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ATRIUM BUILDINGS ENVIRONMENTAL DESIGN AND ENERGY USE

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ABSTRACT

This paper describes a computer-based energy information system for atrium design. It is built on the principle that designers need information and knowledge to make good design but that they themselves make the final decisions. The system advises the user but does not make any decisions. It is there to bridge the gap between the user and the numerical simulation model and to provide information. The development of the system is a part of the Norwegian contribution to an IEA project on "Passive and Hybrid Solar Commercial Buildings." The results of the project will be presented as design guidelines in book form and in a computer-based information system called ISOLDE (Mørch 1990; Mørch et al. 1991). The computer system contains several knowledge bases and simulation/calculation facilities. ISOLDE runs on a microcomputer. Expert system and interactive video techniques are used to develop the system.

The atrium section of the system has three parts or levels. The first level is called "General Advice" and contains a rule-based evaluation of different building typologies and solar systems. The second level, "Case-Oriented Analysis-Calculation," considers factors such as climate and building use, shape, and orientation. The third level, called "Case-Oriented Analysis-Simulation," consists of a simulation tool, simulation strategy evaluation, and design strategy evaluation. Above these three levels is a summary facility that keeps track of several cases, makes comparisons between cases, and prepares reports.

An architect using the atrium section for planning a building in Oslo is described in a scenario. The scenario shows the use of all the sections and provides examples of information given by the system. The structure and the calculation tools of the "Case-Oriented Analysis-Calculation" are described, going into detail with the heating section. Examples are given of rules for evaluating energy principles (e.g., heat conservation, solar collection) and information from the system when suggesting principles for the atrium.

To match the system model of the task to that of the user, the system provides visual, textual, and numerical information about passive solar design and the methods applied in the system.

INTRODUCTION

Knowledge Sources

The development of this system is part of the Norwegian contribution to the IEA Task XI project, "Passive and Hybrid Solar Commercial Buildings." The IEA project is subdivided into heating, cooling, daylighting, and atrium working groups. Each group has worked on three subprojects: case studies, simulation models, and design guidelines. The case studies are classified into advanced and basic cases, each of which is presented in a report that contains a collection of reports and slides. The design guidelines are reported in the source book that will be the main shared output from the task. Some of these results are also presented with other design knowledge and simulation facilities in an information system called ISOLDE. The information system contains numerous knowledge bases, calculation and simulation facilities, and a collection of video pictures and information about the case studies. The information in the atrium section of ISOLDE is derived from the IEA Task XI atrium working group and from the design guidelines by AIA (1980), Balcomb et al. (1984), and Minne (1988). The system as a whole is described by Mørch (1990) and Mørch et al. (1991).

Information or Expert System

The development of this system was inspired by the theory of human-centered system design described by Marmolin (1989). This design method is based on belief in human possibilities rather than limitations. It suggests the development of systems that make use of human strength in managing complex situations. The theory is founded on modern research in psychology and behavioral science.

Traditionally in engineering a human is considered an incomplete component. We have tried to make systems that reduce the role of humans and attempted to compensate for human limitations. The theory of human-centered system

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design leads to systems that are different from traditional ones. The view of humans in human/computer interaction can be summed up as follows (from Marmolin): "The human is target oriented, exploring, emotional, social and unique."

Human-centered systems try to take advantage of these characteristics. It may be hard and expensive to fulfill all the requirements made by these characteristics.

In the development of the information system for atrium design, focus has been placed on the potential of the exploring and target-oriented human. The user defines the target himself/herself and the system suggests solutions, but the user is always free to choose/do what he/she wants. This is the opposite of systems that have fixed targets, that automatically generate optimum solutions and limit the user to choose among these. In these systems, the user has to spend a lot of time dealing with constraints, factors that may not even be clear to him/herself. If the constraints are poorly defined, these systems will generate many solutions that are unrealistic.

A designer normally has a clear conceptual idea about the building and its systems. This conceptual idea is closely related to real physical objects and processes and is based on the designer's knowledge and experience. In other words, a designer knows that increasing the floor insulation will increase the floor temperature, reduce the energy consumption, cost more, and so on. Most designers expect the design tools to model all phenomena properly. They also expect a direct link between the objects that cause the phenomena and the observed phenomena.

The simulation tools consist of algorithmic models of the real world. These models are always to some extent simplified. The reasons for simplification vary, but often it is because of the lack of accuracy in input data and the need for quick results. When a physical model is simplified, sometimes the direct link between the cause and the result disappears. The simplification of the infiltration model shown in Figure 1 is an example of this. This will confuse the user if he/she is not aware of it. It is also necessary to be aware of this difference between the model and the real world to interpret the results and suggestions of the system.

Human computer interaction literature (Norman and Draper 1986) describes this discrepancy between the user and the system as a gulf that must be bridged: "In the ideal case, no psychological effort is required to bridge the gulfs. But such a situation occurs only with either simple situations or with experienced users. With complex tasks or with nonexpert users, the user must engage in a planning process to go from intentions to action sequence. This planning process, oftentimes involving active problem solving, is aided when the person has a good conceptual understanding of the physical system. The problem is to design the system so that, first, it follows a consistent, coherent conceptualization—a design model—and, second, so that the user can develop a mental model of that system —a user model—consistent with the design model." (In this context, a physical system is a physical computer system.) These ideas are used as a basis for our information system. The system explains both the fundamentals of the physical phenomena involved in the system and the models that are used for the phenomena. Figure 2 shows how these ideas are applied in the system. The system should also explain where and why the input data are used.

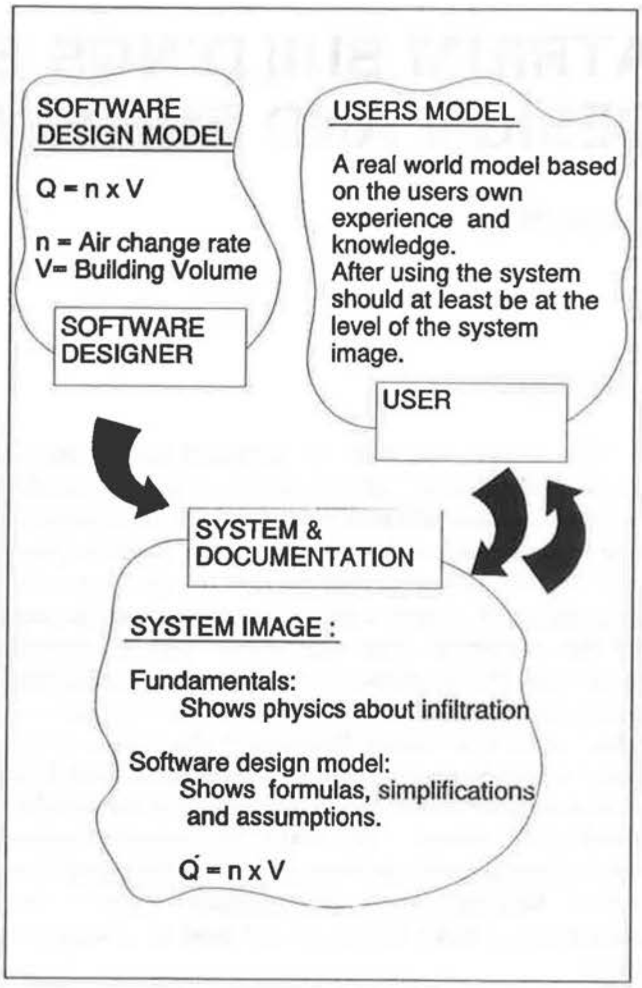

Figure 1 *Conceptual models and system image for air infiltration. (This figure is based on the figure in Norman and Draper [1986], p. 46.)*

As indicated, this system is characterized by a philosophy that the user should make all the decisions and choices, while the system provides suggestions for good solutions and informative presentations of results, suggestions, and knowledge. In these terms, it is an information system rather than an expert system.

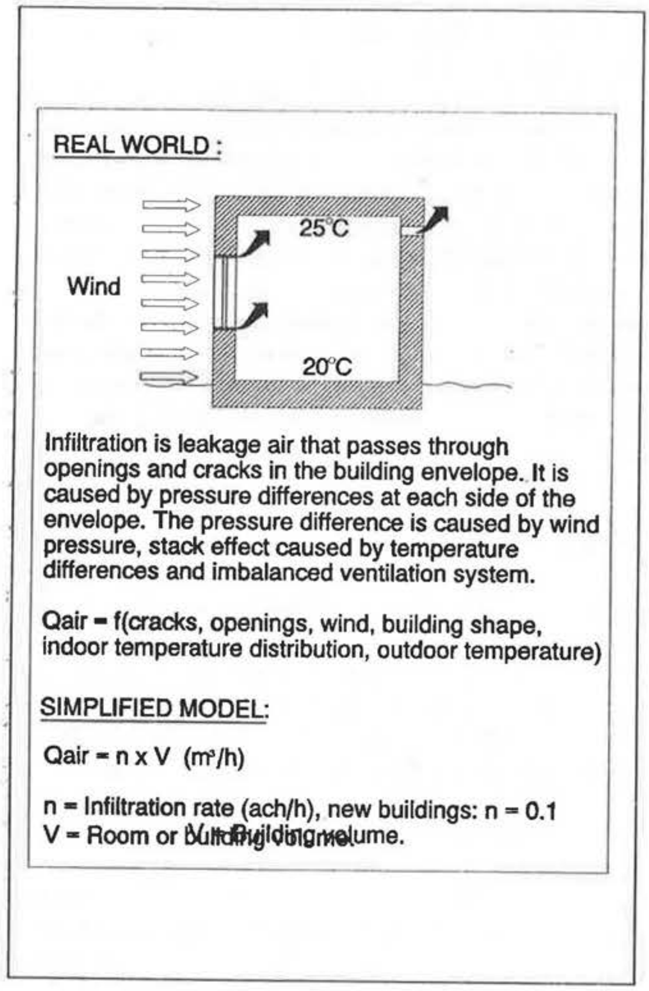

Figure 2 *Information to bridge the gap between the user's conceptual model of air infiltration and the model in the system.*

SYSTEM STRUCTURE

The knowledge base stems from design principles and typologies developed by architects. It has three levels for working, where a single case is initially studied, roughly leading to the second and third levels of detailed design. The system structure is shown in Figure 3. The first level is called "General Advice" and contains a rule-based evaluation of different building typologies and solar energy systems. The second level, called "Case-Oriented Analysis," considers such factors as climate and building use, shape, and orientation. This level has a design strategy evaluation based on data from a simple calculation, and it also provides data for a simulation strategy evaluation. The third level, called "Simulation," consists of a simulation tool, simulation strategy evaluation, and design strategy evaluation based on the simulation results. Above these three levels there is a summary facility that keeps track of several cases, makes comparisons between cases, and prepares reports.

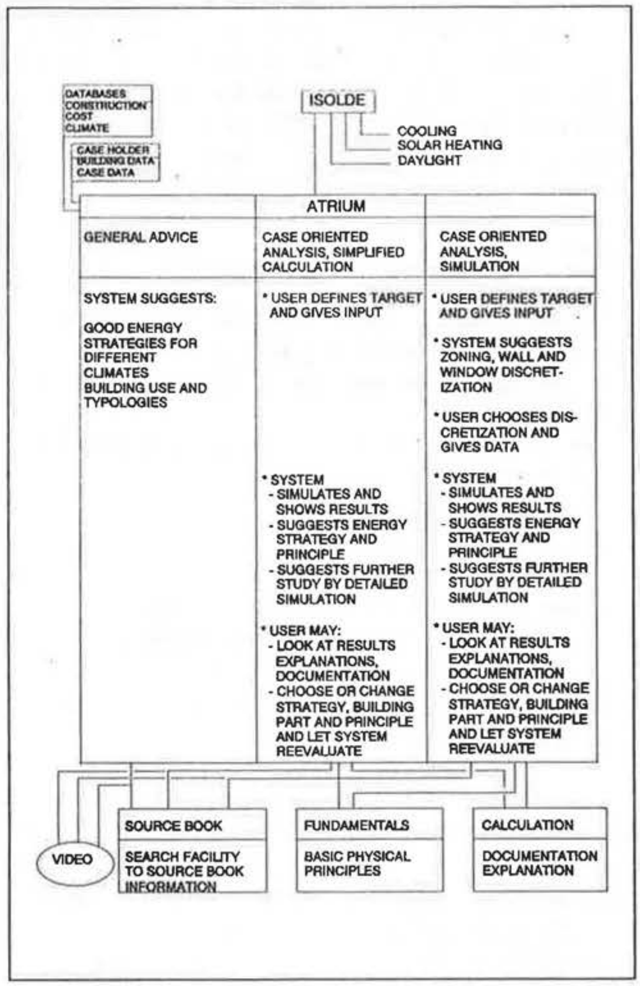

Figure 3 *ISOLDE atrium section, system structure.*

The intended users of the system are students and architects who are not experts. The objective is to provide an interactive tool that can be used for education and training. The system can also be used to generate ideas during the early design phases.

SCENARIO

The architect in this scenario plans a day care center in Oslo. She wants to design the building for the passive use of solar energy and uses a design tool called Atrium-Isolde (here called Atrium for short) for the passive solar design of atrium buildings. Atrium, a computerized system, has three parts, "General Advice," "Case-Oriented Analysis—Calculation," and "Case-Oriented Analysis—Simulation."

Studying Examples and Learning Design Rules

As a novice in passive solar design, she starts using the "General Advice" (GA). In the "Source Book" section, she looks through the design principles and recommendations and studies some videos of monitored and simulated projects. Once sufficient basic knowledge of the topic is gained, she turns to the "Advice" section, still in

GA. "Advice" queries her about the ambient climate, indoor temperature in the atrium, and building typologies.

She chooses the ambient climate for Oslo. The system characterizes the climate (AIA 1980) and suggests energy strategies, a facade solution, and ventilation principles for this climate.

Heating Strategy:

- Let the sunlight through in the winter: Vertical south-, southeast-, southwest-facing glazing.
- Avoid infiltration and use a heat exchanger for ventilation.
- The atrium may be used as an air preheater if the atrium is energy positive.

Cooling Strategy:

- Protect the house from summer sunshine: Movable shading, shading by trees, vertical overhangs.
- Allow natural ventilation in the summer.
- If the outside air is cold, the atrium may be used to preheat ambient air.

She chooses a building typology, "Integrated," and a minimum indoor temperature of 10°C for the atrium. The system responds with possibilities and limitations for heating strategy, facade, and ventilation. It also evaluates the combination of climate, building typology, and indoor climate together. The system evaluates the combination as quite good but suggests that a lower minimum atrium temperature will reduce energy consumption.

She wants to study the "Integrated" building type further and searches the word *integrated* through the source book and studies the video with examples of this building type. She then moves to the part called "Case-Oriented Analysis-Calculation" (CA-calc).

Energy Analysis

The scenario continues with the same data as before. The system asks her to define the target of the analysis in addition to climatic requirements. The targets are defined for energy, power, and lifetime cost. The target is low energy (which means < 80 kWh/m^2 floor area for heating in this climate) and no cooling energy for both the atrium and the adjacent space. All appliances are low-energy types and are set to a minimum. The architect starts studying the atrium part of the building. The system queries her about the thermal data for the walls and windows enclosing the atrium and the infiltration and ventilation systems connected to the atrium.

The monthly average, minimum winter, and maximum summer atrium temperatures are calculated. This average is too low and the maximum summer temperature is too high. The system then makes suggestions about improvements without the use of heating.

The energy balance of the atrium glazing is calculated to investigate whether the atrium works predominantly as a solar collector or buffer. The architect has chosen single glazing, and the energy balance is calculated to be positive. The atrium works as a buffer. Since the atrium is heated to 10°C, the regulation restrictions are also checked. The loss is within the regulation restrictions, but since the glazing is "energy negative" and the heating demand is greater than the target, the architect is advised to choose glazing with less loss or to reduce the area. She tries with two layers and gets better results. However, before making the final decision, the whole building has to be studied.

Similar data are given for the rest of the building, along with data on internal gain distribution, and on how freely heat will move inside the building (depth of building, separating walls). The energy flows and energy consumption for heating are calculated. U-values for the windows and the walls are evaluated according to the regulations. Energy and cost gradients are calculated for atrium glazing area and U-value, intermediate area, atrium temperature, and other ventilation system solutions. Based on these data, the system suggests solutions and points out areas of conflict. She may ask why questions are posed and choose or skip the suggestions. In this case, the system suggests energy conservation techniques and solar control. Changing the atrium to a solar collector is not suggested since the building only has a heating demand from mid-October to February. The architect tries better U-values and reaches a solution that is satisfying. The system gives a report on the uncertainty of the results based on the uncertainty in input. Precalculations indicate that further zoning is necessary, the solar radiation should be more correctly modeled, and the local climate behind and in the atrium should be studied in more detail. The system suggests further studies by a more detailed simulation program. CA-calc also prepares data to help the architect formulate the problems into the simulation model.

The architect works out four alternatives. All the data are stored in the "Case Holder," which contains

- building model data,
- selected information from the source book,
- advice from GA, CA-calc, and CA-sim, and
- simulation and calculation model data and results.

The architect then uses different predefined views to compare the alternatives. Some of the reports are connected to the building and some to the analyses that were performed. The reports for a whole year's simulation are energy demand, cost, power, temperature statistics, and comfort. She then prints out the building model, energy, and cost report as a basis for discussions with the client.

Summer Conditions

The client decides upon one of the alternatives but asks the architect to make a detailed study of summer conditions in the atrium and the area behind the atrium.

For the detailed study of the atrium and the office behind the atrium, she uses CA-sim. She retrieves the actual case and indicates that she wants to do a part study of the building. The system suggests the following alternatives: reduce the amount of load from equipment, run the ventilation system at night with outdoor air, make natural ventilation possible. The architect reaches a solution with increased thermal mass in this area and a double ventilation rate at night, while the north facade has no ventilation. In the atrium, internal shading and natural ventilation are necessary to avoid overheating.

CASE-ORIENTED ANALYSIS—CALCULATION

The case-oriented analysis consists of four main sections: input, calculations, design strategy evaluation, and design principles evaluation. The sections may be visited separately and independently, but some sections are dependent on results from other sections (see Figure 4). There is also direct access to the video section. Much of the knowledge in this section is dependent on the climate. Rules are only implemented for a cold climate such as Norway's.

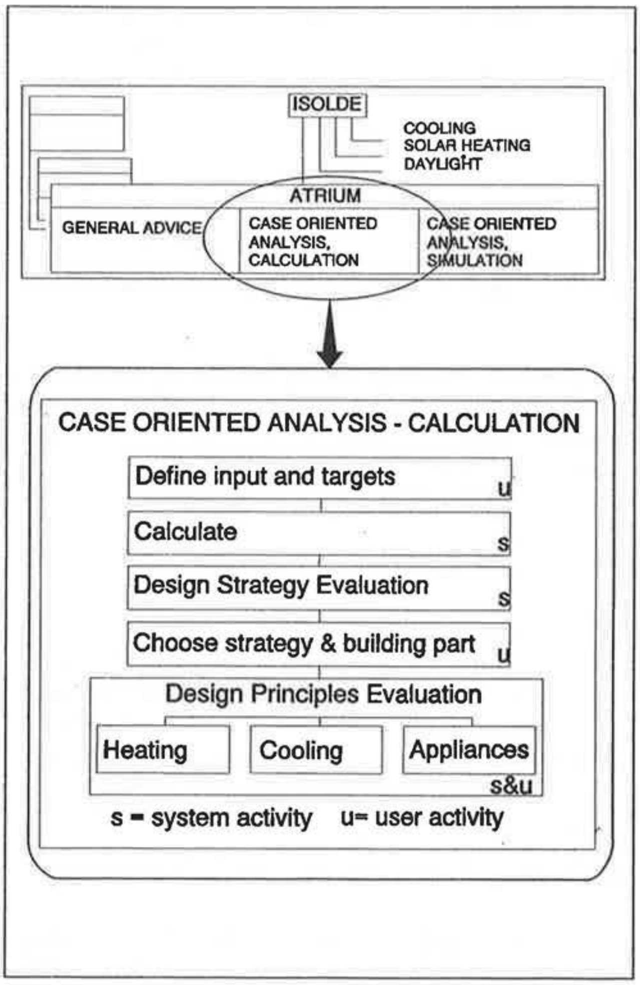

Figure 4 *Case-oriented analysis—calculation, system structure.*

Input

In this section, data are given for the building, its plants, equipment and use, and energy targets. It is an ASCII interface with pop-up menu, and graphics are used to provide information for the user.

The menu is structured by grouping data that are logically related. All data connected to the building's construction are given under "building description." Pure geometrical data are given separately for consistency and to ease future connection to CAD programs. Other menu options are connected to modeled physical phenomena such as transmission, infiltration, and solar radiation. Help is provided by giving information about the fundamentals of the phenomena, how the phenomena are modeled, and tool(s) and data required. Help with data is also provided by a library of various constructions and window types.

Calculation

Calculation means a numeric analysis with average values for a month or 24-hour period. These are simplified methods that were previously performed manually. They normally require few data and give quick results. Because of their simplicity, they are also limited and are only intended for use in early design. Since they are based on monthly averages, they cover only the simplest principles. If the required principles are not handled in the calculation methods, a more detailed simulation tool must be used.

The heating and cooling calculations are performed for a two-zone building. The two zones may have four facades (a facade is one or several walls and windows with the same orientation), each with an intermediate facade. The main zone is expected to have stable temperatures, while the atrium temperatures are expected to fluctuate. The atrium conditions are always studied initially, the main temperatures considered stable at setpoint. When calculating for the main building, the calculated atrium temperatures are used.

The energy consumption for heating is based on Norwegian Standard NS3031, described by the Norwegian Council for Building Standardization (1986), which, in turn, is based on ISO 9164, "Thermal Insulation Calculation of Space Heating Requirements for Residential Buildings."

Børesen (1979) describes a manual method for calculating average, maximum, and minimum temperatures in a 24-hour period and the cooling power. The method is widely used by practitioners in the early design phase and does not cover the calculation of cooling energy consumption. According to ASHRAE (1989), the cooling degree-day energy calculation is similar to the heating degree-day calculation if no ventilative cooling is considered. Instead of using the heating setpoint temperature, the cooling setpoint is used. If ventilative cooling is considered, the latent heat gain must be added to the sensible heat gain. A similar method will be applied here. The cooling energy required to reduce the monthly average temperature to what is demanded will be calculated. This is a very rough estimate and should not be used for detailed design.

Design Strategy Evaluation

The design strategies are heating, cooling, and appliances. Their priority in the design process depends on the description from the energy target.

Energy Target The target is defined for energy and power at various levels of detail:

Alternative 1: Total for the whole building
Alternative 2: Separate for heating, cooling, and appliances for the whole building
Alternative 3: Total for atrium and main building
Alternative 4: Separate for heating, cooling, and appliances for atrium and main building

If the target is specified to have less detail than alternative 4, the system will generate a suggestion at the level of alternative 4. The user is helped by a figure that shows a classification of high, medium, and low targets. The chosen values are shown in the graph. This classification is dependent on the building type and climate.

Strategy Evaluation The design strategy evaluation is based on the results from the calculation of energy consumption for heating, cooling, and appliances and the energy target. It will suggest starting by improving the part of the building with the highest deviation from the energy target. The strategies will be suggested in the following order *if there is a deviation* from the target: (1) appliances, (2) cooling, (3) heating.

Appliances are suggested initially since they will reduce any cooling load and increase heating deviation. Cooling is proposed next, since the gains should be under control before looking at the heating strategy.

Design Principles Evaluation

In the design principles section, one goes into a part of the building to work with the principles of a strategy. The heating and cooling sections are analogous in their classification of principles into losses, gains, and requirements. The appliances section is classified by type of appliance and contains principles to reduce load. Only the heating section will be described here. The heating principles are evaluated when heating is chosen as a strategy and the part of the building is defined. Figure 5 shows an information diagram for CA_{calc} with the heating strategy.

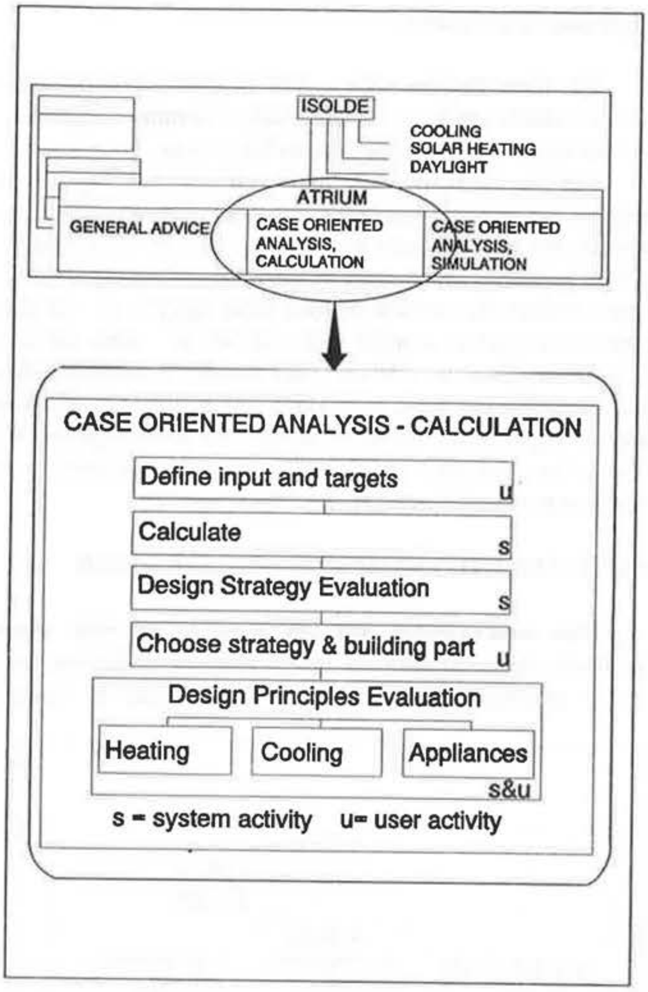

Figure 5 Design principles evaluation, heating section.

Heating Principles	Intention
Heat conservation	Reduce losses
Solar collection	Increase use of free gain
Heat distribution	Increase use of free gain
Heat storage	Increase use of free gain
Heating atrium*	Increase use of free gain
Buffer atrium*	Reduce losses
Reduce requirements	Reduce demand

*Only if atrium is unheated.

The definition and decisions of the design principle evaluation rules are based on work by AIA (1980), Balcomb (1984), and Minne (1988).

The heating principles influence each other. Thus a well-insulated building will have a short heating period and therefore have less potential for the use of solar energy than a poorly insulated building. These are called "conflicts within strategies." The principles work in one of three ways: (a) to reduce losses, (b) to increase use of free gain, or (c) to reduce demand.

The principles may be applied separately or together. Normally one at least combines working principles A and B. To make a good combination, it is important to be aware of "influence on principles within strategy," which means that one principle influences the potential for others. The energy target value and a suggested value for solar saving fraction (SSF) are used to find a balance between the losses and gains.

There are also side effects of a principle on other strategies. This could mean that a solar collection design for heating may cause overheating in summer. This is called the "influence on other strategies." A principle is not suggested without a warning before the conflict is solved.

Some of the principles reduce the maximum heating power, while others increase it or do not influence it. Evaluation of this is necessary since the energy target may have restricted maximum power.

As may be seen, there are several aspects that make a principle into a good solution. Several principles may serve as a good solution, and they are all suggested as being possible. The choice of one of them is performed by the user. To fulfill the idea that the system should be a knowledgeable assistant while the designer is the expert, the system suggests solutions and provides information while the user makes all the decisions. In the losses and gains part, the losses should always be studied initially. In both the losses and gains parts, the system displays data about the losses and the suggested principles. The displayed data are energy, power, and cost, which give the user a basis for criticizing the suggestions and making his/her own decisions. They are therefore arranged in a tree structure to provide access to the most detailed information.

Once a principle or a group of principles is chosen and described, the system re-evaluates and shows the results. The system uses a generate-and-test method, as described by Alty and Cooper (1983), for all principles to sort out possible solutions. The test routine that works through all the principles is shown in Figure 6, and an example of the routine for a principle is shown in Figure 7.

After evaluating a principle, the user is free to refine or change the principle, change strategy, move to another building part, look at results, or end this part (see Figure 5).

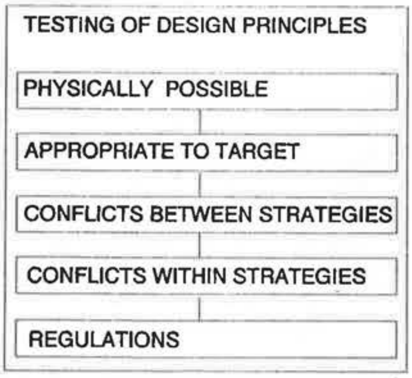

Figure 6 Testing of design principles, logic structure.

HEAT CONSERVATION

BUILDING ELEMENT: Wall

PHYSICAL REASON:
Net loss through element

APPROPRIATE TO TARGETS:
Reduce indoor temperature
Reduce energy consumption
Reduce peak power

CONFLICTS BETWEEN STRATEGIES
May cause summer overheating=>
Increase Cooling

CONFLICTS WITHIN STRATEGIES
Reduce heating period

REGULATION:
Ti >= 18 C => U =< 0.3 W/m2K
10 C <Ti < 18 C => U =< 0.6 W/m2K
0 C <Ti < 10 C => U =< 0.8 W/m2K

SOLUTIONS:
Reduce U-value
Reduce area

Figure 7 Testing of the heat conservation principle.

Examples from Advice, Data, and Menu Screens

Heating Strategy in Main Building The system presents indoor climate data and energy flows related to heating energy. Numerical values and graphical presentations are used. Calculated indoor climate data are shown along with the required values. The system shows the calculated and suggested values for losses and gains. The solar saving fraction (SSF) is used to define the targets for losses and gains. Detailed data on losses and gains are provided in separate sections.

The losses section shows the losses to ambient and the atrium. An example of the content in terms of data, update, and editing screens is shown in Figure 8. Losses are subdivided into transmission, infiltration, and ventilation. For transparent materials, indication is given whether they are energy positive or negative. Data are displayed, principles suggested, and editing and studying functions are provided. Construction data, such as area and material, energy data, and cost, are required. The data are displayed in a data base structure for study at several levels. The user makes the improvements. The system supports these by giving an update of the energy use, deviation from the target, and losses of all the elements.

Heating Strategy in a Heated Atrium The evaluation is similar for the main building except that there is no atrium as a source in the gains part. In addition, the energy consumption is calculated for several atrium temperatures. The system shows

- total and specific energy consumption of the whole building,
- total and specific energy consumption of the building without the atrium,
- total and specific energy consumption when the atrium is unheated,
- which atrium temperature gives equal energy consumption to the building without the atrium, and
- which atrium temperature gives equal specific energy consumption to the building without the atrium.

The system suggests that the atrium should not increase the specific volumetric energy consumption of the building.

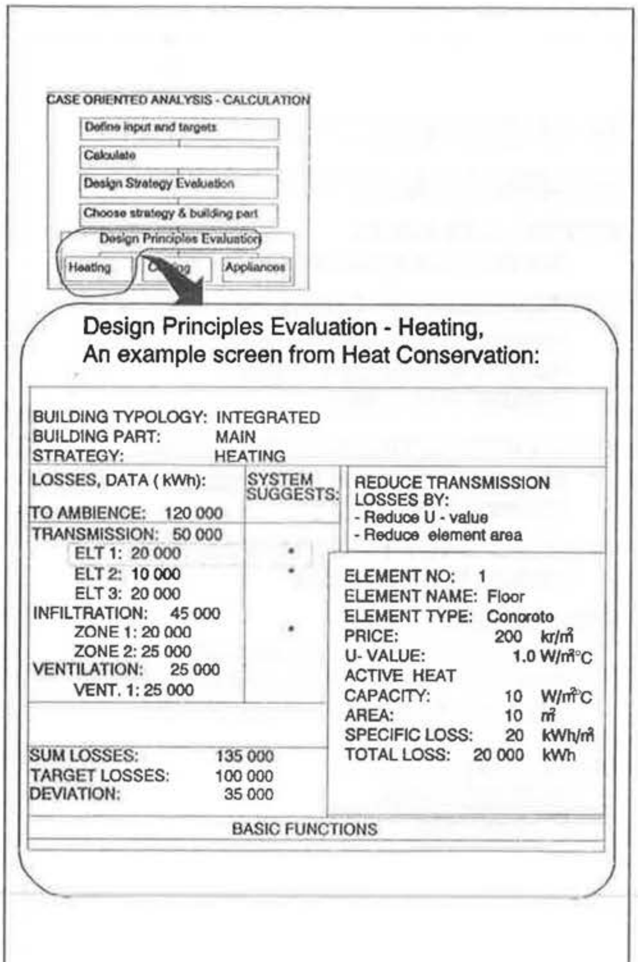

Figure 8 *An example screen from "heat conservation, losses" data.*

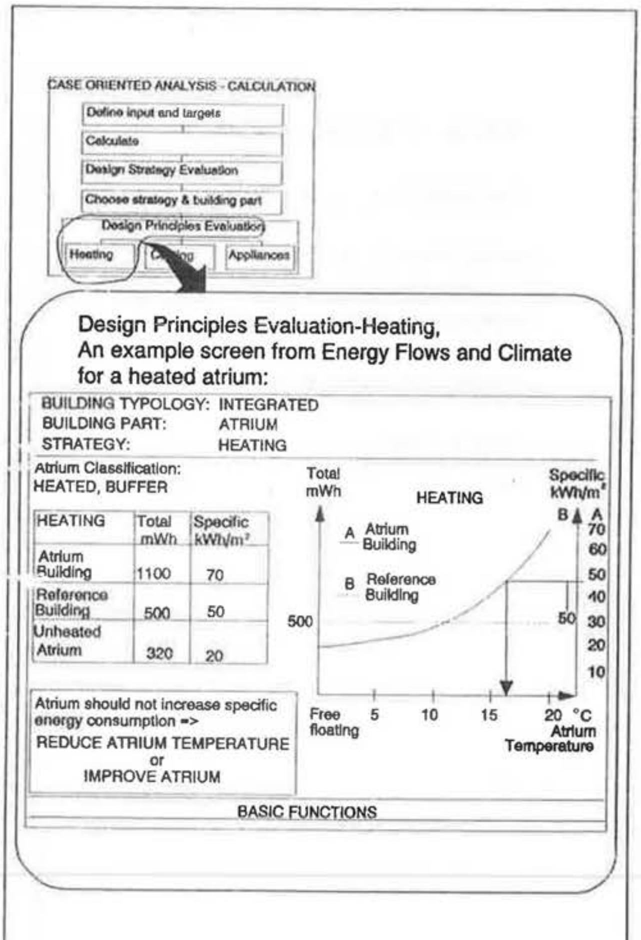

Figure 9 *An example screen from "energy flows and climate" for a heated atrium.*

Figure 9 shows the initial presentation of indoor climate and energy consumption in the atrium.

Heating Strategy in an Unheated Atrium If the atrium is unheated, the losses and gains targets are decided by the minimum and average temperature requirements or by the requested energy from the main building. There are at least two reasons for optimizing the unheated atrium:

a) to reduce the energy consumption of the main building,
b) to improve the climate of the atrium.

The temperature requirement data are transformed to losses or gains requirements data. The system suggests losses or gains targets. The user chooses or edits these targets and moves to either of the two parts. The losses and gains parts are similar to those for the main building. The "improve atrium" option is omitted.

Given the climate in Norway, all atria will work as buffers in the coldest periods and as solar collectors in the summer. The status of an atrium as a buffer or a solar heater in the heating season decides how it should be optimized to fulfill the requirements. The average temperature in the atrium in the heating season tells whether it is a solar heater or a buffer. It also tells how well the atrium works as such. The system initially presents climatic data and energy flows. The energy flow screen has a diagram that shows the net energy flow between the atrium and the ambient and the heating demand of the main building. An example of this screen is depicted in Figure 10, which shows when the atrium is a buffer and when it is a solar heater. The accumulated net energy flow for the atrium is also presented in the diagram to the right of Figure 10. The graph with full utilization of the gain in Figure 10 demonstrates its potential as a solar heater. The other graph shows whether and to which degree the atrium works as a solar heater or buffer for the whole year. The rest of the atrium evaluation depends on the energy or climatic targets for the atrium.

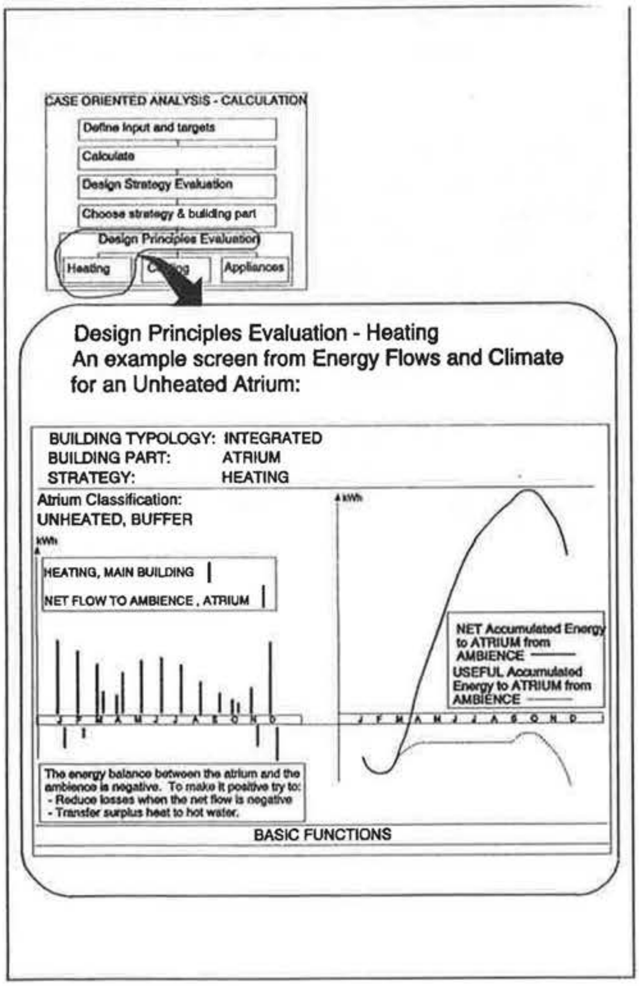

Figure 10 *An example screen from "energy flows" for an unheated atrium.*

DISCUSSION

Daylighting

A connection to a daylighting design tool was initially planned. The results of IEA Task XI indicated that no such tool has been developed for an atrium and main building. A simplified tool is planned to be developed within the next year. Daylight may be studied for a single room in the separate "Daylight" section outside the "Atrium" section.

Optimization

The system has no optimization facilities. As stated earlier, we do not consider automatic optimization to be a good solution, but it could be used as an option.

Direct Manipulation

A system based on direct manipulation seems to be favored by most users. All the visual information and graphics in building design are natural for direct expression, and the reason for not doing this is purely technical. At the time when the development started, there was no tool that could fit all our requirements and constraints (including cost). The tool we selected did not have any graphic facilities.

CAD Connection

The system is planned to be connected to a CAD system, but it is not within the scope of this project to make this connection.

CONCLUSIONS

A system is described that is based on the results and theory of the IEA Task XI project, "Passive and Hybrid Solar Commercial Buildings." A design theory based on Balcomb (1984) and Minne (1988) is implemented and extended. The system has several integrated facilities that work on the same data: design guidelines in "General Advice"; examples on design in the "Video" section; and design advice, calculation, simulation, and simulation advice in the "Case-Oriented Analysis" section. The system is integrated with the other ISOLDE sections on heating, cooling, and daylighting that work in one room.

The whole system works on a microcomputer with expanded memory and a special video card. No extra players or screens are required.

The system is controlled by the user, which provides an environment that activates the user but also allows for more relaxed reading and studying.

Information is connected to heat transfer phenomena to bridge the gap between the user and the system. The information describes the fundamentals, the model, and the data required by the model. Information about where and why it is used is connected to all the data that is queried.

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