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INTEGRATION OF BUILDING AND SOLAR ENERGY SYSTEMS INTO ONE PREDESIGN TOOL

Heidrun Faninger-Lund

SOLPROS
Oltermannintie 13 A 4
FIN-00620 Helsinki, Finland
Telefax: ++358-9-777 49 58
E-mail: solpros@kolumbus.fi

Peter Lund

Helsinki University of Technology
FIN-02150 Espoo, Finland
Telefax: ++358-9-451 3195
E-mail:peter.lund@hut.fi

ABSTRACT. The outline of the energy concepts is often made and even fixed in the early design phase of the building project. The resources for doing sophisticated analysis of the different options and comparing different technologies and strategies are often very limited.

The objective of this work has been to develop an integrated predesign tool that includes the relevant technologies for building energy systems in one tool. Also, the intention has been to keep the tool easy to use, fast and user-friendly but also accurate.

The integration approach developed here is implemented in the ALLSOL© all-in-one-tool. The program includes at present a large range of technologies. The program is able to make a energy, environmental and economic analysis of the user defined building and energy system. In addition, the program can be used for dynamic building analysis.

1. INTRODUCTION

The best opportunities for energy savings exist in general in the early design phase of a building project. It is often at this stage when the fundamental decisions are made about the building energy concept, energy strategies and building components. Unfortunately, most of the available design tools are applicable only in later phases because they require more detailed input which are mostly unavailable in the first design phases. The first schematic and conceptual design is always the starting point for generating effective concepts for building energy systems.

Advanced components, new materials, advanced technologies and innovative architectural design concepts are available today and have opened a quite new area in the energy conscious building design. Together these have the potential of reducing significantly the energy needs of buildings but at the same time maintaining, or even improving the living conditions and occupant comfort. It is important that these innovative approaches are handled properly in the pre-design phases.

In addition to building or architectural components, there exists a range of energy technologies that could be incorporated into a building, e.g. solar thermal, wind and photovoltaics, heat recovery and heat pumps, control and different operating strategies, etc. All these measures influence significantly the building energy performance and should be included in the predesign tools. Seldom all these components are found in one tool as such and several tools are needed to cover the range of options interesting for a designer. Designing with several tools at the same time may cause problems with interfacing but also is a cost issue.

When dealing with building energy performance it is most useful to be able to break down the total building energy use into its end-use loads, i.e. heating, cooling, lighting, domestic hot water, and other. These broad categories are relatively easy to assess but they need to be broken further down to be able to incorporate innovative and dynamic features. Thus, for example the heating load is composed of infiltration, ventilation, conduction, radiation, solar and internal gains.

The main philosophy behind ALLSOL© has been to incorporate all above mentioned features into one design tool to be used in the energy-wise important early design phases of building energy systems and building energy performance. Also, in order to enable dissemination of innovative and advanced energy designs and technologies in general important for our mission, we have striven for a tool that could be widely applicable and accepted.

The objectives set for the development of ALLSOL© are shown in Table 1.

Table 1. Requirements for an integrated predesign tool

REQUIREMENT	**SOLUTION**
all-in-one tool	comprehensive range of components, energy, environment, comfort, cost
accurate modeling	energy balance equations for each component, hour-by-hour simulations, verified
user friendly and low cost	Windows interface and self-documented, low price
easy and fast to operate	minimized input needs, macro-inputs fast numerical solution algorithms

In addition to predesign needs, the integration approach may also be used for much more sophisticated tasks such as advanced modeling of building multi-energy systems, optimization of multifunctional energy facades or trade-off analysis of different energy technologies

2. INTEGRATION APPROACH

The integration approach is illustrated in Figure 1. The building itself forms the central component around which different technologies or strategies can be built. For decision-making purposes, energy/environmental/economic impacts need to be assessed and then incorporated to the general requirements of a building project.

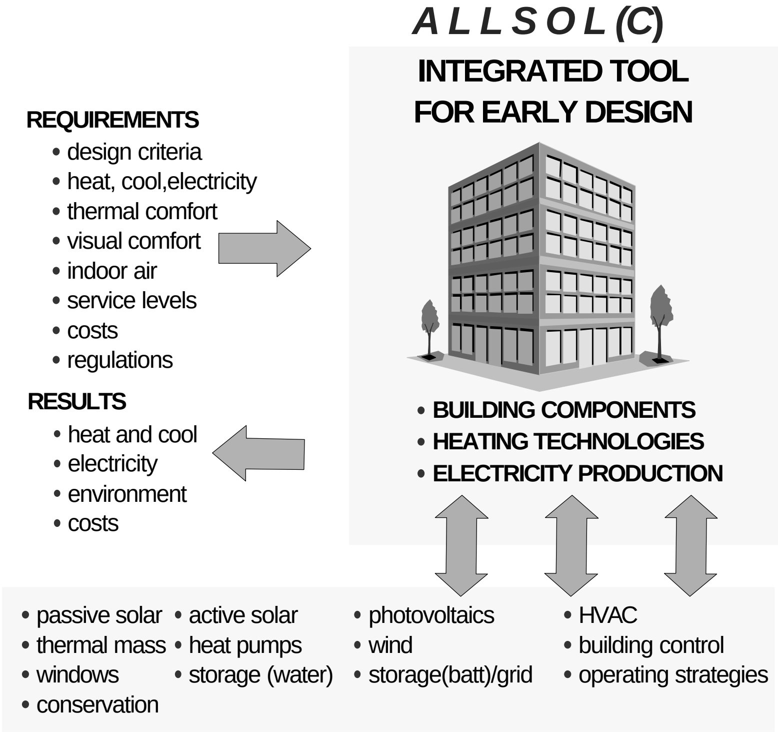

Figure 1. Integration approach for the early building energy design tool ALLSOL©

3. MODELLING APPROACH

The basic mathematical approach used in ALLSOL© is an hourly energy balance simulation of the building in order to be able to track the dynamical behavior of the components important for accuracy of the energy calculations.

The central component from the modeling point of view is the building itself which need to be handled correctly in order to be able to determine accurately the energy or energy service needs. The basis for calculating the energy flows starts from determining the indoor and wall temperature:

$$c_i \frac{dT_i}{dt} = e \times Q_{dirgain} + Q_{intgains} - Q_{infiltration} - Q_{vent} - Q_{air \leftrightarrow wall}$$

$$c_m \frac{dT_m}{dt} = (1 - e) \times Q_{dirgain} + Q_{air \leftrightarrow wall} - Q_{conduction} + Q_{passive}$$

where subscript i refers to indoor air and m to building mass (walls, roof, floor). The energy flows are denoted by Q and for each of these a separate physical equation can be written. For each energy flow component Q, a more sophisticated model is available. If the building structure is massive then a also the lateral heat transfer need to be considered, i.e. instead of $T_m(t)$ use $T_m(z,t)$.

In ALLSOL©, the heat transfer and the effects of the building thermal mass are presented as numerical model and are thus accurately presented. For example for a sunspace shown below, we have the following set of difference which describe accurately the heat transfer process:

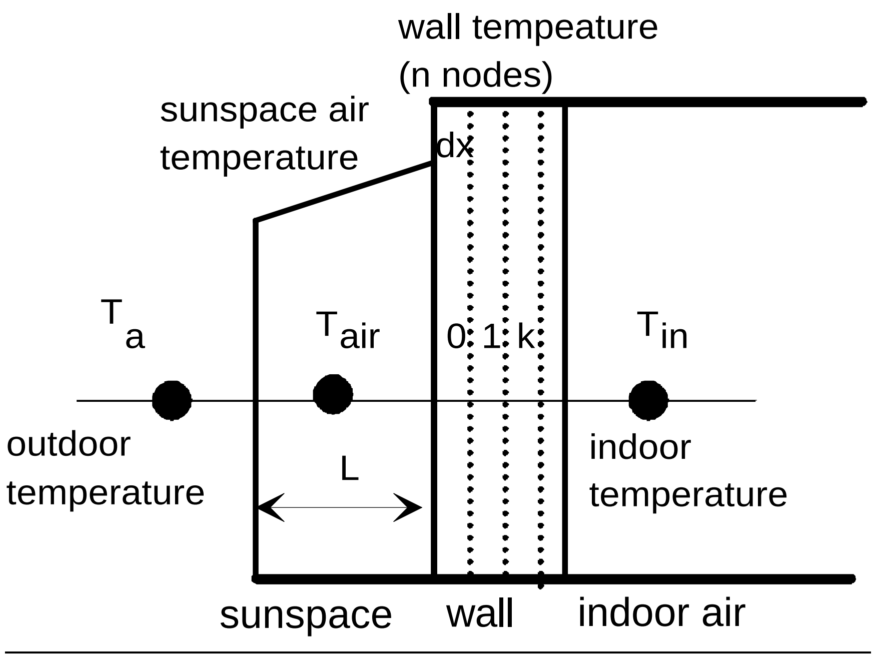

Figure 2. Example of physical model used in ALLSOL©.

$$T'^{t+dt}_0 = T^t_0 + 2\frac{dt}{(rc)_{wall}\,dx}$$

$$\times\left[(1-a)\times Q^t_{sol} - h_s(T^t_0 - T^t_{air}) - \frac{l_{wall}}{dx}(T^t_0 - T^t_1)\right]$$

$$T^{t+dt}_{air} = T^t_{air} + \frac{dt}{(rc)_{air}\,L}$$

$$\times\left[h_a(T^t_a - T^t_{air}) + h_s(T^t_0 - T^t_{air}) + a\times Q^t_{sol} - Q^t_{vent}\right]$$

$$T^{t+dt}_k = T^t_k + \left(\frac{l}{rc}\right)_{wall}\times\frac{dt}{(dx)^2}\times\left[T^t_{k+1} - 2T^t_k + T^t_{k-1}\right]$$

In addition, to have mathematically sound solutions, an aspect often overseen, the stability criteria need to be checked for choosing dx and dt. A varying time step dt is used here to minimize the run time.

In practice, the user of ALLSOL© does not need to specify any of the numerical parameters as these are optimized by the program itself, and the only input for a sunspace would include its solar gain factor, area, width as well as the thickness of the wall and possible insulation.

ALLSOL© calculates heating, cooling, electricity, daylight/lighting components, employs most technology options available, as well as building controls.

4. PROGRAM STRUCTURE

The structure of ALLSOL© is illustrated in Figure 3 that shows the menu interface.

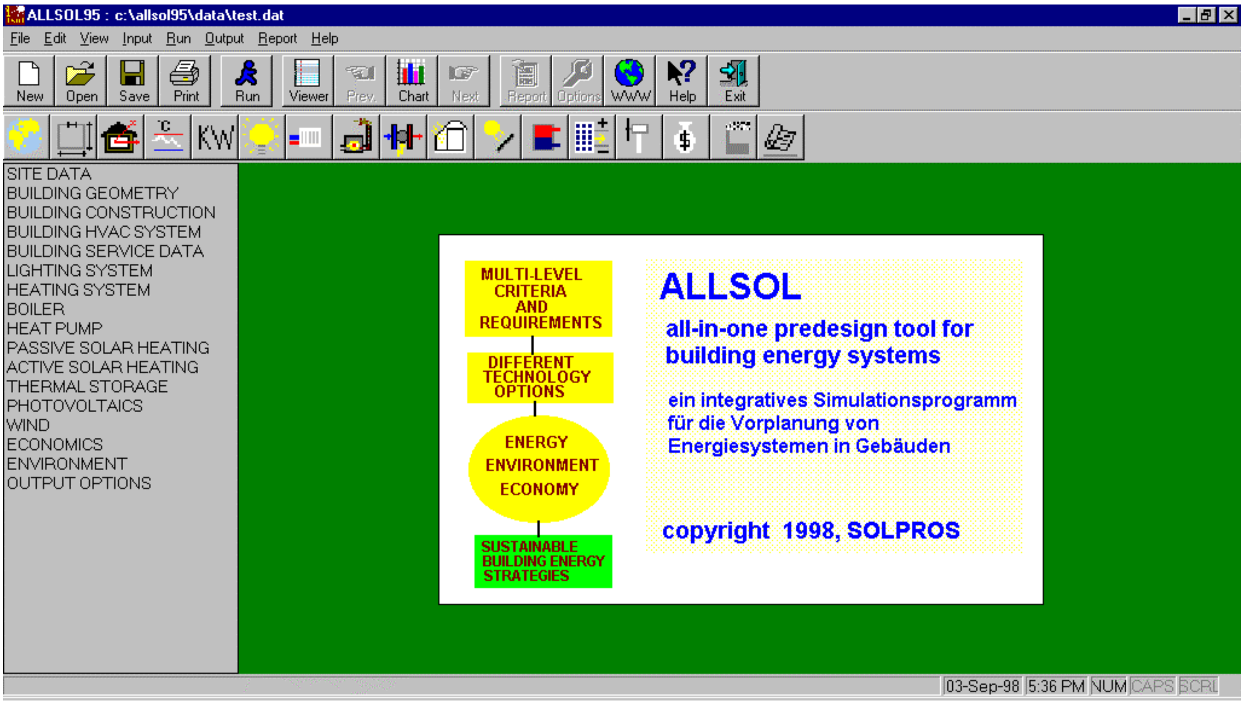

Figure 3. Program structure of ALLSOL©

Through novel numerical algorithms, the run times for a typical year are kept very short or 10-30 seconds per case depending on the complexity of the system configuration. Most of the input is in the form of high level macros whereas the physical parameters of less importance at a predesign stage are embedded into the program algorithms. Through this kind of “macronization” approach the number of input parameters to be specified by the user is considerably reduced and consequently the tool is easy to use and learn.

ALLSOL© offers a versatile range of output results for the designer:

MAIN PERFORMANCE INDICATORS

- system energy performance (yearly energy balance)
- environmental impact (LCA CO_2,SO_2,energy)
- economics (system cost, LCA cost of energy)

BUILDING/SYSTEM PERFORMANCE

- system energy balance (monthly)
- building thermal balance (monthly)
- electricity balance (monthly)
- summer and winter design days (hourly)

SYSTEM DYNAMICS

- on-line graphics module ; hourly or daily performance (T, energy, power)

5. EXAMPLE OF A PREDESIGN CASE WITH ALLSOL©

As an example of the use of an integrated tool, we show a simple case for reducing the energy and environmental impact of a single-family house. The options are:

REFERENCE HOUSE:

-120 m^2 single family house in Central Europe (Vienna)

-wall 0.3 W/m^2K, window 2 W/m^2K, HW 180 l/d, appliances 3 MWh/yr + lighting

LOW ENERGY HOUSE:

-wall 0.2 W/m^2K, window 1.2 W/m^2K, HW 180 l/d, appliances 2.5 MWh/yr +energy efficient lighting

FUTURE HOUSE:

-wall 0.15 W/m^2K, window 0.9 W/m^2K, HW 120 l/d, appliances 2 MWh/yr + energy efficient lighting + daylight, solar $10m^2/1m^3$, PV 2 kW_p

The output and analysis results of ALLSOL© are shown in Figure 4. The case "future house" shows a life-cycle CO_2 and energy reduction of over 70% over an average house. The technologies for such house are already today available.

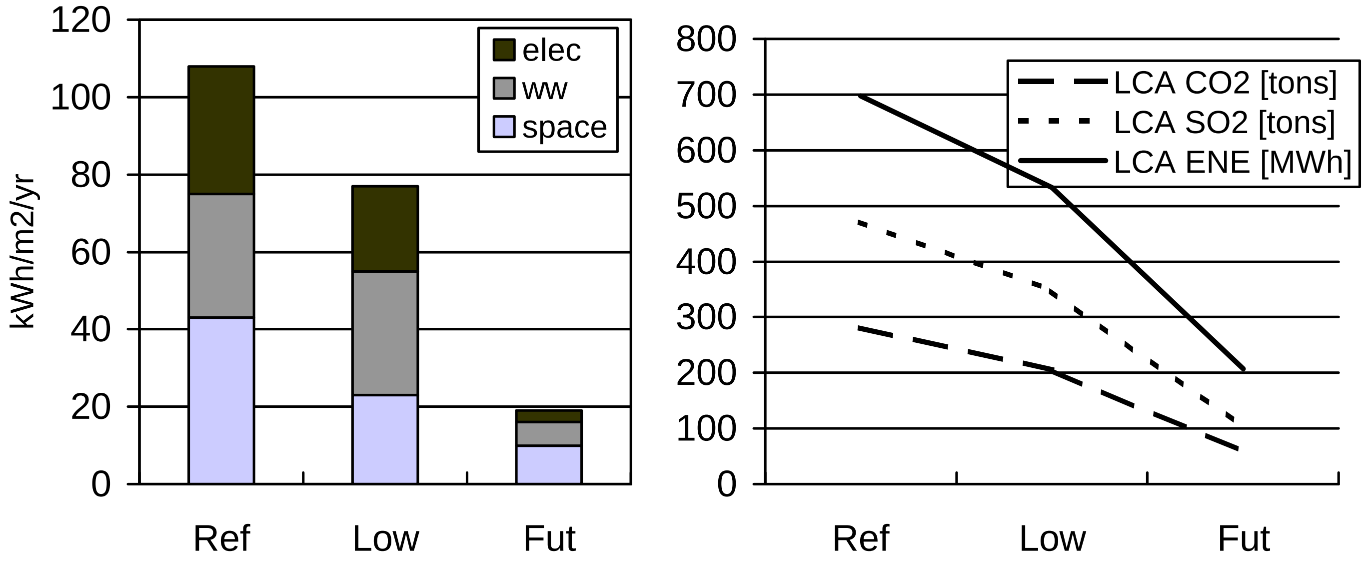

Figure 4. Energy and environmental impact of the different house types.