IDA INDOOR CLIMATE AND ENERGY

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ABSTRACT

IDA Indoor Climate and Energy is a recently developed tool for building performance modelling and simulation. It represents a new generation of BPM software in several ways. (1) It is entirely implemented in a general-purpose simulation environment, IDA. (2) All models are available as NMF source code. (3) It covers a range of advanced phenomena such as integrated airflow and thermal models, CO_2 modelling, and vertical temperature gradients. (4) It has a multi-level GUI to accommodate different types of users. An overview of the new tool is given and the paper is concluded with a discussion of CAD integration issues.

INTRODUCTION

IDA Indoor Climate and Energy (ICE) is a new tool for simulation of thermal comfort, indoor air quality and energy consumption in buildings. It is primarily intended for HVAC designers but is also appreciated by educators and researchers. Marketed by AB Svensk Byggtjänst (http://www.byggtjanst.se), the Swedish version was released in May 1998. The international version, released in May 1999, is marketed directly by Bris Data AB (http://www.brisdata.se).

IDA Indoor Climate and Energy is first in a new generation of building performance simulation tools. The mathematical models are described in terms of equations in a formal language, NMF. This makes it easy to replace and upgrade program modules. For the end user, this means that new capabilities will be added more rapidly in response to user requests and that customized models and user interfaces are easily developed. Advanced users can use IDA Simulation Environment in conjunction with IDA ICE to tailor models and user interfaces according to their own needs.

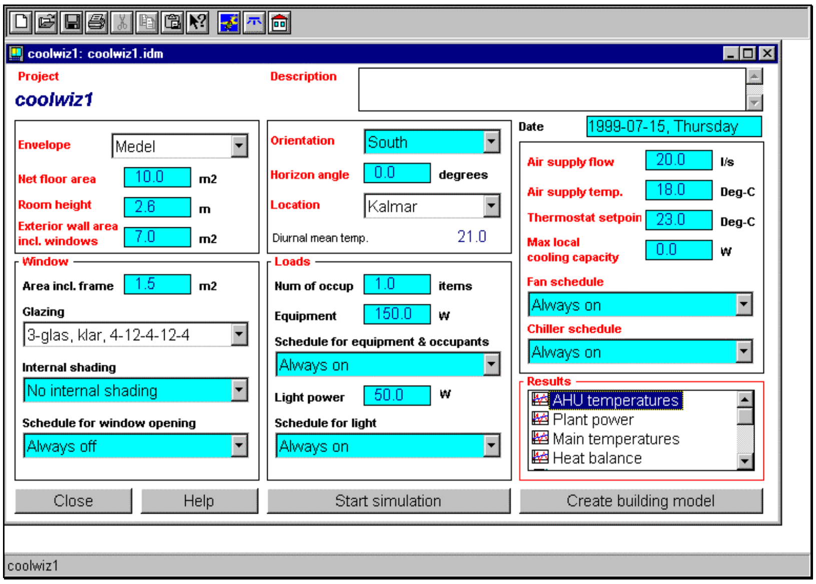

Figure 1. A wizard for single zone cooling load calculations. Data objects, which have been selected from the database, may be opened and edited.

IDA ICE has been requested, specified and partly financed by a group of thirty leading Scandinavian AEC companies. The mathematical models have been developed at the Royal Institute of Technology in Stockholm (KTH) and at Helsinki University of Technology within the framework of IEA SH&C Task 22. All models are available as NMF source code (See the accompanying paper [Vuolle, Bring and Sahlin 1999]). Bris Data is responsible for the com-

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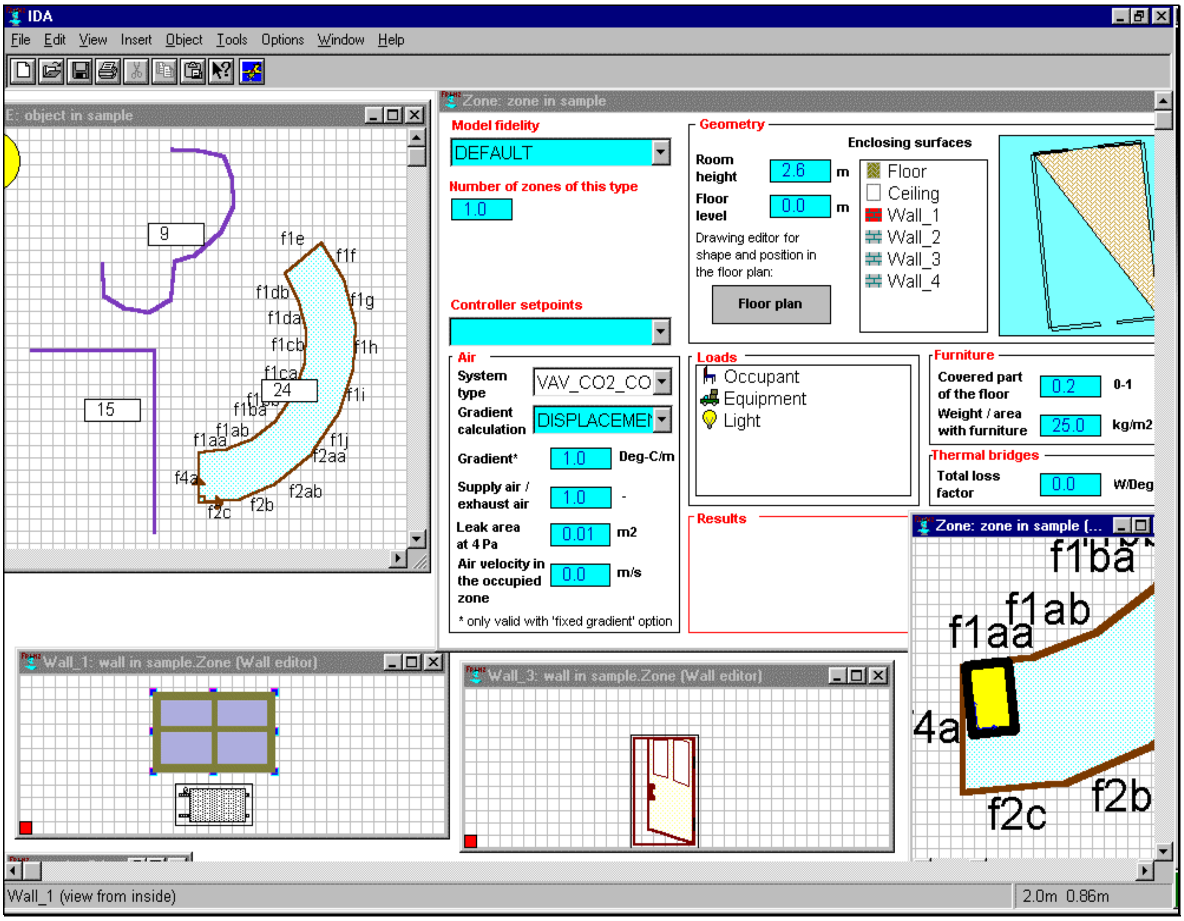

Figure 2. In the standard level interface, building parameters are defined graphically or numerically according to user preference.

mercial product. The models are not tailored to Scandinavian needs but seek to capture the international state-of-the-art in building performance modelling. Whenever appropriate, models recommended by ASHRAE (American Society of Heating, Refrigerating, and Air-conditioning Engineers) have been used.

A principal requirement has been usability by non-experts. The user interface has been designed to support an infrequent user as well as the company simulation expert. Wizards provide easy access to key input fields for common simulation tasks such as sizing of cooling equipment (Figure 1). Such a simulation can be carried out from scratch in just a few minutes. Tailored editors are used to describe geometry. Advanced database features support model reuse.

IDA ICE may be used for most building types for calculation of:

- The full zone heat balance, including specific contributions from: sun, occupants, equipment, lights, ventilation, heating and cooling devices, surface transmissions, air leakage, cold bridges and furniture.
- Solar influx through windows with full 3D account for local shading devices as well as surrounding buildings and other objects
- Air and surface temperatures
- Operating temperature at multiple arbitrary occupant locations, e.g., in the proximity of hot or cold surfaces. Full non-linear Stephan-Bolzmann radiation with view factors is used to calculate radiation exchange between surfaces.
- Directed operating temperature for estimation of asymmetric comfort conditions
- Comfort indices, PPD and PMV, at multiple arbitrary occupant locations
- Daylight level at an arbitrary room location
- Air CO_2 and moisture levels, both which may be used for control of VAV system air flow
- Air temperature stratification in displacement ventilation systems
- Wind and buoyancy driven airflows through leaks and openings via a fully integrated airflow network model. This enables study of, e.g., temporarily open windows or doors between rooms.

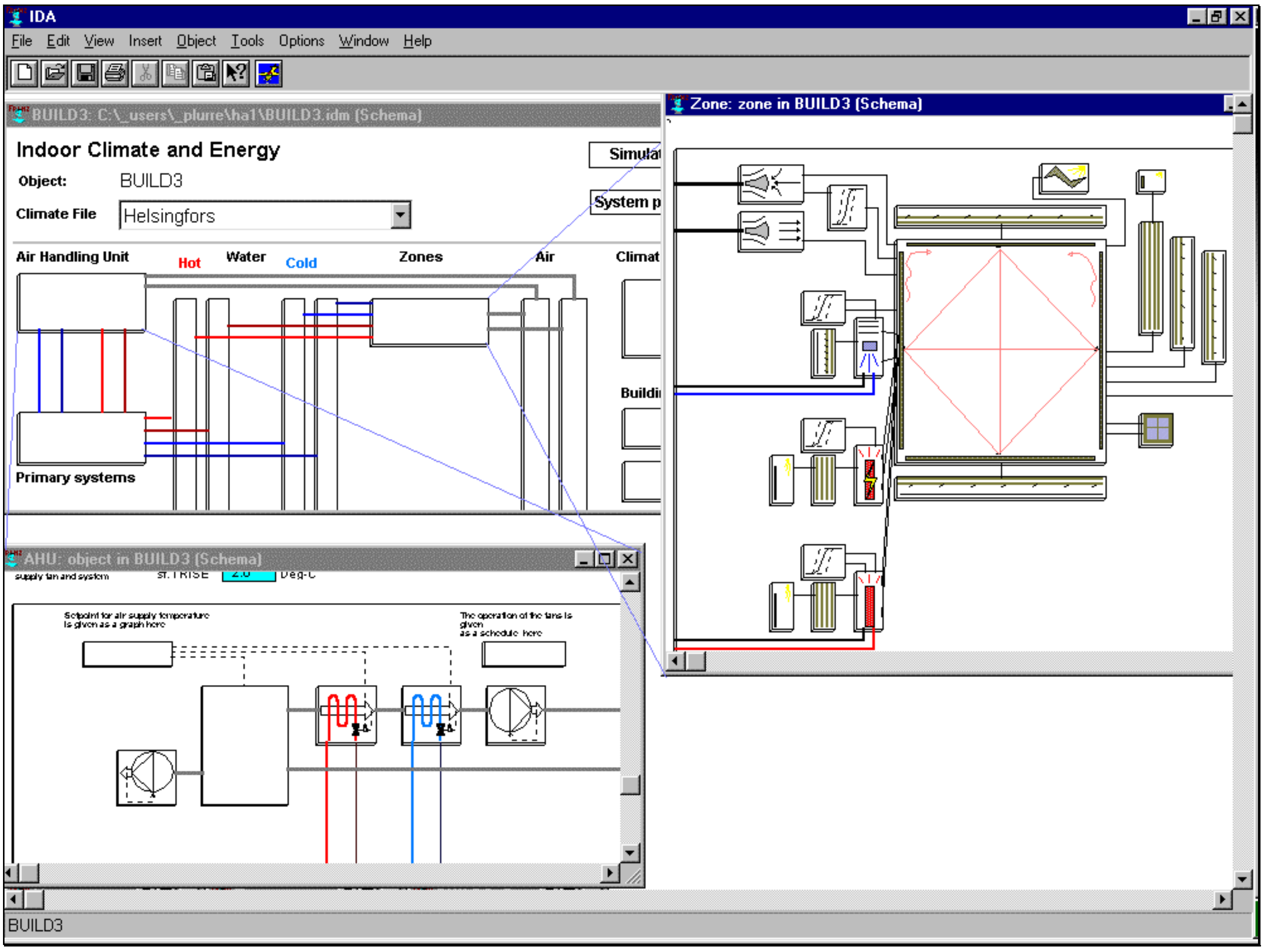

Figure 3. In the advanced level interface, the user may interconnect NMF models at will. User-defined models may be included. Equations may be examined.

- Airflow, temperature, moisture, CO_2 and pressure at arbitrary locations of the air handling and distribution systems
- Power levels for primary and secondary system components
- total energy cost based on time-dependent prices

A single zone ICE model with default primary and secondary systems comprise a total of about 600 time dependent variables, any of which may be plotted. The most common output requests are easily selected, while more sophisticated options require navigation in the mathematical models.

Execution time is highly dependent on model structure and control. As an example, a yearly simulation of a single zone model (600 variables) took 300 seconds on a 300 MHz Dell laptop. The execution time increases very close to linearly with increasing number of zones.

The full system of equations is solved with a general purpose, variable timestep solver, IDA Solver, with a time resolution of a few minutes.

Any variable may be plotted with this time resolution. Alternatively hourly, daily, weekly or monthly averages are presented or tabulated in a text window. Output signals may also be converted into duration form over arbitrary time intervals. A special function enables export to Microsoft Excel.

Special reports are available for single page printout of key output summaries of, e.g., monthly energy totals over the year including energy cost or zone climate summary over a day.

Most input parameters are grouped into objects, which in turn contain other objects. A user selects most inputs by choosing objects in a database. Library material is available for the object types of Figure 4.

Since IDA ICE is built with IDA, mathematical models may be connected arbitrarily by the end user. This is particularly useful for configuration of non-standard system types. Available building material for this type of work is first of all the native ICE library of some sixty NMF models. Also directly compatible is the ASHRAE toolkit for secondary systems and a full library of multizone airflow models. See the Simulation Model Network for information on available model material http://www.brisdata.se/nmf/simone.htm.

WEATHER DATA

ICE handles two types of weather data: design days and yearly weather files. Design days are based on daily extreme wet and dry temperatures and some additional parameters that are readily found for most locations. Models are provided to calculate climate conditions for any time during the day based on the given parameters.

Weather files are stored in the standard text format of IDA time-series (*.PRN). Time resolution is arbitrary, but most sources of data are based on hourly measurements. Each file is associated with a database entry to provide additional information about the data. Interpolation is by default linear, but the user may select higher order interpolation.

A range of Scandinavian weather files are provided, in addition to a set of Test Reference Years for Europe. (These lack information about wind direction).

Weather files based on monthly averages and interpolation between stations can be generated with, e.g., the METEONORM software (http://www.meteotest.ch), for most international locations.

ICE is delivered with a separate utility program for conversion of some of the established weather data file formats into PRN-files, e.g. European TRY, TMY, Swedish SMHI, and METEONORM output. The conversion program is also provided as C source code. This enables advanced users to process any file format.

VALIDATION

Validation is an ongoing exercise that has been carried out throughout the development of ICE. A large number of inter-model comparisons has been made against the BRIS program [Brown 1990], which in turn has been extensively validated against measurements over the years and which therefore is well trusted by Swedish professionals. BRIS is a heat balance program that models non-linear radiation and convection. Model options are available in ICE which more or less exactly reproduce BRIS results. These are normally not selected by default.

An extensive empirical validation exercise based on test cell measurements has recently been carried out within IEA SH&C Task 22 [Guyon, Moinard and Ramdani 1999]. A beta version (build 28 of 49) of ICE 2.00 was used. In spite of very careful test cell construction and measurements by Electricité de France, a problem with significant thermal bridges were discovered at a late stage in the exercise. The ICE models were not among the models that were compensated for this, resulting in a systematic over-prediction of air temperatures by about a degree C. When compensated for the thermal bridge effect, ICE predictions were very accurate. Some problems remain due to interior film coefficients, which in ICE are non-linear functions of temperature difference and surface slope. Average air velocities in the test cells were rather high due to mechanical stirring and strong convective plumes and the ICE film coefficients proved to be somewhat too low for these conditions.

MATCH WITH DOE/DOD PRIORITIZED ISSUES

Trying to anticipate future user requirements is of course fundamental to successful software design. Two international workshops have been organized jointly by the US Departments of Energy and Defense in order to provide some indicators [Crawley et al. 1997].

Workshop participants were encouraged to brainstorm and wash out issues (phrases) that many regarded as being part of a likely future scenario. Needless to say this is not an exact science. Many repetitions and even misconceptions survive the process. Table 1, at the end of the paper, contains a list of ICE features according to prioritized issues by workshop participants. An explanation of associated user benefit has been added to each issue in the context of this paper.

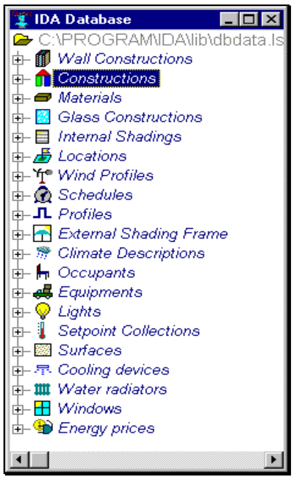

Figure 4. Object types in the parameter database.

CAD INTEGRATION

It is hardly controversial to claim that 3D CAD models will play an increasingly important role in the building design process of the future. The natural boundaries between different types of tools in such a scenario is by no means clear today. Nevertheless, decisions regarding these issues must be dealt with when designing a new tool with ambition to survive into the product modelling era. In this section, we will outline our basic position with respect to CAD integration and present some prototype work that has been done.

In a future product model based design scenario, a user must be able to comprehend and interact with multiple representations of the design at hand. A typical chain of such representations is:

1. **An Integrated Data Model** (IDM). This is the repository for all project data. From the general product model, all interesting views are derived, e.g., drawings, bills of material, and input data for various building simulation tools.

2. **A Simulation Tool Specific Building Representation**. This is a physical description of the building that contains all the data that is relevant for a particular simulation experiment. This data corresponds to the input file of a traditional batch oriented building simulation program, or to the aspect data model of a modern interactive tool.

3. **A Mathematical Representation**. In a modern, modular simulation tool, the simulation model is expressed as a large system of differential-algebraic equations (or some equivalent representation.)

Data for each successive stage is derived (mapped) from the previous. The user must also at each stage be able to view, manipulate, and add to the automatically derived data. The mapping of data between each stage must be transparent, so that a critical user can resolve the origin (in the previous stage) and processing background of each datum.

Development of integrated data models (level 1) is still to a large extent a research topic but successively more complete data models are beginning to emerge also in commercial applications. Two bottlenecks in the introduction process of product model technology are need for standardization and the required level of sophistication of the user. The Industrial Foundation Classes (IFC) is a proposed starting point for such an industrial standard and several CAD vendors have shown dedication to it. User sophistication will develop with time through training, increased specialization, generation shift, and "survival of the fittest."

We think that IFC has sufficient momentum to evolve into a useful standard and that the level of IFC compatibility of CAD tools will prove to be crucial. It is unlikely that various commercial IDM:s with a specialized focus, on for example building simulation, will survive.

Traditional building simulation tools are normally limited to level 2 in the depicted scenario. The mathematical representation of the simulated system (level 3) is almost without exception hidden inside the simulation tool, without possibility of user inspection or manipulation. Usually both the mathematical representation itself and the mapping of data to this representation are rather fuzzy and infor-

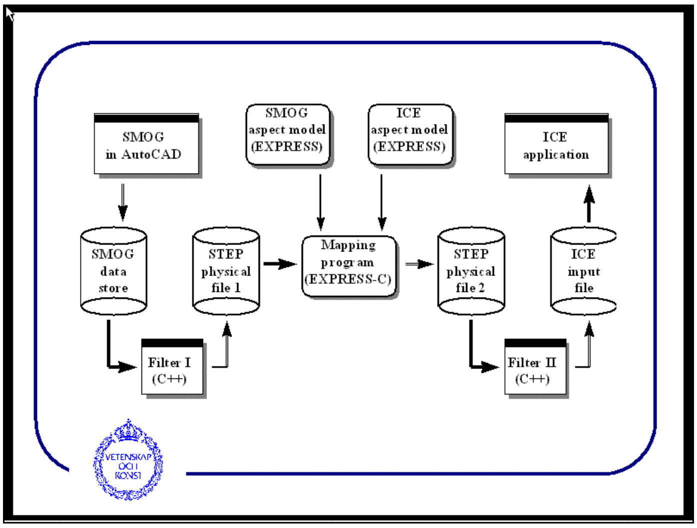

Figure 5. The structure of the SMOG to ICE mapping prototype.

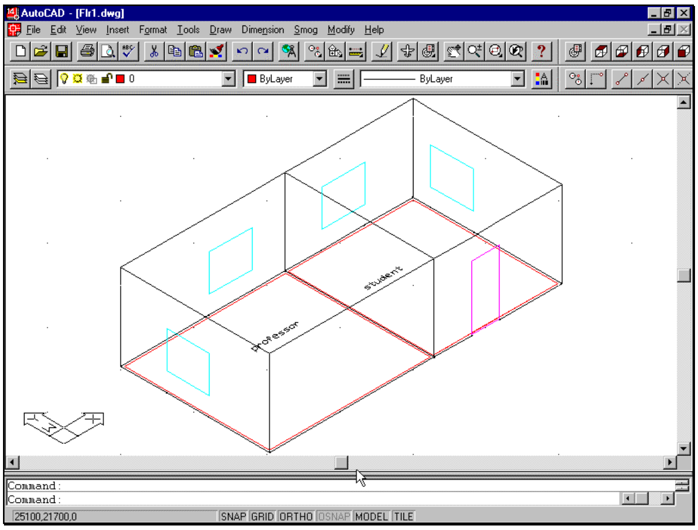

Figure 6. A two-room example in SMOG.

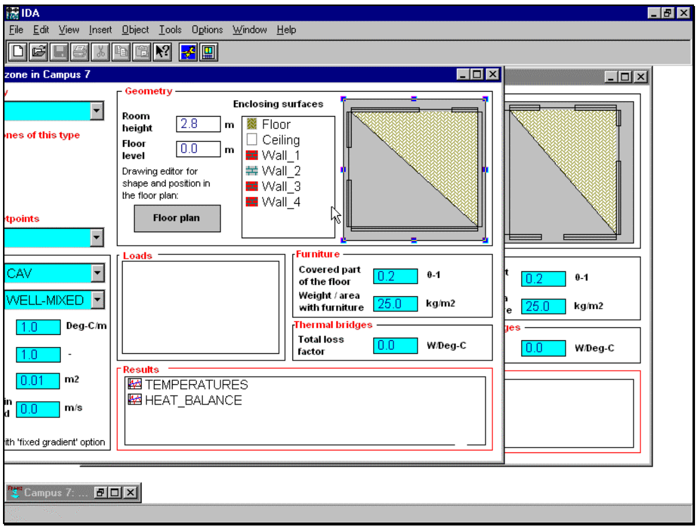

Figure 7. The two-room example when mapped into ICE.

mal. This lack of transparency and formality creates a situation where the user is left to trust that the simulation tool does a sufficiently good job, without having a real possibility to check this for the given case.

A fundamental advantage of a tool like ICE is that the data models of both levels 2 and 3 are formalized, as is the mapping of data between them. An ICE user has full access to both instantiated models. Level 2 corresponds to the standard level user interface (Figure 2) and level 3 to the advanced (Figure 3). ICE relies on a tailored mapping language between levels 2 and 3 but the language is sufficiently simple to enable a user to understand the mapping process. At level 3, the simulation problem is expressed as a large system of NMF equations that is solved to a user-selected level of accuracy. The individual equations are available for inspection.

THE SMOG TO ICE PROTOTYPE

In the ICE development, some prototype work has been done to study the mapping between levels 1 and 2 [Nordqvist and Noack 1998]. In this work, a proprietary 3D CAD model (SMOG, by Olof Granlund Oy, Finland, http://www.granlund.fi/) has been used. Initially in the mapping process, a trivial mapping of the native SMOG format to STEP is done. Then a formal mapping code in EXPRESS-C is applied to generate another STEP file that corresponds to the level 2 data model of ICE. Finally, another trivial mapping is done to generate the proprietary ICE file format. An overview of the whole process in depicted in Figure 5. Figure 6 shows a screen capture from SMOG and the corresponding ICE (standard level) view of the system can be seen in Figure 7.

The SMOG to ICE prototype is wanting in several ways:

- The SMOG application is not widely used
- All SMOG spaces are mapped to ICE zones. Additional work done in ICE, e.g. deleting some zones and furnishing the model with missing data, such as loads, setpoints, HVAC-system etc., has to be repeated each time a revision is done in the SMOG model.
- It is limited to rectangular zones.

Work is currently underway to generalize the CAD interface of ICE to accept IFC compatible models and to remedy the other shortcomings of the prototype. A commercial quality release is scheduled for Q3 2000.

CONCLUSION AND FURTHER WORK

ICE is the first fully comprehensive, commercially available building simulation tool that relies on:

- domain-independent equation based formal model descriptions (NMF)
- a general-purpose, variable timestep DAE solver for all parts of the model
- A simulation specific toolbox of GUI elements (IDA Modeller) for the graphical implementation. Most resources that are needed to build a building simulation application have a wider applicability. Examples are general manipulation and presentation tools for time series and schedules in a calendar context, parameter and simulation experiment handling tools. In the future, optimization tools will also fall into this category.

ICE provides unique service to its users both in terms of modelled physical phenomena and of the ease of making customizations and extensions. A recent example of this is the inclusion of features for simulation of floor heating systems. Development and testing (in the advanced level interface) of the mathematical models for this took two person-hours for a trained developer. This included testing various types of massflow controllers and running a yearly simulation.

Some development directions have already been pointed out. Focusing on needed-by-user rather than possible-to-developer is crucial. To this end, an interview study among commercial ICE users has been conducted. Since the release of the Swedish version in May 1998, some 180 licenses have been shipped in total. Approximately 60 users from 14 Swedish companies were interviewed.

At the top of the list of desired developments are things that otherwise hardly would have been prioritized by the developers: better tailored reports for energy simulations, easier presentation of directed operative temperatures, better support for roof lanterns and supply air beams etc. Encouraging is also the interest shown in "advanced features" such as work at the NMF level and natural ventilation models.

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Table 1. ICE features according to DOE/DOD prioritized issues

DOE/DOD prioritized issue	user benefit
Clear separation of interface and computational engine	*The "computational engine" or solver may reside on a different, more powerful computer, perhaps connected over the Internet. A parallel version of IDA Solver, IDA Star, has for example been developed.*
Structured libraries of models	*This enables long-term maintenance and cooperative model development. This way, users and independent developers may contribute to development without strict coordination, c.f., the collective development of the LINUX operating system.*
Equation-based models - NMF format	*Formalized models enable the construction of tool independent model libraries, i.e., models can be utilized in several modular simulation tools. NMF can currently be translated into the following alternative formats: IDA,TRNSYS, HVACSIM+ and Modelica.*
No gap between description and behavior	*The NMF description serves the dual purpose of being both model documentation and source code. (See also the Simulation Model Network http://www.brisdata.se/nmf/simone.htm).*
Powerful differential-algebraic solvers	*By utilizing general-purpose software such as differential-algebraic solvers, building simulation users can benefit from domain-independent advances in numerical methods and computer algebra on new high-performance hardware.*
Integrated systems with modular component models	*CAD integration has the potential of enhancing accessibility of building performance evaluation (BPE) software in the development process. The general benefits of modular tools are explained above.*
Building envelope component models	*Using the same approach for all models enables usage of domain-independent methods as far as possible.*
Shell to facilitate the combining of components into a system	*Advanced users may freely mix and match models.*
Customizable output and reports	*Users of different levels, cultures, languages and objectives need different things from the tool.*
Customizable interface	*Same as above.*
Adaptable to multiple uses	*Same as above.*
Extensive and extensible libraries of building components and systems	*A steadily growing body of related models allows model developers to focus on the problem at hand without being forced to develop all necessary models.*
Simultaneous solution of loads, plant and controls	*This is a given feature of any reasonably modern simulation tool. Decoupling of the solution process works only if the room temperature is close to constant.*
Simple input options	*Quick answers to simple questions are a must.*
Flexible system and plant modeling	*It is impossible for a tool developer to anticipate all the needs of future users. Equally impossible is trying to provide a menu item for every conceivable system and plant structure.*
Realistic simulation time steps/Variable time steps	*Many key phenomena in a building occur on a short timescale. How many minutes will an entering occupant be exposed to unacceptably low temperatures after opening the office door, and switching on equipment and lights? The answer may have significant impact on design decisions.*
Imperfect mixing of zone air	*A natural advance in model prediction capability. Key impact for study of displacement ventilation and atria.*
Indoor air quality	*Some measure of air quality, e.g. CO2, is required for calculation of hygienically motivated air- flow rates.*
Air flow modeling	*Of crucial importance to the study of any building where doors can be expected to be open or where natural ventilation effects are significant.*
Modeling of terrain and surrounding obstructions	*Many sites provide natural shading that have significant impact on the optimal design.*
Wind pressure distribution	*A requirement for the study of natural ventilation effects.*
Comfort evaluation/Occupant comfort	*Occupants experience comfort, not just temperature.*
Costs based on utility rate schedules	*Time dependent energy pricing may have significant impact on the optimal design.*
Daylighting	*Must be studied in conjunction with thermal climate in order to find optimal designs.*