BUILDING DESIGN SYSTEM AND CAD INTEGRATION

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ABSTRACT

In order to provide an integrated building design system that easily can be adapted by building designers, the Danish Building Research Institute has developed such system. It is based on experience gained as participant in the European COMBINE projects and from development of building energy simulation tools. The intention is that a number of computer tools for building design and analyses shares information about the buildings that they analyse, and that data for the building geometry can be provided by a CAD system. Recently two Danish consulting engineering companies have tested the system on building projects in practice.

INTRODUCTION

One of the main obstacles in using advanced computer models for building analyses, such as analyses of thermal or daylight conditions, is the work required to prepare input data for the models. However, many such data used by different models are similar and should therefore be shared among the tools.

The EU JOULE COMBINE projects [Augenbroe, 1995] were among the first international projects with relevance for the building industry to adopt the then emerging ISO STEP standard [ISO 10303-1, 1992] for data exchange of product model data (Figure 1). The scope of the projects were to develop prototypical demonstrations of an Integrated Building Design System, where data integration between architectural and engineering design tools facilitates a more intense, efficient, and fault tolerant use of the tools. The COMBINE projects succeeded in developing and demonstrating the functionality of integrated building design systems. However, it was clear that such comprehensive systems face a problem with complexity, which influences the required effort for development work as well as the efficiency of using the final system.

The Danish Building Research Institute (SBI) participated in the COMBINE projects as a supplier of the institute's tsbi3 program as one of the design tools that were available within the integrated design system. tsbi3 is a program for dynamic building thermal analysis [Johnsen and Grau, 1994].

In order to provide an integrated building design system that easily can be adapted by building designers, SBI has developed a building design system that is limited, integrated and pragmatic. The system is called Data Integrated System (DIS). The development is based on experiences gained by developing tsbi3 and as a participant in the COMBINE projects. The evolution of SBI's building energy simulation tool is shown in Figure 1.

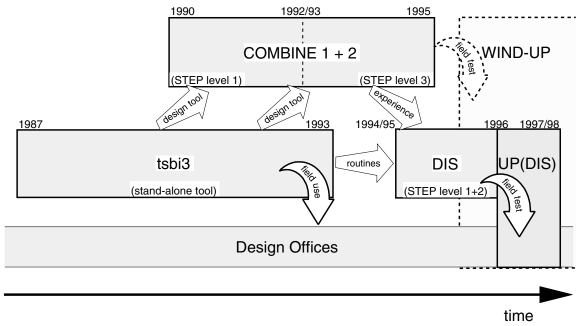

Figure 1. Evolution of a building energy simulation tool from a stand-alone program (tsbi3), over its role as a design tool in an advanced integrated building design environment (COMBINE 1+2), to its present form within the DIS environment [Rode and Grau, 1996].

The core of the system is a common building data model, developed from a subset of the COMBINE data model, and extended with objects supporting the tools.

At present the system consists of a few tools and a database:

- DisView, a model editor for creation, editing and visualisation of the building model
- DxfApp, a tool for extracting drawing information from the architects CAD drawings
- Bv98, a compliance checker for calculation of buildings' heating demand in accordance with the Danish Building Regulation
- DanLight, a simple daylight calculation tool
- tsbi5, a tool for dynamic building thermal simulation of buildings
- DisDB, a common building components and materials database used by all the tools.

COMMON DATA MODEL

The core of the system is a common data model shared by all applications i.e. design tools. The data model is separated into different sub-models describing different aspects of a building. The sub-models are:

- A 3D Geometry/topology model for overall layout of a building described as Cells, Face Sides, Faces, Edges and Vertices
- A Space model describing the space objects (Ground and Rooms) having the Cells as geometry/topology representations
- An Enclosure model, describing enclosing elements (Constructions, 'Windoors' and Holes) that have the Faces as geometry/topology representations. 'Windoor' is a common description for windows and doors. In addition the enclosing elements have a description of the two Finishes that have the FaceSides as representations
- A Building Component model describing standard building components and materials. The model describes the physical properties of the enclosing elements. Finishes also use this model
- A System model describing various HVAC systems and operations.

Sub-models are defined as NIAM diagrams (Nijssen Information Analyses Method) [Nijssen and Halpin, 1989] using a graphic NIAM editor capable of exporting the data definitions in EXPRESS format [ISO 10303-1, 1992]. The NIAM diagram for the Geometry/topology sub-model is shown in Figure 2.

The EXPRESS definitions of the sub-models are compiled into C++ classes using *Expresso*. *Expresso* is a stand-alone program developed by SBI that takes the data definition of an EXPRESS file and produces C++ classes corresponding to each entity of the EXPRESS file's data model. The generated classes are manually supplemented by methods (e.g. calculation of the area of a Face and the volume for a Cell). Each of the *Expresso* generated classes inherits from C++ base classes that provide the functionality of a STEP interface. They also provides methods for reading and writing physical STEP files [ISO 10303-21, 1994], and methods for manipulation of entities of a STEP model.

All C++ classes in the sub-models are compiled into a Windows Dynamic Link Library (DisMdl.dll) to be used by all applications within DIS as a shared resource. The STEP functionality is implemented in Step5.dll, which DisMdl.dll depends upon. A detailed description of the implementation details is found in [Rode and Grau, 1996].

SYSTEM ARCHITECTURE

Currently the DIS system consists of a few design tools and utilities, all based on the common data model, see Figure 3. The design tools are implemented as separate Windows programs with their own user interface. Physical STEP files transfers the data for a building model between the programs.

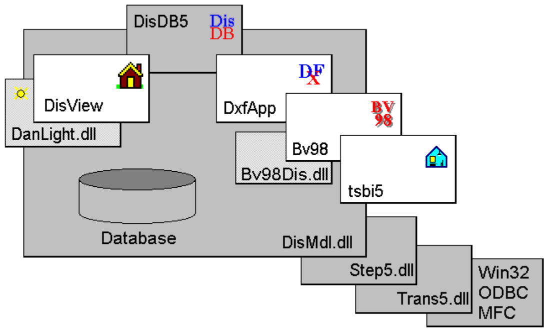

Figure 3. DIS system architecture.

The implementation is done with Microsoft Visual C++, version 6.0, and Microsoft Foundation Classes (MFC), version 6.0. The system can be used on a PC running Microsoft Windows 95, Windows 98 or Windows NT, version 4.0 or later.

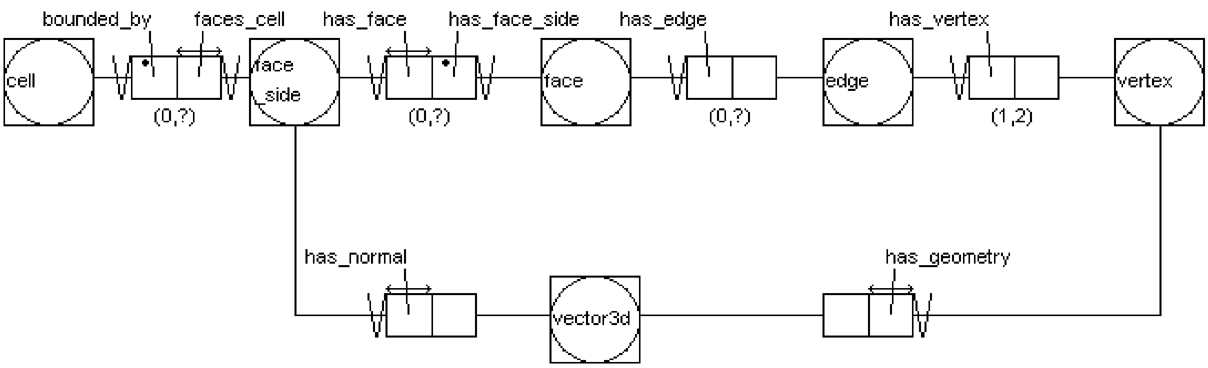

Figure 2. Geometry/topology sub-model NIAM diagram, generated using the Nessie tool [Wix, J. et al. 1993].

IMPORT OF CAD DRAWINGS

Before analyses can be performed for a building project, the building must be defined according to the data model of the design tools. The ideal situation would be that the CAD systems used by the architect and engineer was based on the same data model as the design tools. In this case the analyses could be performed immediately on the common digital model of the building project.

The reality today is that most CAD systems and design tools have their own data model. Data transfer between tools has to be performed manually or by a program mapping data between the different data models. This process is risky because of misinterpretation, or even impossible, because concepts in one model do not exist in the other model.

The industry has realised this problem and formed the International Alliance for Interoperability [IAI, 1997], and has launched an initiative to define a *de facto* standard for a common building data model. The standard is called Industry Foundation Classes (IFC) to be used by CAD systems and design tools. Currently, the first commercial systems based on IFC, release 1.5 are emerging.

It will take a long time before IFC is fully defined, before it is accepted and implemented in the different CAD systems and design tools, and even longer before the systems and tools will be in common use in design offices.

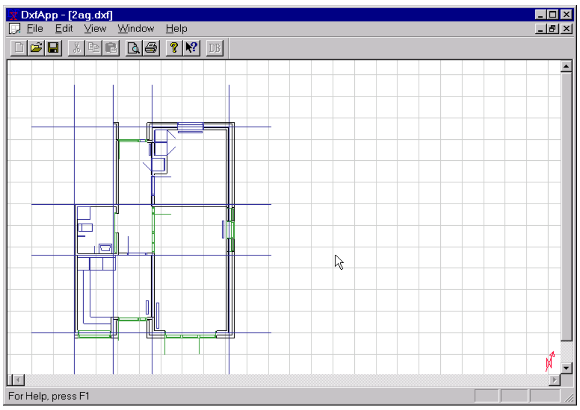

Figure 4. 2D architectural drawing without layer structure showed by DxfApp.

However, it is important to be able - easily and safely - to create a building model from the architects drawing at an early stage of the design process in order to influence the design. Therefore the tool DxfApp has been developed as a front-end to DIS for the creation of the building geometry for DIS based on a DXF file extraction of the architects 2D drawing.

The basic principle is to refer to lines in the architectural drawing to create new 'construction' lines to be used for creation of the 3D model's Cells and Faces. The construction lines are defined as the line of the exterior side of outer walls and the centre lines of interior walls. The crossing between construction lines (nodes, shown as black squares in Figure 5) represents a corner in the third dimension.

In the early phase of the design process, many architectural plan drawings consists only of lines and symbols in just one layer, as shown in Figure 4. This makes it difficult to create the construction lines, because there are too much information in the drawing.

In Denmark it is quite common to make the drawings according to layering rules defined by the Danish CAD user group. Lines belonging to a wall are drawn in a certain layer, lines for a completion element are drawn in another layer, etc., each layer having a unique identification. By applying a filter on the layers when reading the DXF file, only the relevant information is shown, see Figure 5.

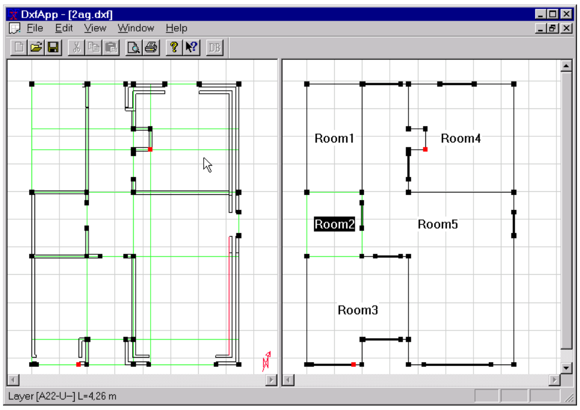

Figure 5. Filtered architectural drawing versus the constructed DIS model.

The 3D model is created in the following way:

- The construction lines are created from the lines in the DXF drawing (left pane in Figure 5)
- The relevant nodes are constructed as crossings between construction lines
- The walls are constructed as lines between two nodes
- Wall lines enclosing a room are selected and defined as being a room (right pane in Figure 5)
- Windows, doors and holes in walls are constructed in a similar way as lines between two nodes.

MODEL EDITOR

The model editor, DisView, is the central program in DIS. It is used for the creation, editing and visualisation of the building model, and for the activation of the design tools, see Figure 6.

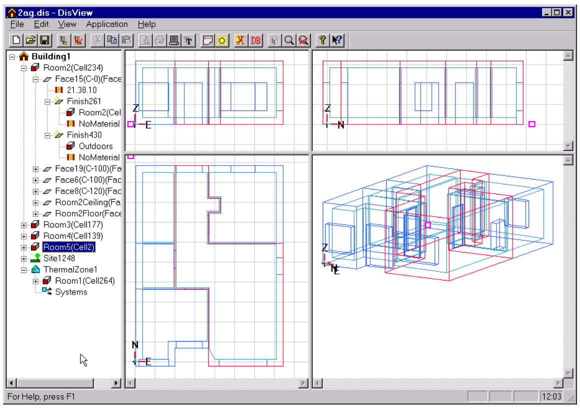

Figure 6. The model editor DisView showing the 3D model created by DxfApp.

The user interface is organised in the following way:

- The right view is split up in four panes showing the building graphically. The lower left pane shows a plan view of the building. The two upper panes shows the elevations, and the lower right pane shows a 3D parallel projection

- The left view shows the building as a hierarchical tree. Left clicking the mouse on an item in the tree view, the same item will be highlighted in the graphical view. Right clicking the mouse on an item in the tree view, a dialog box pops up. In the dialog the user can enter attributes associated with the selected item. In addition the automatically calculated properties, i.e. areas of walls and volumes of rooms are shown.

DisView has built-in facilities for the creation of models for buildings with simple box shaped rooms, and facilities for editing and consistency checking of the models.

From DisView the model can also be exported to Radiance [Ward and Shakespeare, 1998] for visualisation, see Figure 7.

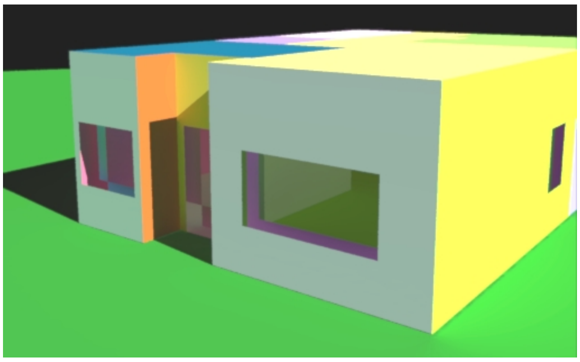

Figure 7. Outside view of the building at June 21, 8 AM in Denmark, generated by Radiance.

DATABASE

Physical properties for building elements, constructions, windows, doors and finishes can be user-defined or chosen from pre-defined examples in a building component database DisDB. The database is a relational database in Access format managed by the Open Database Connectivity (ODBC) engine. The database is provided with its own user interface (see Figure 8), implemented as a DLL accessible from DisView and all the tools.

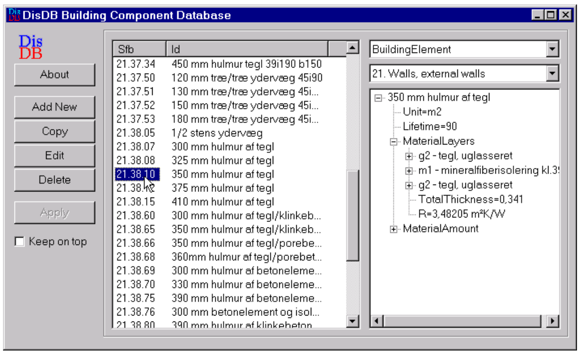

Figure 8. User interface for Building Component Database DisDB.

To attach a building element from the database to a wall or 'windoor' in the model, or to attach a finish material to a finish in the model:

- Open DisDB from within DisView

- In DisDB locate the building element or material to be used

- Drag it with the mouse to DisView's tree view, and drop it on the item to be attached.

The database is organised so it can be used for different aspects of analyses. Building elements can be defined as:

- An item 'MaterialLayers' giving a description of the order of layers in the construction, the layer thickness and thermal properties

- An item 'MaterialAmount' giving a description of the material amount and environmental properties used for life cycle assessments (LCA).

Building materials are organised similarly with properties for different use, i.e.: construction, glazing, finish and environment material.

COMPLIANCE CHECKER TOOL

The Danish Building Regulations BR 95 and BR-S 98 make ways for documenting the space heating requirement of a building in three different ways. One of these is the maximum heating demand per m^2, depending on the type and topology of the building.

The official tool for doing this calculation is Bv98 [Wittchen and Aggerholm, 1999].

From within DisView it is possible to export the whole building model for doing a calculation of the monthly heating demand. The calculation method used in Bv98, complies with European standard EN832 [CEN TC 89/WG 4, 1998]. Bv98 can be used as a stand-alone tool as well.

DAYLIGHT ANALYSIS TOOL

From DisView it is possible to perform daylight calculations using DanLight. This tool can perform fast computations of daylight illuminance levels at reference points situated in any convex shaped room confined by plane polygons. For any of the sky models ('Uniformly overcast sky', 'CIE-overcast sky' or 'CIE-clear sky') the direct, the externally reflected and the internally reflected components are calculated.

A daylight calculation can be performed at one reference point at a time. Reference points can also be generated as a regular grid in a plane in the room (e.g. the workplane). After calculation of the illuminance values for all points of the grid – an illuminance map can be displayed graphically.

THERMAL SIMULATION TOOL

Tsbi5 is an acronym for Thermal Simulations of Buildings and Installations, 5th generation.

Tsbi5 is a slightly enhanced, Windows version of the known DOS program tsbi3 [Johnsen and Grau 1994]. The major enhancements in tsbi5 are:

- Full 3D geometry and view of the model
- Windows interface
- Windows compatible export of graphic results through a module with possibility of manipulating graphics on-line
- Import of building geometry from CAD drawings
- Drag and drop editing facilities in the model creation phase
- One common building data model for several tools.

Tsbi5 performs transient thermal simulations of all or part of the rooms of the global building model. The heat transmission internally in the constructions is described non-stationary. The construction is divided into several control volumes. Heat transmission from a neighbouring volume is calculated on the basis of Fourier's heat transmission equation with the approximation that the temperature sequence between the nodal points of these two control volumes is the same as in a stationary situation. This approximation, the difference approximation, replaces the differential temperature gradients in Fourier's law with gradients calculated from finite temperature differences between nodes of finite distance. To make the description general, it is assumed that the two materials each have their own transmission figure and that the control volumes each have their own thicknesses.

From within DisView it is possible to include rooms from the building model in 'thermal zones'. Any room included in a thermal zone can be simulated in tsbi5.

A thermal zone may contain one or more rooms, all with a detailed description of the constructions. If a thermal zone comprises more than one room, only one air temperature node is used representing the average temperature of all rooms. In case of high-ceilinged rooms or several rooms placed on top of each other with an open connection, the vertical temperature distribution is calculated as a linear extrapolation from the simulated temperature in the centre of the thermal zone.

Systems in tsbi5 are any 'system' that influences the temperature of a thermal zone. Any system in tsbi5 is defined by a description of the component (i.e. a detailed description of ventilation components) and a 'control'. The control comprises a definition of how the system is controlled and a definition of the time when the system can be activated.

The list of systems includes cooling, equipment, heating, infiltration, lighting, mixing, moisture load, people load, ventilation and venting. In principle tsbi5 is capable of simulating all zones and systems shown in Figure 9.

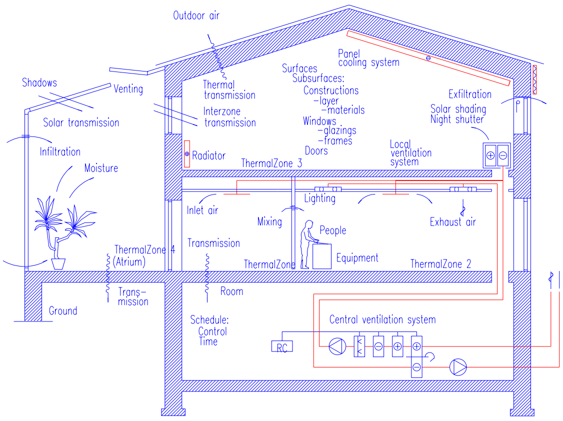

Figure 9. Principal sketch, illustrating the simulation possibilities in tsbi5.

The external boundary of the simulated model consists of ambient climate, ground coupling and adjacent rooms outside the thermal zones. For adjacent rooms only the construction towards the thermal zone and the temperature variation need to be defined in order to carry out a tsbi5 simulation.

Simulations are performed in time steps of 30 minutes or less. Any systems defined in the building model are controlled at time step level.

Results from the simulations are divided into four groups that can be selected or deselected before the simulation. The four groups are data related to weather, thermal zones, faces and 'windoors'. All data in any of these four groups are stored at an hourly basis.

Results of the energy balance on weekly or monthly basis are immediately available and can be presented either graphically (Figure 10) or in tabular form. Any result from one of the four groups of data can be dragged to the parameter part of the window (Figure 11) and analysed in detail either numerically or graphically (Figure 12).

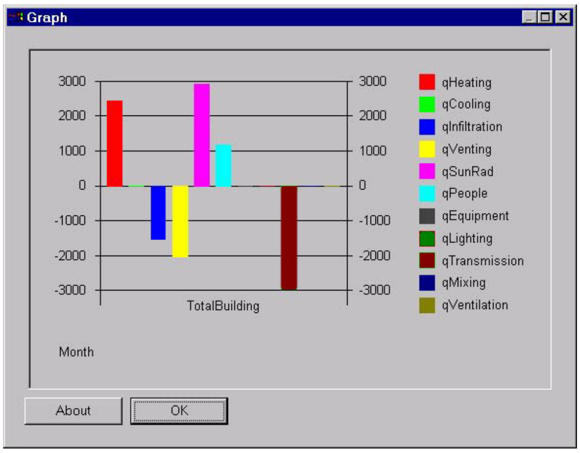

Figure 10. Graphical representation of the energy balance.

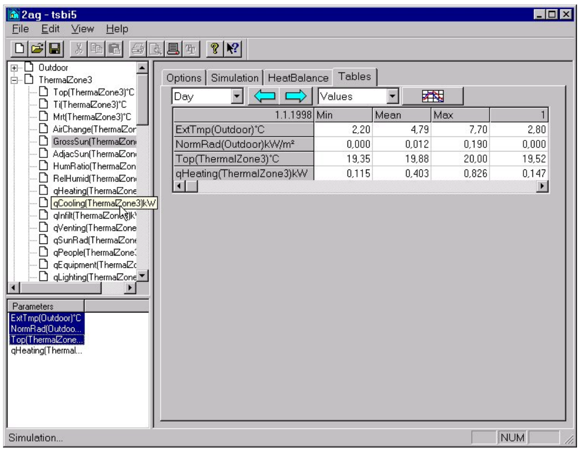

Figure 11. Selection of parameters for detailed analyses on hourly basis.

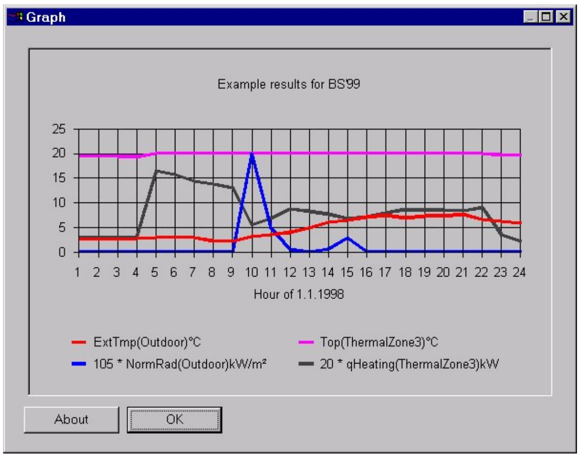

Figure 12. Graphic representation of selected hourly simulation results.

Graphics are presented using the ActiveX control 'First Impression 5' from 'Visual Components, Inc.', which gives the user great flexibility for on-line manipulation of the graphical layout. The ActiveX control also offers the opportunity of exporting the images to other Windows based applications or as physical files in different graphic formats and printouts.

EXPERIENCE FROM PRACTICE

Two major Danish consulting engineering companies have tested a prototype of the program package in practice. Results from this survey are discussed below.

The program was tested on a normal design project in collaboration with an architect, from the early phase of the project to the invitation to submit tenders. The hypothesis was that bringing detailed simulations into the early design phase of a project will give a greater chance of influencing the building design in an energy conscious way (Figure 13). As soon as the first sketch was available a building model was created and a thermal analysis of the building was initiated after which parametric variations could be included for decision making.

Some problems were encountered during these tests which must be dealt with in order to further streamlining the process. At the very start of the architectural design of new buildings, often drawings are not made in a CAD program, and even if they are, they are normally following no drawing standards. Solutions to this could be either to encourage architects to follow such standards, define new drawing standards for the sketch phase or even give the possibility for scanning paper drawings as a basis for creating the building model.

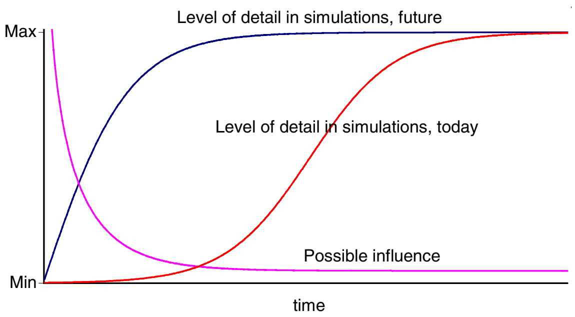

Figure 13. Connection between detail of simulation models and the possibility of influencing the design process (Carl Bro a|s).

The involved design teams stated that detailed simulations in the early phase of the design process was new and offered a better opportunity for re-thinking the design project.

VALIDATION

For validating purposes, tsbi5 has been equipped with a facility of exporting building models to tsbi3. This way it is possible to verify consistency between the results from the two programs. Until now comparisons have shown very small deviations.

This is a pragmatic way of verifying the results as tsbi3 has been extensively tested, among others as part of an international validation exercise undertaken in a joint project of the International Energy Agency (IEA), BCs Annex 21 & SHC Task 12 [Lomas et al. 1994]. In this project tsbi3 was rated as a rather accurate tool, so tsbi5 results, identical to those of tsbi3, can be considered reliable.

FUTURE

A model for sub-dividing thermal zones, allowing data for simulation of an airflow network will be an extension to the current version. If a user wishes to investigate airflow patterns in more detail, an interface will offer the opportunity of exporting boundary conditions to computational fluid dynamics (CFD) programs thus importing the airflow patterns. This activity is carried out in collaboration with Aalborg University, Denmark.

An improved data model for moisture transport in building materials is planned for a future version of tsbi5. A module will offer the possibility of simulating moisture transportation in building materials and furniture. The model will be developed and implemented in co-operation with the Technical University of Denmark.

Data models for natural ventilation will be improved, utilising the possibilities of the full 3D-geometry. SBI has already developed models for natural ventilation ready for implementation in tsbi5.

In tsbi3 a module for simulating solar walls [Wittchen, 1993] was implemented, but due to the new data model this has not yet been implemented in tsbi5.

SBI is also working in the field of life cycle assessment (LCA). The building component database is designed in a way that SBI's LCA tool can access it together with the common building model. This way the user will - within one environment - be able to calculate energy consumption and environmental impact during a buildings life cycle, including production and disposal of building materials. It will be simple and obvious to implement this facility as a tool in DIS.

Improved CAD import will be established when the IFC standard is implemented for CAD tools and being used in practice.

CONCLUSIONS

It is possible to create building simulation tools that use a common building data model for sharing information. The common building model can be used for thermal simulations, check of compliance with building codes, daylight analyses, and 3D visualisation.

The building geometry for the tools can be constructed on basis of a DXF file extraction from the architects' 2D drawing. This technique gives the user the possibility of easily and safe to perform detailed simulations in the early design phases influencing the design.

Experiences from practice indicate that the DIS system will influence the designers' way of working towards more efficient decision making. The DIS environment and the common building data model has potential for developments of further tools easily accessed in other phases of the design process. Architects will find the system a valuable tool for analysing thermal performance of a building and re-thinking the design in a more energy and indoor environmental conscious way.

ACKNOWLEDGEMENTS

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