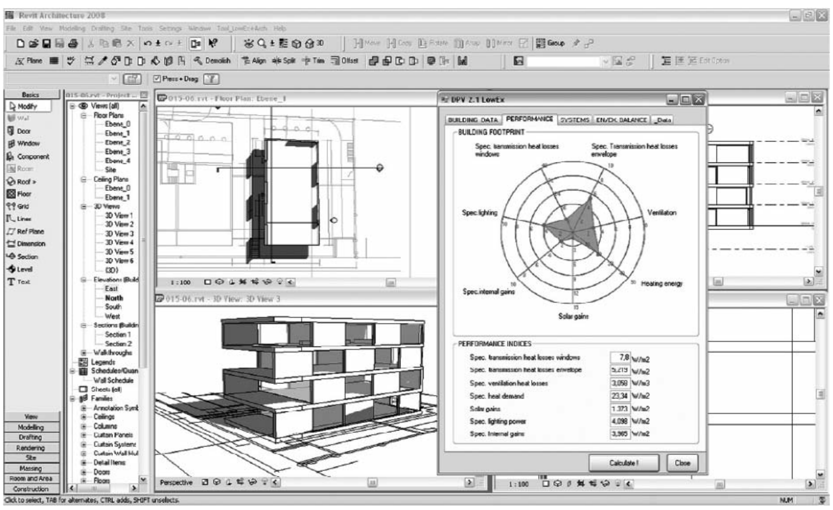

Figure 1: Screenshot from DPV tool with spider graph for comparing the performance of different parts of building design.

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DPV was created for use in a 1-week course at the ETH Zurich called LowEx+Arch, and was used for a studio on the renovation of a particular building. With one click the students could see the performance of the building based on the German EnEV (Energy saving standard) calculations with different performance aspects like wall losses or solar gains compared in a spider graph. A Sankey diagram is also automatically generated of the energy flows. Finally, there is also a flow chart of the relative exergy destruction as calculated in the Excel tool developed within the Annex 49 project.

The second version of the DPV expanded the flexibility, allowing any building type from offices to housing to be iput. This was then applied to a series of projects in the full LowEx+Arch course. The energy calculations were also updated to the Swiss SIA standard methodology and the graphics were improved to facilitate comparisons. The inputs in the tool are similar to those for the Excel tool in this version with drop down boxes for various installation types and heating systems. The input screens of the tool along with the spider graph, Sankey diagram, and exergy flow chart are shown in the figures 1-4 for the second DPV version.

The tool has now been utilized in several week-long courses as well as twice in semester courses at the ETH. The exergy aspect of the tool illuminates the importance of the type of system chosen by the designer, especially with respect to the temperature of operation. The value of low temperature heating and high temperature cooling is demonstrated in the use of the DPV, and it helps teach these concepts to the students.

The Swiss Federal Office of Energy is very interested in the development of the tool. The use of the SIA calculation makes it an attractive way to simplify the application of energy analysis in building projects. The tool has also attracted the attention of a big façade company where the BIM aspect of the tool makes it very helpful for the implementation of their façade elements that now include many advanced energy features. The interest in the DPV tool is growing rapidly and the startup keoto AG (www.keoto.net) will soon begin consulting in the use of the tool.

At present, the third iteration of the DPV is under final development. The interface has been completely revamped and dynamic calculations including weather data are being implemented. Also the exergy calculations will be reevaluated better to show the direct impact of certain design decisions, not just in the system drop down boxes, but within the parametric model itself. This is where the real preliminary design decisions are made, and if exergy can play a role there, it would become even easier to reduce the building primary energy demand. This latest iteration of the DPV will be piloted this fall again in the LowEx+Arch class. It is expected that the interest will continue to grow, and it is hoped that the DPV will be able to guide the creation of many energy efficient, high performance, and LowEx buildings.

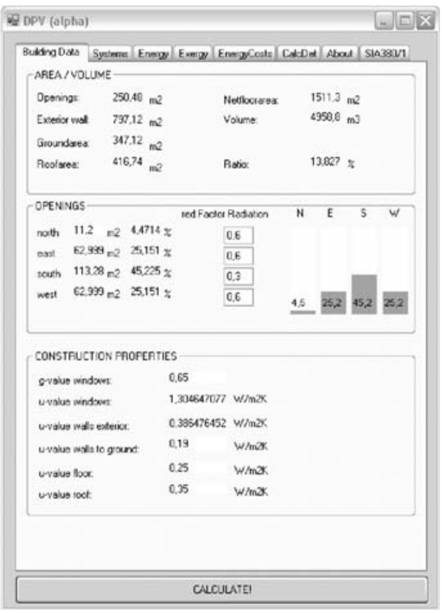

Figure 2: This tab shows the building data acquired from the Revit Model

Figure 3: This tab allows the user to input various system parameters

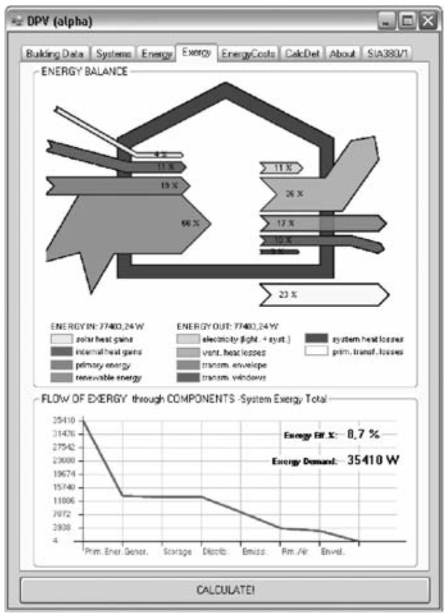

Figure 4: This panel contains the energy balance showing the Sankey diagram and below is the exergy flow through the building systems.

SEPE: AN EXCEL CALCULATION TOOL FOR EXERGY-BASED OPTIMIZATIONS

Marco Molinari[2]

SEPE is an acronym that stands for Software for Exergy Performance Evaluation developed at KTH, the Royal Institute for Technology, in Stockholm: it is an excel-based software that utilizes the iteration features of Excel to perform steady-state exergy evaluations and optimization of different cooling and heating systems.

By copying and pasting different existing components it is possible to combine them to create and simulate heating or cooling systems. The connection of the different systems is easy as it is only necessary to couple absolute temperature and pressure of one system to the following one. To perform loops, once the required components have been placed and connected in the excel sheet, the input variables (absolute temperature and pressure) need to be connected to the output ones of the loop: once the iteration options of excel have been enabled, the program automatically updates the values until convergence (see Figure 5).

So far, the following models have been developed and included in the software (Table 1):

Table 1: Available models in SEPE

GENERATION	EMISSION	DISTRIBUTION	OTHER MODELS
Boiler	Air handling unit	Air ducts	Room model
Heat pump	Floor cooling/heating	Water pipes	Heat exchanger
Adiabatic saturator (for evaporative cooling)		Pumps	

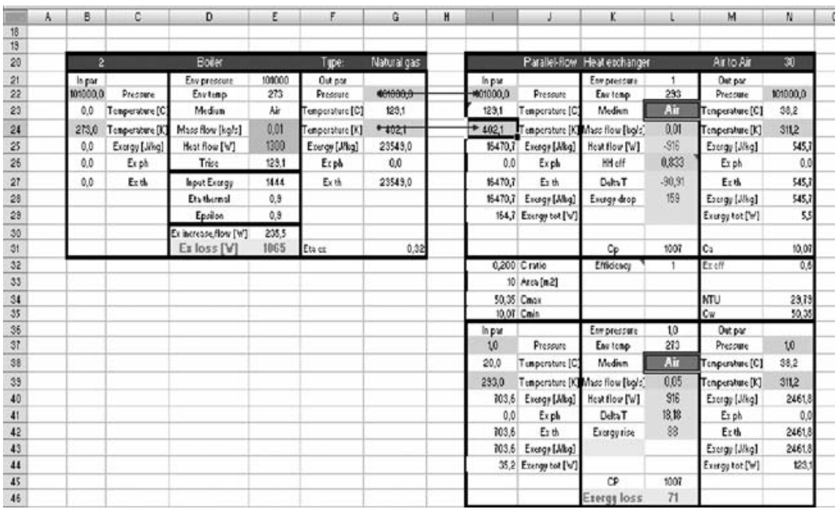

Figure 5: Example of a two-systems layout and connections

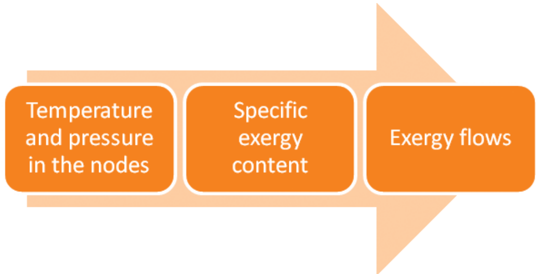

Figure 6: Exergy flows calculation steps

The ability to perform thorough and meaningful simulations relies also on the user ability to model the system and adapt the existing components for his own needs: a heat exchanger is for instance used to allow heat exchange from the primary to the secondary loop but it is effective also as a heat recovery system in the air, as well as a saturator can be used both for evaporative cooling and as a cooling tower.

Basically, all the systems share the same structure. Each model is divided into three areas: an input area on the right, an output area on the left and the central part. All the defining equations are included in this central area: they define the transfer function (how the values are processed from the input to the output value) of the model. The user is requested to insert sizing and characteristic parameters to define the model: for example, a heat exchanger is modeled by the type and the mass flow of the energy carriers in the first and the second loop (air or water), the exchange surface and the type of heat exchanger itself (i.e. parallel or counter flow).

The calculation of the exergy flows is performed by evaluating inlet and outlet pressures and temperatures in the nodes, given the reference temperature: by this, specific thermal and pressure exergy are calculated in two different ways according to whether the medium is water or air. The computation of the exergy flows and exergy losses is then made possible by multiplying them for the mass flow passing through the system (see Figure 6).

By means of this program wide possibilities of analysis and optimization are available: in the whole chain from generation to room system, through primary and secondary loops heat exchange, distribution and emission systems, exergy losses are found and therefore a better understanding of the weaknesses of the different systems is met.

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A CALCULATION TOOL FOR HUMAN-BODY EXERGY BALANCE

Toshiya Iwamatsu[3] and Hideo Asada[4]

Here in this article, we would like to introduce a calculation tool for exergy balance within human body. We have developed this calculation tool on a spreadsheet application software since 2007. The theory for Human-body Exergy Balance started in the mid of 1990s by Saito and Shukuya and then reached the present status in the mid of 2000s. The original version of this calculation tool was developed by them as a FORTRAN code. We converted this FORTRAN code to a Visual Basic version and added a Graphic User Interface for the spreadsheet application.

According to the research work on human-body exergy balance having been made in over the last ten years, for winter condition, a combination of higher mean radiant temperature and lower room air temperature provides the human body with the lowest exergy consumption rate. Such indoor thermal environment usually consistent with good level of thermal comfort according to architects and engineers. Quite recently, for summer conditions, it has also been found that a combination of mean radiant temperature and appreciable air current with a bit higher temperature and humidity provides the lowest exergy consumption rate within human body. Such indoor thermal environment may well be provided with a high-temperature radiative cooling systems combined with natural ventilation. These results suggest that the development of the low-exergy heating and cooling systems is on the right track. Studies should be continued to confirm further these findings both in vivo and in vitro situations and also to extend the investigation in relations to occupants' behavior and thermal cognition.

Figure 7 shows the appearance of the calculation tool, which is composed of two parts: upper one to fill in the input values and lower to display the results of the calculation. A gray button in between is for executing the calculation.

Inputs are metabolic energy generation rate, clothing insulation level, mean radiant temperature, surrounding air temperature, relative humidity, air velocity, and also outdoor air temperature and relative humidity.

The human-body exergy balance equation is derived by combining the energy and entropy balance equations together with the environmental temperature for exergy calculation, which is outdoor air temperature. In this calculation model, the human body is assumed to consist of two subsystems, the core and the shell, because the temperature of the former is stable due to its homeothermic mechanisum, but the temperature of the latter, the peripherial part

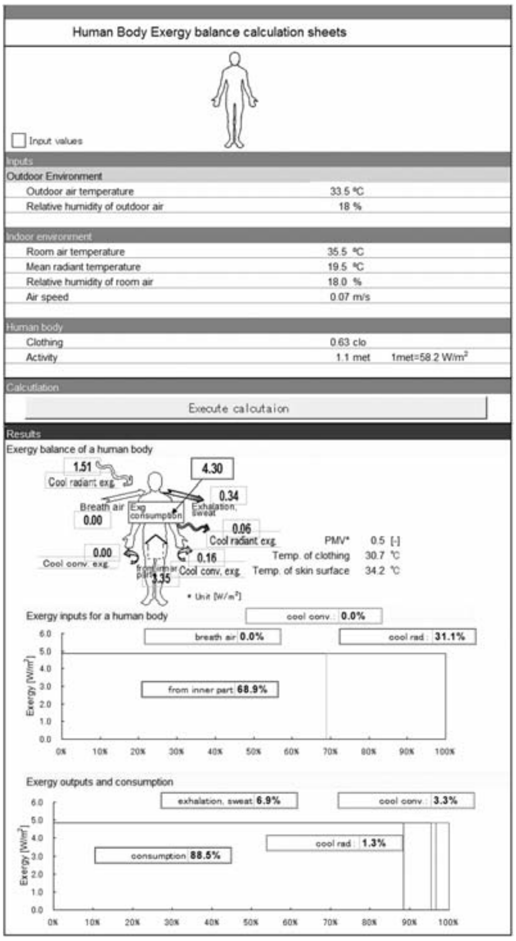

Figure 7: The Appearance of a Spreadsheet Tool for the Human-Body Exergy Balance Calculation

varies due well to the surrounding thermal conditions.The tool consists of two subprograms: one is to calculate the temperature of core, skin and clothing surface based on the two-node energy balance model the other using the core, skin and clothing temperature values to calculate input and output exergy fluxes together with the exergy-consumption rate within the human body.

As you fill in the eight input values and push the button, "Execute Calculation", then you will find immediately the results of the calculation. The quantities on the drawing of human body in Figure 7 are in coming and outgoing exergy fluxes and the exergy consumption rate. The twin-bar graph indicates the whole exergy balance. The upper bars shows all of exergy input rates and the lower bar the sum of the rates of exergy consumption, exergy stored and exergy output. The vertical axis attached to these two bars shows the value of exergy and the horizontal axis the percentage of each component of exergy rates.

This tool enables us to know the thermal exergetic condition of human body in relation to a given thermal indoor and outdoor environmental condition.

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CASCADIA TOOL

Ken Church[5]

As a means of improving the viability and sustainability of their communities, planners and developers are actively seeking approaches and techniques that minimise the environmental impact of their designs including the reduction in demand for fossil fuels. An approach able to provide the degree of scientific rigour necessary would distinguish between energy forms using the thermodynamic property, exergy. Therefore, to help decission makers on community level design, an excel based tool, called "Cascadia", has been developed.

The model implemented in this tool represents the building as a simple thermal load and emphasises more, the form of the energy supply and its distribution network. The model of the neighbourhood, shown in Figure 8, consists of a centralised energy plant supplying a district heating piping network. The district energy concept is utilised to take advantage of a variety of energy supplies of differing supply conditions. Heated loads consist of a typical neighbourhood and include high rise apartment buildings, low-rise or detached residential homes and a retail sector comprising strip malls or single storey retail buildings. Individual buildings are connected to the district energy system in a parallel configuration with the supply and return lines although the three categories of buildings – high rise, residential & retail, are connected sequentially.

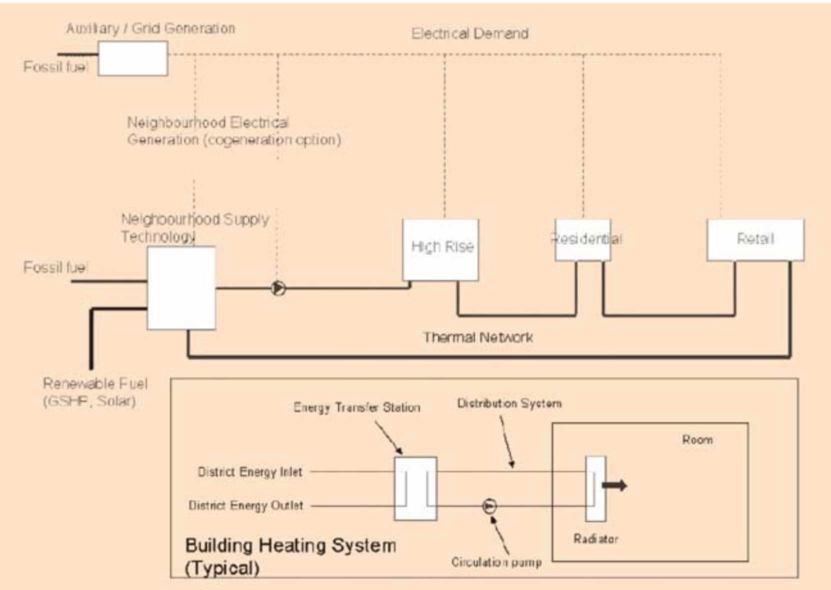

Figure 8: Scheme for neighbourhood design implemented in the Cascadia excel tool.

The model includes an allowance for both space heating and internal electrical loads. Building details provided to the model relate to the heat loss and ventilation requirements of the building and the electrical loads (pumps, fans, plug loads, etc associated with the building and distribution system.

Different building designs (high rise, residential, commercial) can be chosen. They are considered only representative for the purposes of this analysis and only serve to provide nominal thermal and electrical loads. Since exergy is independent of load, the load itself affects only the demand for primary energy and not the energy or exergy efficiency. The number of buildings in each category enables the temperature drop in the district energy system to be determined by balancing the water flow rate required.

For the evaluation process the district energy supply temperature is selected, based upon the capabilities of the supply technology. Five technologies were included within the model:

1. a medium efficiency gas fired boiler,
2. a high efficiency, condensing gas fired boiler,
3. a reciprocating gas fired engine based cogeneration system,
4. an electrically driven ground source heat pump
5. flat plate solar thermal collectors.

For options 1 to 3, the initial exergy level is related to the combustion temperature of the fuel. Electrical power where not provided by the neighbourhood system (i.e. in options 1, 2, 4 & 5) is assumed to originate from a utility owned gas fired simple cycle cogeneration system.

In the district energy loop, the supply temperature is considered to be 90°C for the first three options and reduced to 54°C for the heat pump and solar panel options. Heat distribution within the buildings can be either forced air or radiators where the radiator design is to DIN 255 standards for the supply temperature to maximise their efficiency of operation.

Keeping in mind the concerns relating to urban design and energy use and in particular the desire to reduce the need for fossil fuels as outlined earlier, the model can be used to examine the implications of different energy supply technologies, urban formats and heating techniques in terms of their overall energy and exergy usage.

The results of the analysis are presented in terms of the primary energy requirements i.e. the fossil based energy required for the creation of all thermal and electrical needs of the system. Since the intent of the tool is to demonstrate the impact of both technology and reduced demand for fossil fuel, information is provided on:

- energy efficiency of system – heating and electrical generation as a percentage of input primary energy – this illustrates the amount of energy usefully deployed as space heating or as available electricity
- exergy efficiency of heating system – heating and electrical generation exergy as a percentage of available exergy – illustrates the exergy consumed in

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space heating and generation of available electricity.

- exergy efficiency of overall system – the total exergy consumed in the process of space heating and power generation as a percentage of the overall exergy available – this illustrates the exergy lost on the delivery system.
- fossil fuel efficiency – heating and electrical generation energy as a percentage of fossil fuel energy input – illustrates the potential for reduction in fossil fuel.

Results are also displayed graphically in terms of the exergy flow through the district heating network and the temperature level in each use within the supply structure. In Figure 9 two examples of such graphs are shown for a supply with a condensing boiler (above) and solar flat plate collectors (below).

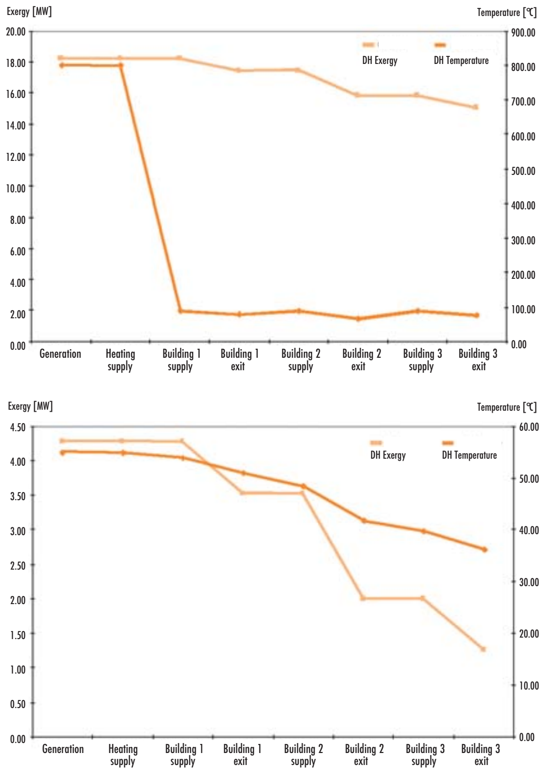

Figure 9: Graphs displaying the results of investigated options. Above: district heating network is supplied by means of a condensing boiler; below: network is supplied with flat plate solar collectors.

EXCEL PRE-DESIGN TOOL

Anika Knöll and Herena Torio[6]

The excel-based pre-desing tool aims at increasing the understanding of the exergy flows within the built environment and at facilitating further improvements on the energy use in this sector. It is a simple and transparent tool which brings the exergy approach in an easy to understand and comprehensible manner for its users, such as architects and construction engineers.

The concept and structure of the tool are based on the excel tool developed within the IEA ECBCS Annex 37 (it can be downloaded under www.lowex.org) and represents a further development of that tool. Main changes introduced in Annex 49 tool as compared to the base tool from Annex 37 are:

- Two different energy sources, or energy supply systems for DHW and space heating demands can be combined, e.g. solar thermal collectors and heat pumps, boilers, etc..
- Renewable energy flows are accounted for, both in energy and exergy terms, in the generation and primary energy transformation subsystems.
- Renewable and fossil energy and exergy flows are regarded separately, allowing good traceability of different energy sources on the energy supply chain.

The field of application is mainly focused on buildings with normal and low internal temperatures respectively, as e.g. residential buildings, daycare facilities for children and office buildings. From the user, a definition of the building details (e.g. building envelope, air tightness,…) is required. By means of several drop-down menus, different building systems can be chosen to supply the required building demands. This allows limiting the required number of input data. Energy calculations are based on the German energy saving Standard (EnEV-2006) and follow a steady-state approach. In Figure 10 a screenshot of the menu for required input data to define the building and the drop-down menus for selecting building services are shown.

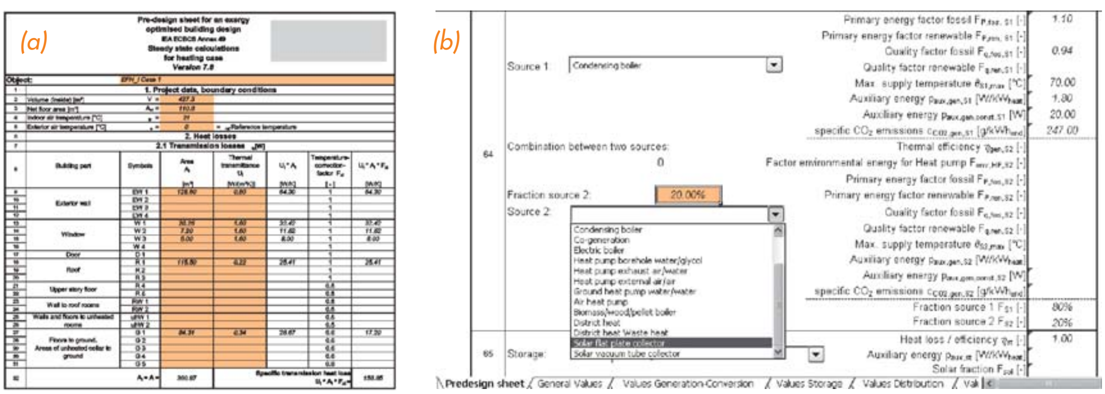

Figure 10: Fields for input data to define the building envelope in the pre-design excel tool (a) and drop-down menus for selecting building services (b).

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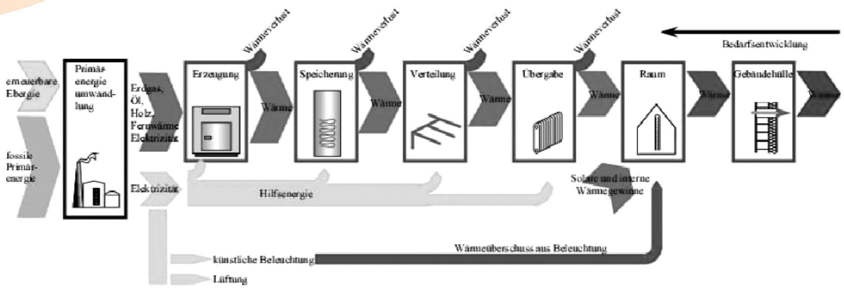

Figure 11: Energy supply chain.

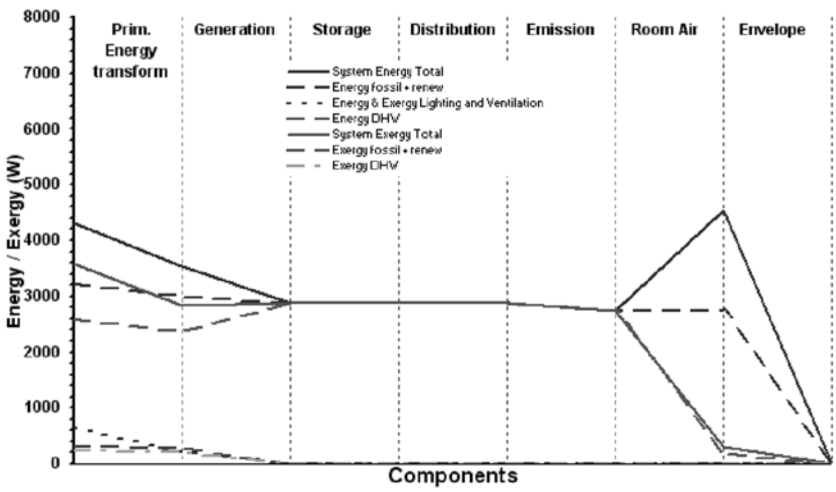

Figure 12: Exergy and energy flows in each subsystem of the energy supply chain

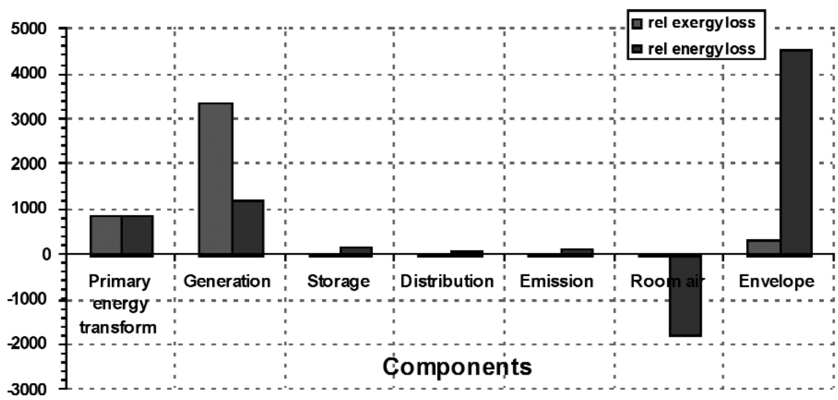

Figure 13: Exergy and energy losses in each subsystem of the energy supply chain

Based on the energy flows obtained, and depending on the temperature levels chosen for the building systems, an estimation of the exergy flows is carried out on a steady-state basis. The equations for each of the performed exergy calculations are directly shown in the calculation sheet. Furthermore, all required assumptions such as energy efficiencies and temperature levels regarded for the operation of the building systems are introduced in tables displayed in worksheets within the excel file and referred to in the calculations. The user can modify the default assumed values for these parameters, allowing him to adjust the parameters to his particular system. In addition, this allows transparency and intends to enhance understanding of the thermodynamic background and calculations within the tool.

In the energy and exergy analyses all steps of the energy chain – from the primary energy source to the building and the environment (i.e. the ambient climate) are considered, following the energy chain as shown in Figure 11.

The calculated energy and exergy flows are illustrated in two diagrams. Here, a separation occurs for the heating system and the DHW production. Therefore, an energy and exergy analysis for each specific energy demand is possible (see Figure 12).

Additionally, several parameters allow a direct and quantitative comparison between the performance of different building systems. The main parameters included for these use are:

- **Overall exergy efficiency:** indicates the efficiency of the total energy supply chain of the building.
- **Effort figures:** represent the amount of exergy losses arising in the supply chain.
- **Exergy expenditure figures:** they provide an idea of the "matching" between the quality levels of the energy demanded and supplied.

In Figure 13 all energy and exergy losses are shown separately for each subsystem. Negative values of the energy and exergy losses in a component indicate gains in this component, e.g. solar gains. Since all energy flows are regarded in the balance (i.e. fossil and renewable), the only system where energy and exergy gains are possible is the building envelope. Here, energy gains through the building envelope are regarded and contribute to compensate the total transmission and ventilation losses.

Annex 49

Low Exergy Systems for High-Performance
Buildings and Communities

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ECBCS ANNEX 49

Annex 49 is a task-shared international research project initiated within the framework of the International Energy Agency (IEA) programme on Energy Conservation in Buildings and Community Systems (ECBCS).

Annex 49 is a three year project starting in November 2006, following a preparation phase of one year. About 12 countries are currently participating.

For up-to-date date information see:

www.annex49.com

International Energy Agency
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