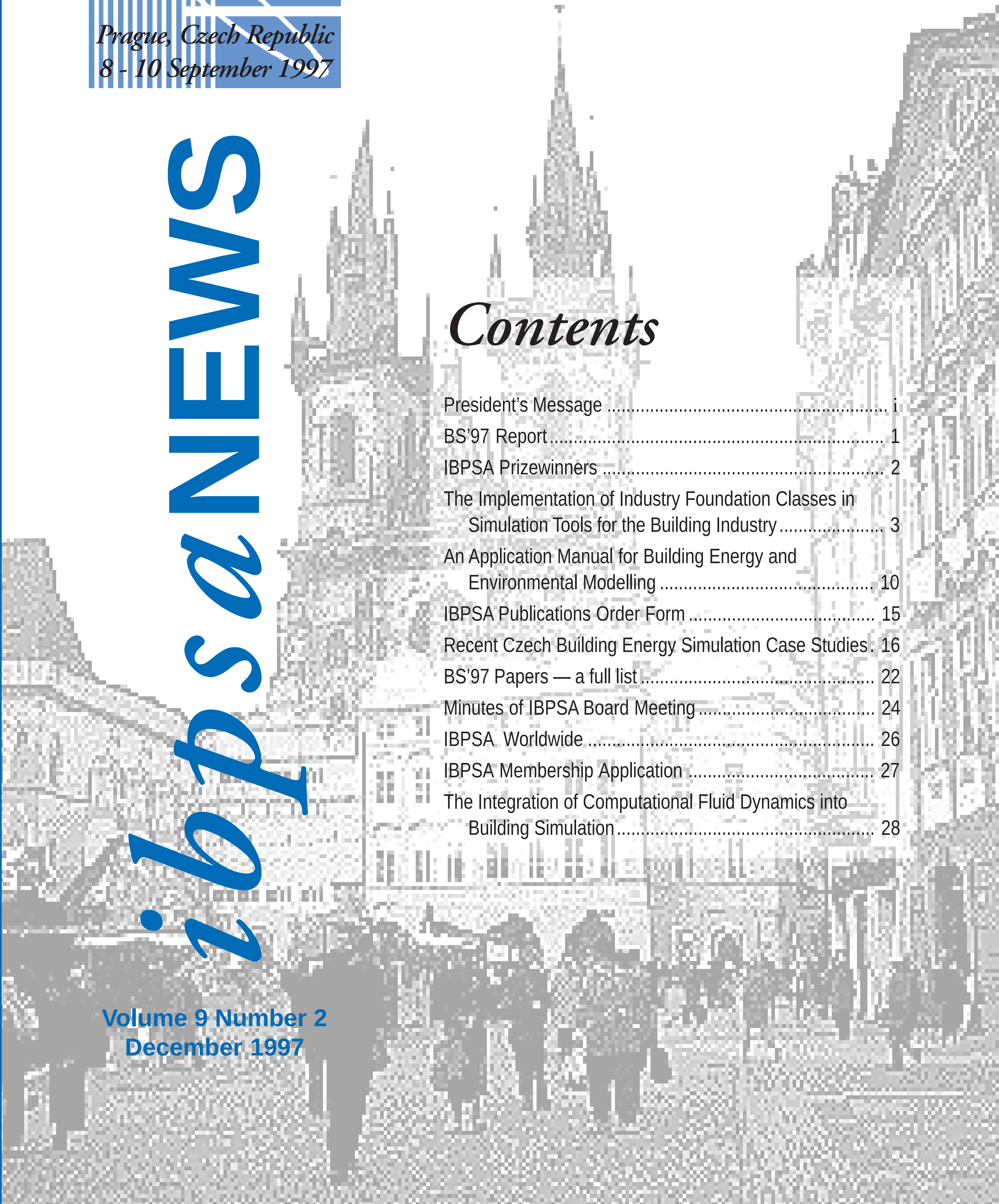
BS'97

Prague, Czech Republic
8 - 10 September 1997

ibpsaNEWS



Contents

Volume 9 Number 2
December 1997

The International Building Performance Simulation Association (IBPSA) exists to advance and promote the science of building performance simulation in order to improve the design, construction, operations and maintenance of new and existing buildings worldwide.

President
Joe Clarke
ESRU, Energy Systems Division
James Weir Building
University of Strathclyde
Glasgow G1 1XJ, Scotland, U.K.
Phone: 44-41-552-4400, Ext. 3986
Fax: 44-41-552-8513
e-mail: joe@esru.strath.ac.uk

Vice-President
Per Sahlin
Dept. of Building Services Engineering
Royal Institute of Technology
Stockholm S-10044 Sweden
Phone: 46-8-411-3238
Fax: 46-8-411-8432
e-mail: plurre@engserv.kth.se

Treasurer
Edward F. Sowell
Fullerton State University
P.O. Box 939
Placentia, CA 92634 U.S.A.
Phone: 714-773-4092
Fax: 714-449-7168
e-mail: sowell@ fullerton.edu

Secretary
Larry O. Degelman
Texas A&M University
Dept. of Architecture
College Station, TX 77843-3137
U.S.A.
Phone: 409-845-1015
Fax: 409-862-1571
e-mail: larry@archone.tamu.edu

Volume 9 Number 2
December 1997

President's message

Three important items spring to mind since the last issue of IBPSA News.

Firstly, Building Simulation '97, IBPSA's 5th international conference, took place in Prague from 8-10 September. I am certain that the 169 delegates will agree with me when I say that the event was an unqualified success both technically, with some 121 papers covering a range of topics, and culturally: who will forget the majestic architecture of Prague and the moving pre-dinner entertainment in Melnic castle. It is with genuine pleasure that I take this opportunity to extend IBPSA's thanks to Professor Drkal and his colleagues for a job well done. The report on page 1 summarises the conference and explains how to obtain the proceedings in book or CD format; there is a complete list of papers on page 22 and an order form on page 15. I am also pleased to announce that Building Simulation '99 will take place in the Far East, with bids from Hong Kong, Kyoto (Japan) and Singapore currently being considered by the Board.

Secondly, the regionalisation of IBPSA is gathering momentum, with 7 regional affiliates now operational (Australasia, Canada, Czech Republic, France, Greece, UK and USA) and several more in the process of applying. This issue of IBPSA News is evidence of the first tangible benefit from IBPSA-Net, with articles gathered from different regions, production undertaken by IBPSA UK and printing/ distribution handled by IBPSA Czech.

Thirdly, the IBPSA Board is in the process of changing its composition in order to better reflect the growing regional focus and nurture relationships with other international groups. In future, the Board will comprise a small executive (President, Vice President, Secretary and Treasurer) to attend to IBPSA's day-to-day business and evolve a relevant development strategy, an individual nominated from each affiliate to ensure that the regional viewpoints are well represented, and several "members at large" to liaise with groups undertaking complementary work (e.g. on application interoperability) or undertaking projects on IBPSA's behalf (e.g. conference organisation).

And finally, my warm congratulations to Jean Lebrun and Veronica Soebarto, the recipients of this year's IBPSA awards for Distinguished Service to Building Simulation and Outstanding Young Contributor respectively. Now that their cheques have been despatched, I have high hopes that they will be first in line to pay their 1998 dues.

Joe Clarke, President, IBPSA

BS'97

Report

Innovation and success

Building Simulation '97 was the 5th of IBPSA's biennial international conferences, following successful events in Vancouver, Canada ('89), Nice, France ('91), Adelaide, Australia ('93) and Madison, USA ('95).

With growing interest in building simulation from practitioners, researchers and academics in eastern and central Europe, BS'97 was held in Prague, Czech Republic on 8 - 10 September 1997, hosted by the Faculties of Mechanical and Civil Engineering at the Czech Technical University.

169 delegates …

121 papers …

"an unqualified success"

The conference included:

- paper presentations on all aspects of building simulation state-of-the-art;
- poster sessions to allow extended discussions;
- software sessions to enable demonstrations of latest developments;
- a permanent exhibition to promote available products and services
- and panel sessions to debate current issues.

BS'97 attracted 169 delegates from North America (26), Australasia (13), the European Union (94), central and eastern Europe (30) and elsewhere (6). Everyone agreed that the event was an unqualified success both technically and culturally.

The conference exhibition was well attended. The largest contingent of exhibitors came from the UK, with stands in a 'trade pavilion' organised by IBPSA's UK affiliate, the Building Environmental Performance Analysis Club (BEPAC). BEPAC also organised a successful commercial event at which Czech practitioners were briefed on the building performance assessment services and products available from the UK.

BS'97 introduced several innovations, including:

- electronic communications for paper submittal and review
- Web site advertisements and communications
- proceedings on CD-ROM
- a variety of presentation formats
- multiple software sessions
- panel sessions, and
- public access to the exhibitions.

All proved successful.

The wide range of software demonstrations were a particular highlight, with twenty one developers presenting their programs.

The plenary panel sessions were also very well received. They addressed two important questions: "How good is our state-of-the-art and how can we improve it" and "Where should IBPSA be leading the building simulation field".

Technical themes

Building Simulation '97 had several technical themes:

- Fundamentals and approaches for building related phenomena, such as heat, moisture, air, fluid and power flow, artificial and natural lighting, acoustics, indoor air quality and environmental impact.
- Implementation, integration, and quality assurance of modelling and simulation tools.
- Application of modelling and simulation in the design of new and refurbished buildings and HVAC systems.
- Integration of modelling and simulation in higher education.

Some outcomes

Several conclusions stand out.

In terms of software development, we seem to be in a transition period between the established, relatively monolithic simulation tools and a more modular new generation.

Various developments of established software were presented, some concerned with the merger of existing programs to give more all-encompassing capability, and others with new additions. New and improved user interfaces were demonstrated for a number of programs.

New, more modular simulation tools were also prominent. These allow flexibility in describing buildings and systems. In most cases, implementations were within customised simulation environment, while a few implementations were based on general environments such as Matlab and Simulink.

Interoperability was a recurring theme in BS'97. Emerging standards (such as STEP, and those being promulgated by the International Association for Interoperability) allow building simulation programs to communicate with each other and with CAD programs. A direct interface between a building simulation program and one of the major CAD programs was demonstrated.

Various papers dealt with the issue of quality control, in terms of validation and uncertainty analysis. Several authors stressed the need to educate and better support users: this is the aim of the CIBSE Application Manual for Building Energy and Environmental Modelling which was introduced at the conference.

Some papers stressed the need to undertake more work on appropriate interfaces to complement the developments at the theoretical level.

The world-wide-web is emerging as an apt medium. A pilot study with simulation software running remotely using the Web was presented. Another application involved delivering teaching classes in modelling and simulation classes over the Web.

Fundamental scientific developments were reported in the model reduction, air flow and moisture transport simulation areas.

One issue gaining more prominence is how to decrease the gap between the software and its effective use in practice. This was addressed in various papers covering, for example, aggregate space-time performance indicators and the communication of performance assessments of intermediate building design states.

The presented papers were not limited to energy in buildings but include a variety of issues such as daylighting, indoor air quality, acoustics, mould growth and large-scale renewable energy exploitation.

Two prizes were awarded. The IBPSA prize for most promising newcomer went to Veronica Soebarto of Texas A&M University, while the IBPSA distinguished service award went to Professor Jean Lebrun of the University of Liege.

We believe the 121 papers at BS'97 will be a valuable reference for future research. The proceedings are available in three-volume printed form and on CD-ROM. The CD incorporates colour images and comes complete with a pdf browser (in versions for PC, Mac and UNIX machines) and a full-text text search facility. The full reference is Proceedings of *Building Simulation '97, 5th International IBPSA Conference, Prague*, Volumes I, II and III, eds J D Spitler and J L M Hensen, ISBN 80-01-01646-3.

This issue of *ibpsa*NEWS only has space to include three BS'97 papers, but they well illustrate the width and depth of the conference in implementation, technology transfer, practice and application. A complete list of BS'97 papers is also included (page 22) and there is an order form for the proceedings, in both formats, on page 15.

IBPSA Prizewinners

Distinguished Service Award: Jean Lebrun, University of Liege

IBPSA's Distinguished Service Award recognises individuals who have 'a distinguished record of contributions to the field of building simulation over a long time period.'

Jean Lebrun, Director of the Laboratoire de Physique du Batiment at the University of Liege, was an early pioneer in building simulation research and has been a familiar face in the energy-in-building community since the late 1970s. He coordinated the Belgian national 'Energy' R&D programme from 1978 to 1982, and has represented Belgium on the executive committee of the IEA's Building and Community Systems programme for nearly 20 years. He has been Operating Agent for three IEA-BCS projects, Annexes 10 (System Simulation), 17 (Evaluation and Emulation of BEMS) and 30 (Bringing Simulation to Application). He chairs one of ASHRAE's Technical Committees, and is a member of two others and of the ASHRAE Journal's Editorial Committee. He was a progenitor of the Systems Simulation conference series, and chaired the technical committee for this year's CLIMA 2000. He has been principal investigator in many European and ASHRAE research projects, and published over scientific 200 papers.

Somehow, Jean manages to combine all this with family life and four children!

Most Promising Newcomer: Veronica Soebarto, Texas A&M University

Veronica Soebarto graduated in Architecture from the University of Indonesia in Jakarta in 1987. After three years teaching and practising architecture she moved to Texas A&M University to study for her Master of Architecture and then her PhD, under Larry Degelman. An accomplished programmer, Veronica wrote the new Visual Basic interface for ENER-WIN before going on to use ENER-WIN as the basis for a teaching course package on building performance prediction, and later in studies of energy efficiency strategies for buildings in Texas.

Veronica has published over a dozen papers, and made her first contribution to IBPSA conferences with two papers at BS'95, in Madison. This year, at BS'97, she has drawn on her PhD work for her impressive paper 'Calibration of hourly energy simulations using hourly monitored data and monthly utility records for two case study buildings'. Larry says this 'takes the art of calibration to new levels' — and adds that Veronica is a 'super person'. Truly a promising newcomer.

The Implementation of Industry Foundation Classes in Simulation Tools for the Building Industry

Vladimir Bazjanac[1] *and Drury B Crawley*[2]

Industry Foundation Classes (IFC) provide an environment of interoperability among IFC-compliant software applications in the architecture, engineering, construction, and facilities management (AEC/FM) industry. They allow building simulation software to automatically acquire building geometry and other building data from project models created with IFC-compliant CAD software. They also facilitate direct exchange of input and output data with other simulation software.

This paper discusses how simulation software can be made compliant with version 1.5 of the IFC. It also describes the immediate plans for expansion of IFC and the process of definition and addition of new classes to the model.

INTRODUCTION

In a fundamental sense, the building industry still operates the same way it has for many decades. It utilizes contemporary computer and information technologies — the backbone of many other industries today — only in the most rudimentary way. Though enormous amounts of information are generated for each project, exchanging that information among participants is inconsistent, usually reduced to a very small subset and only a few of the many participants in the project at a time. Most information is eventually lost. Some is generated in contradiction to other or is unnecessarily duplicated. Computer-based buildings tools are used in a stand-alone manner and cannot exchange data directly, even when they are used by the same party. This often results in omission, repetition, confusion, misunderstanding, error, delay, and, eventually, in litigation. Because of that, buildings take longer to design and build and cost more to construct and operate than necessary.

The potential for the use of contemporary information technology in the industry is enormous, and so are the potential cost savings. In his July 1994 report on the UK construction industry, Sir Michael Latham challenged the industry to use contemporary technology and save up to 30% of the cost of building projects by the year 2000. (Latham 1994) The use of *information* technology is clearly implied in the report.

THE INTERNATIONAL ALLIANCE FOR INTEROPERABILITY

In the spring of 1993, some of the major companies in the building industry of the United States started discussing ways of bringing modern information technology to the industry. This group formed the Industry Alliance for Interoperability in the early summer of 1994 and demonstrated interoperability among a group of CAD and simulation tools at the AEC Systems Show in Atlanta, Georgia in June 1995. The Alliance became a public organization, open to any member of the industry, in September 1995 and formally became a global organization in May 1996. At that point the name was changed to the International Alliance for Interoperability (IAI).

The IAI is an action oriented, not-for-profit organization. Its mission is to define, publish and promote specifications for Industry Foundation Classes (IFC) as a basis for world-wide AEC/FM project information sharing throughout the project life cycle, and across all disciplines and technical applications. IFC define a single, object oriented data model of buildings shared by all IFC-compliant applications. IFC project models define individual buildings for which compliant applications can exchange information accurately and error-free.

IFC are public and "open" for implementation and use by any member, are defined by the industry, are extensible and will evolve over time. Software implementation of IFC is proprietary to protect the data and technologies of member companies that compete in the market. IAI member companies hope that IFC may eventually become a de facto industry standard.

By June 1997, the IAI had seven chapters in North America, Europe and Asia (with three more organizing in Australasia and Europe) and a total of almost 500 member organizations and companies. The organization is governed by the IAI International Council. Each chapter has its own Board of Directors, Coordination Committee and various "domain" committees. Two technical committees — Research/ Advisory, and Software Implementation — are international and report to the International Technical Management Committee. Most committee interaction takes place through teleconferences and over the Internet. Individual chapters hold joint face-to-face meetings as often as once a month. International technical meetings take place quarterly.

IFC 1.0

The IAI announced the release of Version 1.0 of the IFC (IFC 1.0) in June 1996 and published the *End User Guide* (IAI 1996a) and a "pre-release" *IFC 1.0 Specifications.* (IAI 1996b) The complete documentation, available to IAI members through their respective chapters or the Internet, contains four additional volumes which describe:

- Domain processes enabled with the model
- The complete IFC 1.0 model specification

---

[1] *Lawrence Berkeley National Laboratory, Berkeley, California CA 94720, USA.*
[2] *U.S. Department of Energy, Washington, DC 20585, USA.*

- Static file exchange
- Runtime interfaces

IFC 1.0 consist of an object oriented core model, four independent resources models, and four initial domain extensions (architecture, building services, construction management, and facilities management). The core model defines objects, attributes and relationships common to domain extensions. Resource models document the definition of geometry, units and common utilities. Extension models define objects, attributes and relationships specific to domains.

Volume 1, *AEC/FM Processes Supported by IFC*, documents AEC/FM domain processes supported by Release 1.0. It effectively defines the scope of this release from the users' point of view.

Volume 2, *IFC Project Model Specifications*, defines the IFC project model — all information required by AEC/FM processes described in Volume 1, structured as object classes, data types and standard interfaces. This volume also discusses several key IFC design concepts, such as design intent, sharing of semantic relationships, model extension by application developers, static file exchange and runtime interfaces.

Volume 3, *IFC Model Exchange Specifications*, documents the data model view of the IFC project model. It contains the complete EXPRESS (ISO 1994a) and EXPRESS-G definitions of the core model, the four independent resources models (attribute-driven and explicit geometry, measures and utilities), the four domain models, and the description of file-based exchange (early vs. late bound toolbox implementation). Exchanged information can contain the entire project model or only a part of it. This volume also includes sections devoted to conformance testing. It provides sufficient information for application developers to use existing CASE tools (that automate the process of software implementation) directly with the EXPRESS definition.

Volume 4, *IFC Model Software Interfaces* contains a discussion and reviews of object models and languages and the documentation of Microsoft Interface Definition Language (MIDL) files for the core, resources and domain models in IFC. (Microsoft 1996)

The geometry resource models allow multiple representations of objects:

- Reference geometry
- Bounding box
- Attribute-driven geometry representation
- Explicit geometry representation

Reference geometry (oriented vertex) defines the object's origin point and orientation in three-dimensional space. The bounding box defines the rectangular envelope in which the physical object fits completely. (The shape representation of all HVAC equipment is limited to bounding box in IFC 1.0.) Attribute-driven representations define location, orientation and dimensions of building elements that have shape (such as walls, windows, etc.). Explicit geometry representations define building elements that have shape as solids; they are based on a subset of STEP Application Protocol 225, known as AP225. (Haas 1996)

PILOT IMPLEMENTATION

With the publication of IFC 1.0, 26 companies in the U.S., Canada and Europe announced their intent to make their software IFC-compliant. These companies include the major international CAD vendors Autodesk, Bentley, Nemetschek, and IEZ.

A smaller group, the IAI Pilot Implementers, showed proof of concept for IFC 1.0 at the ACS Show in Frankfurt in November 1996. Four CAD companies (Autodesk and Bentley from the U.S., and Nemetschek and Softech, German subsidiary of Softdesk, from Europe) exchanged files that contained geometry data. The exchange took place among special IFC-compliant versions of their commercial CAD software. These were "live" exchanges of fairly complex building representations, displayed as two-or three-dimensional drawings.

The three-dimensional model of an existing historical building that is a celebrated example of De Stijl architecture (Figure 1) was displayed by one CAD program and slightly modified. The modified, IFC-compliant CAD file was then sent to another CAD program that subsequently redisplayed the building showing the modification exactly as it was displayed by the previous CAD program. Separately, building elements (such as walls) were drawn "from scratch" and "passed" to the next CAD program, modified (e.g., by the addition of a window), "passed on," modified again and redisplayed with no loss of accuracy.

In addition, Autodesk showed "live" file exchange among four applications by their third-party developers (architecture, structural, HVAC and FM), running on top of an IFC-compliant version of AutoCAD 13 (Release 13c4a with special ARX extensions). The Autodesk demonstration followed a script in which a portion of a fairly large office building situated in Innsbruck (Figure 2) is remodeled. It showed how designers, engineers and facilities managers can work in an interoperable environment and effectively exchange information on the ensuing problems and solutions. Once again, the building and information exchange were non-trivial.

The November 1996 demonstration of interoperability in Frankfurt showed without any doubt that IFC project model data can be exchanged effectively and without loss of information. It showed that building geometry data can be automatically exchanged among applications and platforms *now* without any loss of accuracy.

The demonstration was repeated at the AEC Systems Show in Philadelphia, Pennsylvania in June 1997. The same implementers that participated in the demonstrations by the IAI and Autodesk in Frankfurt in November 1996 joined forces and demonstrated "live" exchange among a

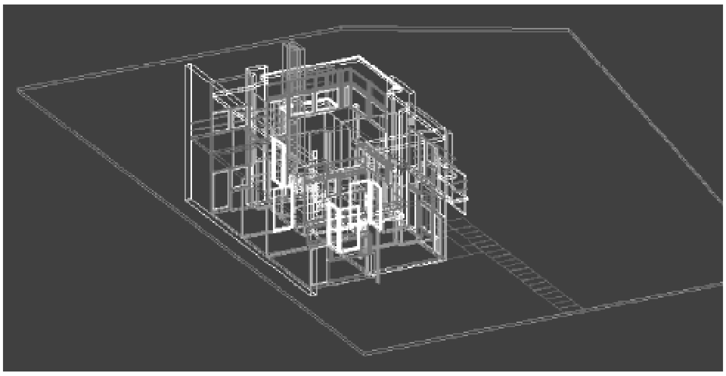


Figure 1 Three-dimensional model of Rietveld's Schroder House©
(courtesy of the Foundation Gerrit Th. Rietveld c/o Beeldrecht, the Netherlands)

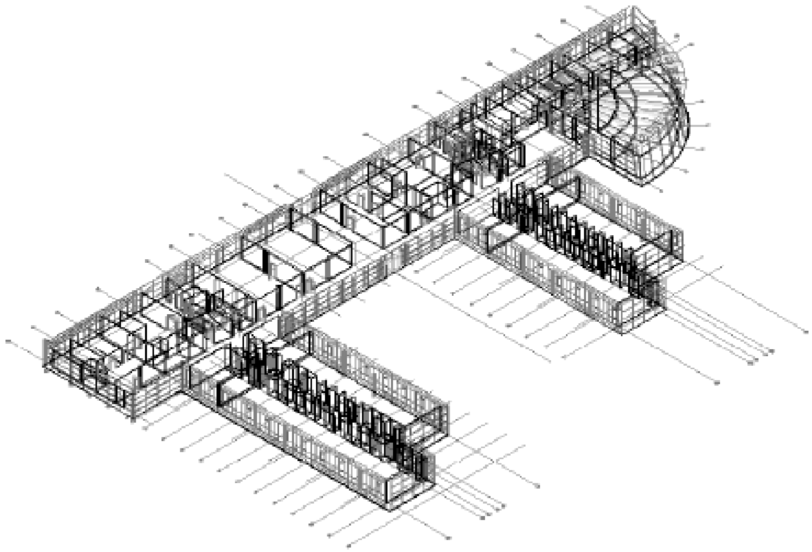


Figure 2 Three-dimensional model of the office building situated in Innsbruck *(courtesy of Acad-Graph)*

larger group of applications. The exchange followed a revised and more complex script of interoperability.

IFC TOOLBOX

To aid implementation, the IAI sponsored the development of a toolbox that facilitates writing IFC objects/ attributes (defined in EXPRESS in the IFC model) in C++ applications. The toolbox function and properties are perhaps best understood if one thinks of the toolbox as a layer above the file format that makes handling IFC-based data and programming IFC-compliant applications much easier.

Figure 3 shows a diagram of the IFC toolbox environment. The IFC Data Model is defined in EXPRESS; the IFC Project Model (which represents a specific building) is an exchangeable ASCII file. The toolbox contains all classes and methods included in the IFC Project Model. The application programmer deals only with classes in the toolbox and can ignore the details of the (original) complex representation of the building and other data — the programmer creates a module (within the application) that only translates toolbox objects to application objects. Data specific to the application or not contained in the IFC Project Model (non-IFC-compliant data) remain unaffected and are ignored by the programmer.

The application's IFC-compliant module receives existing object instances from and sends new instances to the toolbox. The toolbox itself is a library of functions that are present at runtime - the toolbox is integrated into the application. When the information from the Project Model (IFC-compliant data) is present when an application is compiled, the binding is called "early." When it is present at runtime, the binding is called "late."

The IAI Pilot Implementers (with the exception of Bentley, which used STEP tools) used an early-binding toolbox in the development of IFC-compliant software for the demonstration at the 1996 AEC Show in Frankfurt. They all reported that the toolbox was invaluable — it saved substantial time and programming resources. This toolbox was revised to include the stabilized core model and other revisions in Release 1.5 (see below), and became available in July 1997. *Concad* (the German company that developed the toolbox) will convert the toolbox to work with FORTRAN, C or other application programming languages for a fee. A late-binding toolbox (from another vendor) will be available before the specifications for IFC 2.0 are released.

CSTB of France demonstrated an example of a late-binding toolbox at STEP meetings in San Diego, California in June 1997. The tool is an SDAI C++ late-binding platform with persistent storage and transactional services that allows the exchange of data via STEP physical (Part 21) files. (ISO 1994b) It is a building model server for applications (such as mapping) that contains a module which maps from one EXPRESS schema to another. The mapping in the demonstration was from AP225 to IFC 1.0 schema (Figure 4). Software modules that map between other schemata can be added to the tool.

In the CSTB demonstration in San Diego AP225-compliant building geometry was generated using Nemetschek's Allplan FT. The tool was then used to map from AP225 to IFC 1.0 and import that geometry into AutoCAD. The building displayed by AutoCAD was identical to that displayed by Allplan FT. A group of French software developers plans to demonstrate the implementation of this tool in Clermont-Ferrand in September 1997.

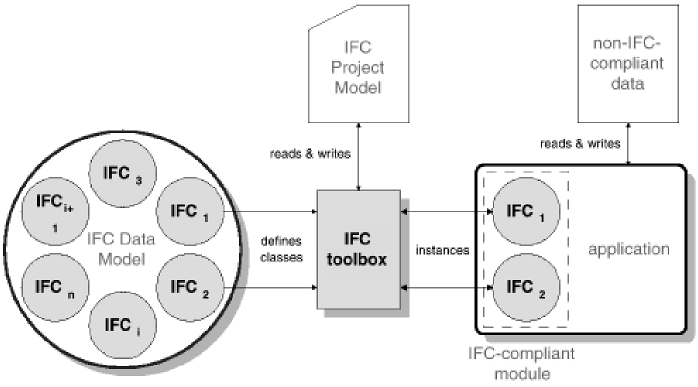


Figure 3 Toolbox environment (for early binding)

IFC DATA MODEL ARCHITECTURE

Work on IFC 1.5 is being completed as of this writing. This is an interim release for developers of commercial IFC 1.0-compliant software applications and the development of IFC 2.0. It allows developers to start implementing IFC in their software with greater ease and provide them with a stable environment for the future.

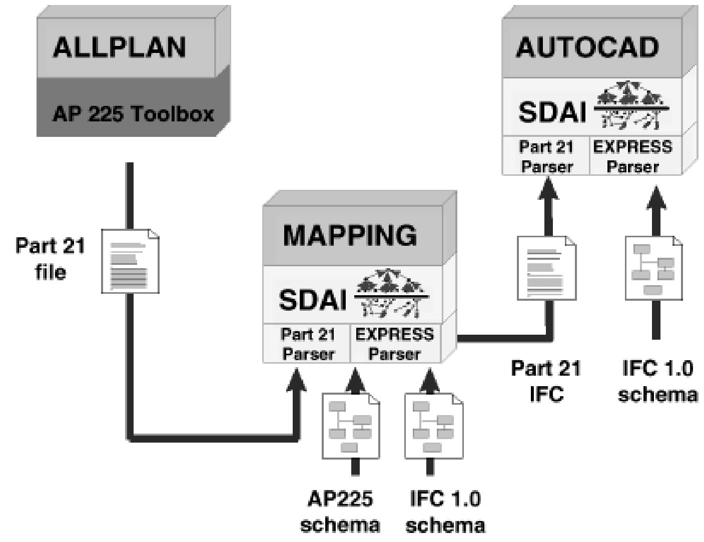


Figure 4 Late binding: exchange of geometry between AP225- and IFC-compliant applications *(adapted, courtesy of CSTB)*

The implementation will be based on the 1.5 version of the core and the 1.0 version of extension models. IFC 1.5 include:

- Stabilized core model
- Refined independent resources (revised geometry)
- Revised IFC model architecture

The stabilized core model is based on extensive review and on experience with pilot implementation of IFC 1.0. It provides a stable environment for development and implementation. The revised model architecture is based on decomposition into four conceptual "layers" (Figure 5). This allows for a modular structure, provides a framework for sharing of information among different domains, facilitates reuse of model components (as well as of software components), makes development and maintenance of the model easier, and permits upward compatibility between model versions. (IAI 1997a)

The basic layer (resources layer) contains independent resources that are grouped into "families:" general resource (classes identification, measure, time, and actor), geometry (shape representation, explicit and attribute-driven geometry) and business concepts family (classes property, classification, cost, and material). The geometry family will include a geometry library in IFC 2.0, and the business family will be expanded with history, state, version, status and approval resources.

The core layer contains the kernel and core extensions. The kernel provides all basic (non-AEC/FM specific) concepts required by the current IFC (classes object, relationship, attribution, and type definition), while core extensions provide AEC/FM specific extensions to concepts rooted in the kernel (classes product, process and modeling aids). Core extensions include classes space, element, site, building and story, as well as grid (a modeling aid).

The interoperability layer contains modules that facilitate interfaces with domain models: building elements and building service elements. The former includes classes wall, roof slab, floor, beam, column, built-in, door, window, and covering, ceiling. The latter includes equipment, fixture, and electrical appliance.

The domain models layer includes three domain models (architecture, building services and facilities management) and application models. These will be extended with limited versions of construction, structural, codes and standards, and cost estimating domain models in IFC 2.0. This layer also includes "interoperability adapters" that facilitate exchange with application models that are topologically different from IFC (i.e., that have a software architecture different from IFC).

A class may use or reference another class only within the same layer or a lower layer. Same layer references are limited to independent resources and core layers. Inter-domain references (within the domain models layer) are resolved through interoperability adapters and core extensions.

IAI ROAD MAP

The plan for development of IFC is defined in the IAI Road Map. It provides the schedule of future releases, defines the new processes to be enabled with each new release, and identifies technologies needed to enable the newly defined processes. It also identifies new opportunities to market specific new functionality. The content of the Road Map is constantly evolving.

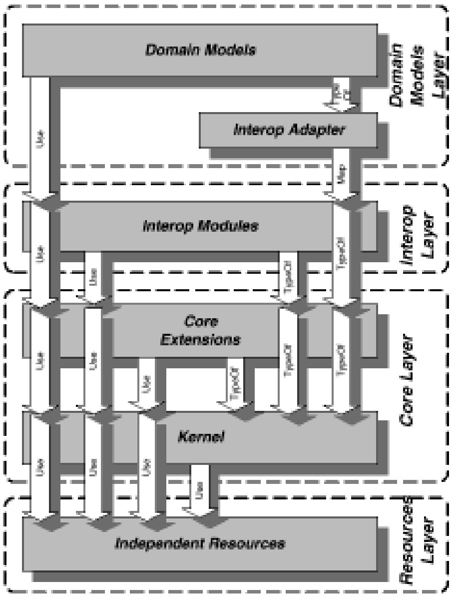


Figure 5 IFC 1.5 architecture

Future releases of IFC will include new domain extension models and expansion of the existing models. Release 2.0 will include three different types of additions:

- New object/attribute/relationship sets
- New IFC technologies
- Subsets of existing, non-IFC based domain models

New object/attribute/relationship sets will be added to the existing domain extensions as well as the new domain extension models. The new technologies (new to IFC and not yet widely used in the AEC/FM industry models) enabled in the next release will include general networks, access to external libraries and data bases, and semantic associations (a general purpose element aggregator). A subset of an external structural steel model (CIMsteel) is also slated for inclusion, if a collaborative agreement can be reached with its authors.

New additions to IFC are planned and executed as “IAI projects.” A project defines the general scenario in which the task that requires the specific addition is placed relative to AEC/FM practice, and defines what exactly needs to be added to IFC and the resources that are required and available to perform the work. (Rules of project formulation are defined in Volume 2 of IFC 1.0 documentation.)

Several projects planned for Release 2.0 and beyond are of particular interest to building simulation:

- Near completion of the architecture extension model
- General networks
- Further development of the building services extension model: HVAC air-side and water-side delivery systems, pathway design, and power and lighting systems
- Access to external libraries and data bases

Release 2.0 will include one project from the simulation domain, which will enable high-resolution visualization. The project will result in the addition of two new object/attribute sets to the IFC: “light source” (with attributes spectral power distribution, luminaire geometry and photometric output distribution) and “surface” (with explicit shape representation, dimensions, material and parameterization). These additions will make it possible for ray-tracing models to become IFC-compliant and benefit from automatic acquisition of geometry and pertinent building data. This, in turn, will reduce the time and cost of input preparation for such models, and make their use in daily practice more likely.

The current schedule for IFC events is:

- Release 1.5 June 1997
- Revised *concad* toolbox (based on IFC 1.5) July 1997
- Prototype commercial implementations based on Release 1.5 model November 1997 (at the ACS Show in Frankfurt)
- Final Release 2.0 end of 1997
- Commercial implementations of Release 1.5 on the market early 1998
- Prototype commercial implementations based on Release 2.0 model June 1998 (at the AEC Systems Show)

At present, all IFC data exchange is limited to the exchange of physical files as defined in STEP Part 21. The IAI plans to move to server-based (client-server) exchange, mostly as defined in STEP Part 22 by 1999. Direct object-to-object exchange is expected by year 2000.

IMPACT OF IFC ON BUILDING SIMULATION

Building simulation tools are currently used only occasionally in projects. High cost of entering data and inability to reuse information contained in the tool are some of the reasons. For example, it can take two or more weeks to enter building geometry for a fairly complex building into DOE-2, a sophisticated building energy performance simulation model. (Winkelmann et al. 1993) Most projects simply cannot afford the cost. For another tool to use the information generated by DOE-2, that information has to be interpreted and then transferred, which can take as much time as preparing the DOE-2 input. This information is lost to tools not engaged in the interpretation and transfer.

Without a common data model, software applications in the AEC/FM industry can directly exchange information only through interfaces that “translate” the data from one format into another. A unique (and costly) interface is required for each pair of applications in the exchange (Figure 6). IFC offer an environment for true interoperability in which multiple applications can exchange information directly, and in which no multiple, unique interfaces are needed.

Compliance with IFC will allow building simulation software, for the first time, to:

- “Talk” to each other directly and instantaneously
- Share and exchange information of common interest and/or reference

This can result in substantial and quite tangible benefits for everyone involved:

- Virtually cost-free access to building geometry and other related data
- Much shorter simulation cycle time
- Better participation of other relevant disciplines in simulation and analysis
- Better use of results of simulation

Automated, error-free acquisition of building and component geometry originally defined with IFC-compliant CAD software, coupled with automated access to IFC-compliant external libraries and data bases, can reduce input preparation effort to a fraction of what it is now. Manual quantity take-off and transfer of information from

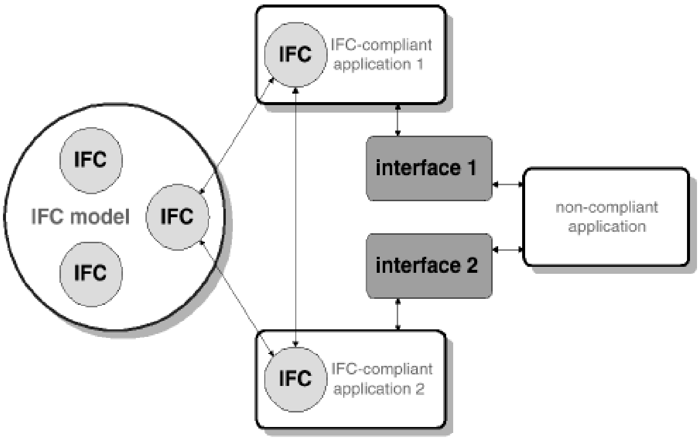


Figure 6 Software interoperability: IFC-compliant applications can exchange information directly, while non-compliant applications must have separate interfaces

textual sources can be eliminated. No information will be lost. This can reduce simulation cost and turn-around time by orders of magnitude and make the use of simulation in daily practice a feasible reality. This makes the U.S. Department of Energy's goal of using energy performance simulation on every building attainable.

In addition, *all* parties involved in the design, construction and/or building operation can have direct and timely access to project information, including the results of simulation. This can result in higher quality of both the simulation and the whole building.

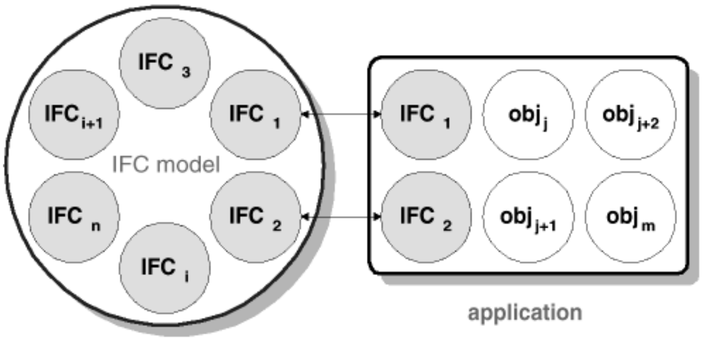


Figure 8 Partially IFC-compliant software application

IMPLEMENTATION OF IFC IN BUILDING SIMULATION SOFTWARE

All simulation tools need data to perform their task. The proportion of data available from IFC Project Models will determine the extent to which a simulation application will be IFC-compliant: fully, partially or not directly compliant at all.

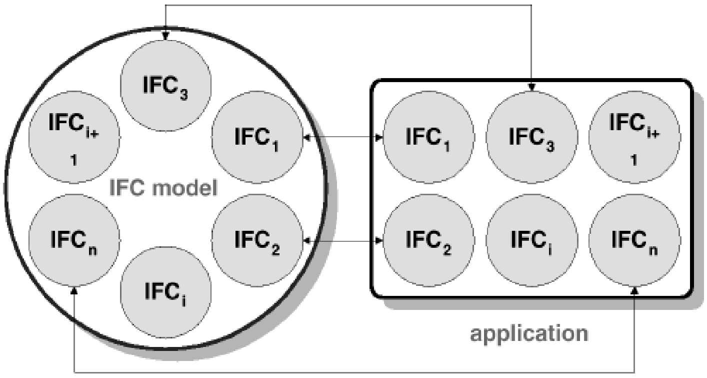


Figure 7 Fully IFC-compliant software application

New simulation tools should be conceived from the beginning as object oriented and fully IFC-compliant, to reap all the benefits of potential interoperability. In the case of a fully IFC-compliant simulation tool (Figure 7) there must be a 1:1 relationship between the objects defined in the IFC Project Model and those defined in the tool. With the toolbox and IFC documentation the mapping of IFC onto a new, object oriented software structure should be relatively "pain-free." All data necessary for simulation can be obtained from IFC-compliant sources.

Often, a simulation tool uses only a limited set of the data available in the IFC Project Model. In such cases it makes more sense to make the tool only partially compliant (Figure 8), even if the tool's structure is object oriented. Only those classes in the IFC Project Model that contain data pertinent to the simulation are mapped to the simulation tool. The remaining data needed for the simulation are obtained from other (either internal or external) non-compliant sources. If such a simulation model needs to exchange these "non-compliant" classes and/or data with another partially compliant model, that exchange is facilitated by IFC interoperability adapters and modules (see IFC Data Model Architecture above). Most existing simulation tools, object oriented or not, that become IFC-compliant fall into this group.

Few existing simulation tools are object-oriented or amenable to incorporation of internal, IFC-compliant interface modules. To make them object oriented or add new internal interface modules would most likely involve a *complete* re-write, which is often not plausible. For such tools there is but one option: make them indirectly and only partially compliant (Figure 9).

This requires writing an *external* object oriented interpreter that contains the same objects as those pertinent to the simulation in the IFC Project Model, mapped 1:1. The essential function of the interpreter is to "translate" data from the IFC Project Model into the simulation tool data format, and vice versa. The simulation still runs as before and continues to acquire data not contained in IFC from the same sources as before, but can now *also* obtain data from IFC Project Models. Through the interface (which is a separate executable), the simula-

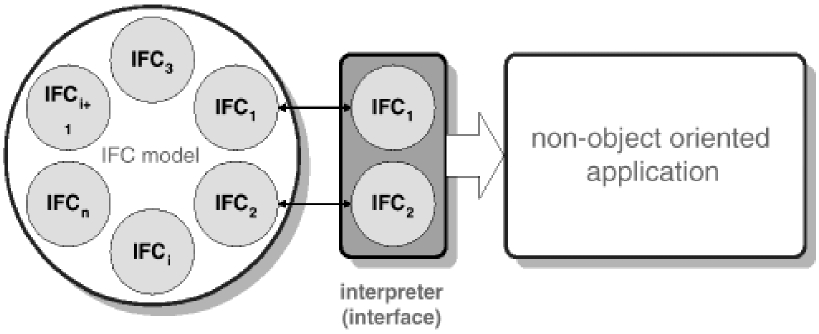


Figure 9 Non-compliant software application

tion tool can now exchange IFC-compliant data with other IFC-compliant applications or interfaces. In that fashion the interpreter converts the non-compliant into a partially IFC-compliant simulation tool.

This approach has been used at LBNL to make several simulation tools for different aspects of building performance (such as energy performance, daylighting, lighting and airflow) IFC-compliant. Most of these tools are large, quite old and not object oriented. A new tool, the Building Design Advisor (BDA), will map IFC that contain building geometry and other information pertinent to LBNL simulation tools to its own object oriented model. BDA will also contain the mechanisms to convert data imported from IFC Project Models to the formats of the tools that use the particular data, and vice versa. (Papamichael et al. 1996)

The approach will allow users of tools linked to BDA to automatically acquire building descriptions from project models generated by IFC-compliant CAD software, as well as limited non-geometrical information already contained in IFC. As the IFC Data Model becomes more complete, new classes containing non-geometrical information required by other tools can be added to BDA.

HOW TO ADD NEW OBJECT/ ATTRIBUTE/RELATIONSHIP SETS

Most building simulation tools use substantial volumes of data in addition to building geometry, data that cannot yet be contained in the IFC Data Model. New object/attribute/relationship sets have to be added to the IFC Data Model to allow the inclusion of such data. (IAI, 1997b) The responsibility to define what needs to be added to IFC falls on simulation users and developers. (Bazjanac and Selkowitz 1997)

If not already a member of the IAI, one should join the appropriate chapter. Information on joining is found on the web at http://www.interoperability.com. Once a member, one can propose new IAI projects through the domain committees that will:

- Identify object/attribute/relationship sets needed for simulation that have not yet been defined for inclusion in IFC
- Define an explicit IAI domain project that includes those object/attribute/relationship sets

After that, one should work within one's domain committee to get the proposed project on the IAI Road Map.

RELATIONSHIP OF IFC TO STEP AND COMBINE

The IAI and the International Standards Organization's (ISO) STandard Exchange of Product model data (STEP) effort complement each other. The IAI is actively using some of the technology developed by STEP and is providing STEP with testing ground in the AEC/FM market place. Most IAI technical experts are also members of STEP. STEP granted IAI official liaison status in June 1997.

It is important, though, to recognize the difference in mission between STEP and the IAI. While STEP is setting standards, the IAI is responding to immediate needs of the AEC/FM industry. By definition, results of STEP work must be proven and robust. IFC are continuously evolving, and are occasionally neither proven nor robust. STEP *must* take as much time as necessary; the IAI *must* act quickly. That is why the two organizations complement each other so well, even if they do not always use common architecture or methodology. (Bazjanac and Selkowitz 1997)

When appropriate STEP technology is available, the IAI uses it. When it is not, the IAI develops its own solutions. For example, the IAI is using STEP Part 21, and has borrowed from STEP General Resources (Parts 41, 42 and 43) and AP225 (explicit shape representation). It will probably also borrow from AP230 (structural steelwork) when it is adopted. STEP Part 106 (the Building Construction Core Model) and the IFC core model are being developed in parallel. The goal is for both organizations to use identical models. The development of STEP AP228 (HVAC) involves several members of IAI Building Services domain committees.

The JOULE project Computer Models for the Building Industry in Europe (COMBINE) is perhaps the best known previous attempt at achieving interoperability in the AEC/FM industry. (Augenbroe 1994) Two important factors separate COMBINE from the IAI:

- COMBINE's interoperable environment is, by design, limited to a selected group of software applications
- COMBINE preceded the IAI by several years

COMBINE and IFC differ conceptually and methodologically. The COMBINE team limited the scope of its work to eight software applications, and the exchange was designed for data pertinent specifically to those eight applications. In contrast, the scope of the IAI explicitly includes the dealing with *any* software application. This necessitated a different approach and method. (Bazjanac and Selkowitz 1997) Because COMBINE preceded the IAI by several years, STEP technology available at the time did not include all the elements relevant to the AEC/FM industry it includes today, such as AP225 or the currently developing Building Construction Core Model (BCCM). (Wix and Liebich 1997)

The IAI benefited greatly from the experience of those who preceded it. The IAI Research/Advisory Committee studied the available documentation on COMBINE and learned from that - some of it was later reflected in the development of the IFC.

CONCLUSIONS

Building simulation software can reap major benefits from IFC *now*. Automatic, error-free acquisition of building geometry and other data available from project models developed with IFC-compliant CAD software can dramatically reduce the simulation input time and cost, and can shorten the simulation cycle. It can facilitate the direct exchange of data among IFC-compliant applications, and can make it possible to use building simulation in daily practice in the AEC/FM industry.

To benefit from IFC, simulation software developers need to make their software IFC-compliant, directly or indirectly. With complete documentation of IFC 1.0, a refined and stabilized model architecture, the associated toolbox and experience from pilot implementation, this is possible *now*.

With major AEC/FM software developers and industry forces behind it, the IAI will continue the development of IFC. Future releases of IFC will include additional domain extension models. Existing models will be completed. This will eventually provide an environment of true interoperability for building simulation tools.

ACKNOWLEDGEMENTS

The authors wish to thank Jim Forester, Wolfgang Haas, Thomas Liebich, Patrice Poyet, and Jeff Wix of the IAI Research/Advisory Committee, as well as Stephen Selkowitz of the Lawrence Berkeley National Laboratory for their contributions to this paper.

REFERENCES

Augenbroe, G. 1994. "The COMBINE Project, An Overview", Proceedings of *the First ECPPM Conference, Dresden*.

Bazjanac, V., and S. Selkowitz. 1997. "The International Alliance for Interoperability: Its Mission and Its Method", LBNL, August 1997.

Haas, W. 1996. "Product Data Representation and Exchange - Part 225 Application Protocol: Building Elements Using Explicit Shape Representation", ISO/DIS 10303-225.

ISO. 1994a. *ISO-10303-Part 11*, ISO-10303-1:1994

ISO. 1994b. *ISO-10303-Part 21*, ISO-10303-1:1994

International Alliance for Interoperability. 1996a. "End User Guide to Industry Foundation Classes", IAI, August 1996.

Industry Alliance for Interoperability. 1996b. "IFC Project Model Specifications, Version 0.94", IAI, May 1996.

International Alliance for Interoperability. 1997a. "IFC Model Architecture", IAI, March 1997.

International Alliance for Interoperability. 1997b. "A Guide to the Development of Industry Foundation Classes", IAI, May 1997.

Latham, Sir M. 1994. "Constructing the Team", H.M.S.O. c1994, 011752994x, 692.068 LAT, July 1994.

Microsoft. 1996. *Visual C++ 4.0*, Microsoft Press.

Papamichael, K., J. LaPorta, H. Chauvet, D. Collins, T. Trzcinski, J.Thorpe, and S. Selkowitz. 1996. "The Building Design Advisor", LBL-38584, March 1996.

Winkelmann, F. C., B. E. Birdsall, W. F. Buhl, K. L. Ellington, A. E. Erdem, J. J. Hirsch, and S. Gates. 1993. *DOE-2 Supplement, Version 2.1E*, LBL-34947, November 1993, Lawrence Berkeley Labo-ratory. Springfield, Virginia: National Technical Information Service.

Wix, J. and T. Liebich. 1997. "ISO 10303 - 106 WD: Building Construction Core Model", NIST, Doc. Ref. N599, June 1997.

❖

An Application Manual for Building Energy and Environmental Modelling

David Bartholomew[1], Jon Hand[2], Steve Irving[3], Kevin Lomas[4], Lori McElroy[2], Foroutan Parand[5], Darren Robinson[5] and Paul Strachan[2]

This paper describes the contents of an application manual for building energy and environmental software to be published in the UK. The purpose of the manual is to provide advice to practising engineers on the selection and appropriate application of such software. This is believed to be the first such manual. UK organisations involved in the project are the Department of the Environment, CIBSE, the Building Research Establishment and BEPAC. Topics covered in the paper include the reasons why the manual was considered necessary, a summary of the overall contents of the manual, and a discussion of the implications for the future development of simulation programs.

INTRODUCTION

In response to the increasing need for the use of building energy and environmental software in the course of building design, a CIBSE Application Manual is being written to provide guidance on the selection and appropriate use of such software. The manual is being produced under the UK Department of Environment's Partners in Technology Scheme led by the Building Research Establishment (BRE). BRE, the Chartered Institution of Building Services Engineers (CIBSE) and IBPSA's UK affiliate BEPAC are the main partners of the project, with funding provided by the Department of Environment and CIBSE. In producing the manual, the partners were assisted by a number of contract authors with considerable input from practising CIBSE members in the form of reviews and comments.

In the case of traditional methods, detailed guidance is given in the guides produced by CIBSE and ASHRAE. However, no comparable information is available for users of simulation software. The objective of the application manual was, therefore, to give general advice to practitioners on program selection and application in areas where the use of simulation is particularly beneficial. Major topics within the manual include:

- the role and coordination of modelling in the design process;
- the applicability of simulation programs;
- guidance on selection of programs;
- guidance on program use;
- illustrative case studies.

The sections in this paper summarise each of the individual chapters in the manual: the role of models in the design process; establishing a simulation capability; the effective use of software; and case studies. Before this, the perceived need for the manual is discussed. At the end of the paper, the implications of the manual for the future development of simulation programs is discussed.

---

[1] *DBa,16 Nursery Gardens, Purley on Thames, Reading RG8 8AS, UK*

[2] *ESRU, University of Strathclyde, Glasgow G1 1XJ, Scotland, UK*

[3] *Oscar Faber Applied Research, Marlborough House, 18 Upper Marlborough Road, St Albans AL1 3UT, UK*

[4] *Inst of Energy & Sustainable Development, De Montfort University, Leicester LE1 9BH, UK*

[5] *Building Research Establishment, Garston, Watford WD2 7JR, UK*

NEED FOR GUIDANCE

The rationale for this manual stems from two main premises:

- an interest in energy saving in buildings as a result of concern for the environment and in particular the recognition that in the UK, as elsewhere, buildings are responsible for a significant proportion of total CO_2 emissions; and
- a recognition that traditional steady state and simplified dynamic calculations, while sufficient for sizing air-conditioning systems for design conditions, may not be adequate for innovative designs incorporating natural or mixed mode ventilation or other passive features. They also cannot provide sufficient information for designers to fine tune the design of a building, its systems and controls.

There is a move in modern buildings to greater interaction with the external climate and increased variation in internal conditions compared to traditional buildings, particularly those with full air-conditioning systems. The increased responsiveness is a result of several factors such as greater use of natural ventilation and natural daylighting, more advanced glazing technologies, higher levels of insulation and airtightness, higher levels of internal gains from equipment, and a greater capability for control of heating and cooling equipment and lighting.

Building Energy and Environmental Modelling (BEEM) software can potentially be used to predict the performance of such buildings and to study different design options and "what if" questions. Although the potential for simulation is large, there has not been a large uptake, with significant barriers being uncertainty regarding the capabilities of the programs and, with the exception of a limited number of experts, no general understanding of how and when to use such programs. There is a lack of coherent guidance on the selection and application of suitable software.

The CIBSE application manual was therefore targeted at two main groups:

a) Partners, managers, or engineers who decide the firm's quality and capability strategies as well as the development of staff resources and training, and who would be responsible for deciding whether or not to use modelling.

b) Engineering and modelling specialists whose day to day job it is to carry out design and modelling.

The overall aims of the manual were to:

- raise the awareness of the building services engineers, architects and clients to the capability of energy and environmental software;
- give a brief, but practically sufficient, account of most of the issues of importance in the selection of such software for those who wish to establish in-house modelling capability;
- give practical guidance to users of BEEM software to carry out the modelling in an appropriate way with due regard to quality assurance.

The manual covers thermal and energy modelling, lighting and daylighting modelling, and airflow modelling, although thermal modelling is dealt with in more detail than the other two areas.

ROLE OF MODELS IN THE DESIGN PROCESS

Because the manual is aimed at designers who may be considering the inclusion of modelling, some emphasis was given to discussing the role that environmental modelling can play in the design process, emphasizing that modelling is a means to an end, not an end in itself, and that, used properly, modelling can provide a focus around which the design develops and by which performance is assessed.

The objectives for this chapter of the manual are thus:

- to identify the benefits of using environmental models;
- to explain how models can help different classes of user;
- to describe the applications to which modelling is best suited;
- to provide examples of how modelling can be used within the various stages of the design process; and
- to give guidance on how to initiate a modelling study.

One of the key issues addressed by the manual is to clarify why and when modelling should be used. The argument is presented that many design questions cannot be addressed by traditional design methods. Two examples are given:

- In heating system design, traditional methods estimate the amount of heat that must be put into a room to maintain the desired temperature during conditions of no sun, constant external temperature and no internal gains. These approximations can lead to oversized plant, with consequences for both increased capital and operating costs due to increased running at part load. Modelling can provide the same answer, but also answers questions such as:
  a) What is the benefit of passive solar gain in offsetting heat demand?
  b) Can the heating be switched off before the end of occupancy, without affecting comfort?
  c) How should the heat emitter be integrated with the ventilation opening to avoid cold draughts in naturally ventilated buildings?
- For calculation of summertime temperatures, the CIBSE manual procedures are based on the admittance method, which is a harmonic analysis using a single frequency with a period of 24 hours. The variation in external temperature, solar radiation and internal gains are all approximated to a single sine wave with this single frequency, repeated daily. However, internal gains in many buildings now form an increasingly significant proportion of the heat gain and these gains are not well represented by a sine wave. Also, the use of high capacity structures result in the capability of storing heating and cooling energy, and this is difficult to represent with traditional calculation techniques.

Other stated benefits of modelling are:

- BEEM software can be used to analyse a much greater level of detail than traditional calculations, with fewer inherent simplifications and assumptions.
- Modelling can provide answers to questions which are completely outside the remit of methods contained in the traditional guidebooks: for example, computational fluid dynamics (CFD) can predict air velocities, turbulence intensities and temperature distributions for a given set of boundary conditions as part of optimising the positioning and performance of air diffusers.

The greatest benefit of modelling is believed to be that it provides a focus within the design team, helping all members of the team throughout all stages of the design/construct/operate cycle. The manual therefore describes how modelling can impact on each member of the design team — the client, architect, engineers, cost consultant, project manager and planning authority.

Clearly, the correct modelling tool must be used. The manual deals with the application areas of thermal, lighting and airflow, and at least for this first edition, does not address other aspects such as acoustics, fire, smoke and pollution dispersal, structural analysis or cost analysis. This restricted choice was made for several reasons — to enable the manual to give specific rather than general advice, to address domains for which a large variety of analysis methods exist, to cover what are probably the most common domains that are tackled by modelling, and to focus on those areas of most importance to "energy and the environment".

Within each application domain covered, there are a number of tools which use methods of varying complexity and sophistication. These methods range from simple correlations of laboratory or field measurements right through to complex numerical simulations of the fundamental physical processes. Tables 1, 2 and 3 summarise the methods, typical applications and principal limitations for load calculation, plant and control simulation, and energy simulation (for energy consumption, internal thermal comfort etc.). Only the more advanced methods, italicised and shaded darker blue in the tables, are covered in the manual. The various methods available for lighting and air movement analysis are similarly described in the manual.

One difficulty found in writing this chapter was in striking a balance between overemphasising the benefits of modelling and making the introduction of modelling into the design process a daunting task.

ESTABLISHING A SIMULATION CAPABILITY

This chapter of the manual gives guidance on how to set up an in-house simulation capability and discusses the costs associated with software, hardware, staff resources, training and the operation of quality assurance procedures. Because successful simulation-based analyses need both

Table 1 Load calculation methods

Method	Typical Application	Principal limitation
Elemental	Calculate thickness of insulation	Only deals with individual wall/roof constructions, not whole buildings
Steady state	Radiator/boiler sizing	Ignores free gains and dynamic effects
Simple dynamic	Chiller sizing	All heat gains must follow repeating sine wave
Advanced dynamic	*Annual heating/cooling loads*	*Fixed time steps*
Full simulation	*Annual heating/cooling loads*	-
Design charts	*Various*	*Fixed range of parameters*

Table 2 Plant and controls design methods

Method	Typical Application	Principal limitation
System efficiency	Calculate heating energy from room loads	Cannot deal with air conditioned or mechanically ventilated buildings
Pre-configured system	*System design*	*Restricted range and configuration of systems*
Pseudo-dynamic component	*System and control optimisation*	*Ignores component dynamics, control lags*
Dynamic component	*Analysis of control stability*	*Exacting input data requirements*

Table 3 Energy simulation methods

Method	Typical Application	Principal limitation
Annual	Heating energy	Only valid for simple heating systems (e.g. domestic)
Seasonal/bin	Heating and cooling energy	Ignores building dynamics and system/climate interactions
Hourly	*Building energy use*	-

Table 4 Establishing a simulation capability: key issues

Choosing the right program	
Modelling methods	Can the program analyse your problems?
Program coding	Do you need source code?
Computer specification	Do you have the right machine?
Input interface	How easy is the program to use?
Output interface	Can results be understood?
Linked modules	Can CAD and other software help?
Associated databases	Is necessary data readily available?
User support	Can you get help easily?
User base	Are there other users who can be contacted?
Validation	How accurate is the program?
Cost	What are the costs for the program, training etc?
Producing reliable results	
Human resources	What people with what skills are needed in a simulation team?
Databases and support program	Where does the input data come from?
Training	What, when and for whom?
Quality assurance	How can you make sure a good job is done?

the right program and skilled operators, the chapter outlines:

- the factors to be considered when selecting the specific program(s), and
- the quality assurance infrastructure which must be put in place.

The factors to be considered are given in a detailed checklist, with the associated issues for each factor. Table 4 summarises the main areas.

Practitioners are naturally concerned with the accuracy of programs, and one problem is how this accuracy can be assessed (although it must be remembered that a similar problem also pertains to traditional methods). Clearly a manual of this type cannot address the question of validity in any depth, although it is a vital issue for potential program users. At present, there is no accreditation procedure for BEEM software — an issue which must be addressed in the future. However, a large effort has been put into checking the predictions of programs within several major validation studies. The manual discusses the issues and techniques of validation as they affect potential program users, and references recent validation work.

When discrepancies in predictions from different programs have been found, it has sometimes been shown to be as a result of user error rather than an inherent program failure. Although further work on program validity and estimation of prediction uncertainties is necessary, future emphasis should perhaps be directed towards improved user training and quality assurance.

The manual addresses the problem of establishing a suitable quality assurance infrastructure. The notion of a simulation team, consisting of a team manager who is responsible for the quality of the work undertaken by program users, is introduced. The cost of establishing a simulation capability needs to consider programs and their hardware as well as human resources, training and the operation of quality assurance procedures.

EFFECTIVE USE OF SOFTWARE

The chapter dealing with this subject has the aim of providing sufficient information for a relatively new user to be able to define and generate a model. The emphasis is on thermal modelling, but with some coverage of lighting and airflow modelling.

The main contents of the chapter provide:

- procedures for undertaking assessments against defined performance objectives;
- checklists for users of simulation programs;
- guidance on sources of input data; and
- guidance on results analysis and reporting.

One of the first requirements to be addressed when undertaking a modelling study is to translate the design questions into specific modelling tasks for which predictions can be made. Some examples of this are given in Table 5.

Table 5 Translating design questions to modelling tasks

Design questions	Modelling tasks
Does this building require air conditioning?	Determine the peak summertime temperatures and their frequency of occurrence with a naturally ventilated scheme.
If so, which air conditioning system will be the most energy efficient?	Compare the degree of temperature and humidity control for various system configurations and evaluate the required capacity and energy consumption.
How can daylight penetration be maximised and glare sources eliminated?	Evaluate and compare daylight factors and glare indices for a range of glazing options and shading devices with and without each feature.
Will displacement ventilation be able to cope with the high levels of internal gain?	Determine the occupied zone comfort levels for a range of loadings and supply air conditions.

Before the models can be created, it is necessary to make important decisions on the form of the model. The chapter discusses some of these decisions - how the reality should be abstracted, the need for a reference against which design options can be tested, the model zoning strategy, the climate sequences to be used, and the degree of modelling resolution required of various aspects of the model. In practice, there are not always easy answers, and there is likely to be some difference of opinion amongst modellers, particularly as to the level of detail required. However, the manual gives a checklist of the issues that must be addressed, with suggestions on how to proceed for new users.

Ideally an application manual should give specific instructions which could be followed to achieve the desired performance measure. For some standard performance assessments, such as overheating risk analysis, regulations compliance or energy labelling, it is possible to develop a procedure which gives the user step-by-step instructions. However, such detailed procedures tend to be lengthy and program specific, and therefore would be out of place in the manual. Also, in practice, the range of design questions asked of modellers is diverse, and it was considered that the manual should only outline general strategies.

The bulk of the chapter deals with program data input requirements. Again, the level of detail possible is limited because it is the intention of the manual that it should not deal with particular programs, and there are differences in specific requirements for each program. However, for each subject area - climate, site, geometry, construction, internal gains etc. the manual sets out in general terms what the data requirements are, the sources of the required data, issues concerning how to model, common mistakes that are made, and lastly a checklist for the user. Emphasis is placed on the need for sensitivity studies where there is uncertainty in what are the correct inputs, in order that the user can get a feel for the likely uncertainties in the model predictions.

Some examples of issues raised when clear guidance is not easy to give are:

- A restriction in program capability: ground heat losses are not generally well modelled, with the majority of programs not taking lateral heat flows into account. These can be significant for uninsulated ground slabs.
- Uncertainty in physical process modelling: there has been much debate over “correct” values for the internal convection coefficients, and there is a need for further work to

generate guidance for appropriate coefficients for different heating and cooling regimes.

- Uncertainty in data inputs: over/under estimation of total internal gains and occupancy levels can seriously affect results. For new buildings, these gains are not always known in advance, so it necessary to create a number of possible scenarios rather than attempting to define actual schedules. The resulting predictions are therefore representative rather than accurate.

CASE STUDIES

A number of case studies are given to serve as examples of procedures discussed within the rest of the manual. These case studies were chosen to show the use of BEEM software in practice, the benefit derived from its use, and examples of design decisions made on the basis of modelling results. The projects had in common the fact that the designers had to resolve questions which could not be addressed by traditional calculation methods alone.

The main selection criteria were designed to:

- ensure the case studies illustrated key points raised elsewhere in the manual — the merits of the specific buildings are less important than the way in which modelling was used in the design process;
- cover the diversity and depth of questions posed by designers;
- cover typical design projects such as extensions to existing buildings and refurbishment, as well as prestige new buildings; and
- cover both highly serviced buildings as well as those incorporating more passive approaches to environmental control.

Each case study is presented in a format which corresponds to earlier chapters of the manual dealing with how modelling should be used within design. Thus the key design questions are described, followed by the translation of these into modelling tasks, a discussion of the modelling strategy employed, details of model creation, and lastly a summary of results from the modelling studies. Where assessments were phased, the design iterations and evolution of the models and performance criteria are also discussed.

It is hoped that the detail given in the case studies will allow readers to understand the use of modelling in projects of varying complexity, and the associated nature of the interactions within the design team.

CONCLUSIONS: IMPLICATIONS FOR PROGRAM DEVELOPERS

The decision to produce an application manual for building energy and environmental software is a result of an awareness that the use of such software is increasing and is likely to become more prevalent. However, in writing the manual, it also became clear that there is still considerable scope for further development of software and the techniques for using it in design. There are many questions which do not have universally accepted answers, such as:

- how should modelling be used in the design process?;
- how can the reliability of predictions be quantified?; and
- how can quality assurance guarantee that the model created was that intended?

It was also clear that contemporary software has limitations — in its functionality as well as ease of use — and that some physical processes are not well represented. In addition, design is multi-faceted and modelling is only just starting to coherently address the problem of integration, when a design decision can affect several aspects of the performance. However, it should always be remembered that a comparison must be made with traditional methods, which in general have more simplifications and assumptions built into them.

From a consideration of the general need for software to improve, and specifically from issues arising during the writing of the manual, the following areas were identified as being of importance to program developers:

- Checklists for data inputs are given in the manual to aid program users. It is believed that developers could introduce a form of such checklists into their user interfaces to aid in model development and quality control.
- In many cases it is true that strict sequential steps for operating programs cannot yet be given except for very constrained problems, but guidance and checklists can be given. Again, it should be possible for program developers to refine the general checklists and guidance given in the manual to more specific instructions for their particular program. In some cases, these instructions could be specialised for various applications.
- If software is to become easy to use by designers, program developers must:
  a) improve interfaces and help facilities, and provide greater feedback to users;
  b) provide more comprehensive databases; and
  c) provide intelligent defaults for early stage design.
- Developers need to continue to extend the capabilities of their programs to reflect the increasing desire for an integrated view of design.
- To improve confidence, programs should have a readily accessible history of validation studies and versioning control of the software. Preferably validation checks should be built in.
- The community as a whole should generate accreditation procedures. These may be for programs (e.g. development of benchmarks to help ensure consistency between programs of the same type), and/or for users (e.g. development of training courses and possibly user certification).

The science of modelling is continually expanding and so guidance on the best ways to use this important class of design aids will need to evolve. The Application Manual for Building Energy and Environmental Modelling provides a good foundation on which this developing guidance can be based.

ACKNOWLEDGEMENTS

Thanks are due to the reviewers who have commented on draft versions of the application manual.

❖

IBPSA Publications Order Form

Proceedings of IBPSA's Building Simulation conferences are available from the Secretary as long as stocks last.
Prices are:

Item #			# Papers / pages	Member Price*	Non-Member Price*	Number ordered
BS-85	Seattle, WA, USA	(Xerox copy)	59 / 416	US$ 40	US$ 75	[ ]
BS-89	Vancouver, Canada	(Xerox copy)	54 / 300	US$ 40	US$ 75	[ ]
BS-91	Nice, France		85 / 675	US$ 55	US$ 90	[ ]
BS-93	Adelaide, Australia		71 / 570	US$ 55	US$ 90	[ ]
BS-95	Madison, WI, USA		81 / 717	US$ 70	US$ 105	[ ]
BS-97	Prague	PRINTED	119 / 976 (3 vols)	US$ 95	US$ 130	[ ]
		CD-ROM	119 / 976	US$ 50	US$ 75	[ ]

* Orders for two or more sets of proceedings are discounted by 30% of total cost.

NOTE: Add 15% to all orders shipped within North America.
Add 15% to all orders shipped overseas via surface mail.
Add $25 for first copy plus $15 for each additional copy for shipping overseas via air mail.
CDs are shipped at a flat rate of $10 for the first copy plus $5 for each further copy.

Enter the number of copies of each title that you wish to order in the list above, and check the method of shipping:

[ ] Domestic N.A. mail [ ] Overseas surface [ ] Overseas Airmail

Amount Enclosed: US$ _________ or Purchase Order Number:___________________

DELIVERY DETAILS

Name: ____

Title: ____

Organization: ____

Street Address: ____

City, State, Zip: ____

Country: ____

Telephone: ______________________ Fax: ______________________

e-mail address: ____

Please pay by **Check** or **M.O.** to: **IBPSA** c/o Larry Degelman, Dept. of Architecture, Texas A&M University, College Station, TX 77843-3137, USA. Tel: (409) 845-1015, Fax: (409) 862-1571, e-mail: larry@archone.tamu.edu.

or by **Purchase Order** by faxing this form to **IBPSA** c/o Larry Degelman (409) 862-1571. **Purchase Orders must be signed:**

Date: ______________________ Signature: ____________________________________

Recent Czech Building Energy Simulation Case Studies

F. Drkal, T. Dunovska, M. Neuzil, V. Skrlant[1]

By describing three recent case-studies, this paper aims to elaborate the current state of building energy modelling and simulation in the Czech Republic in general, and at the Czech Technical University (CTU) in Prague in particular. The studies which are described were carried out at the Department of Environmental Engineering, Faculty of Mechanical Engineering, and concern practical problems related to heating, ventilating, and air-conditioning (HVAC) systems.

INTRODUCTION

The Czech Republic (CR) is one of the most energy inefficient countries in the world. The energy consumed for $1000 of gross national product was 19.33 GJ in 1987 (USA 15.11GJ/$1000, Japan 6.98 GJ/$1000). This situation has improved since then, but not significantly. In the past, the price of energy was heavily subsidised by the government. This is no longer acceptable with the introduction of a market economy in the CR.

The high level of energy production was accompanied with a high level of air pollution since most of the energy was produced in power plants burning brown-coal with low heating value and high sulphur content (up to 4%). This made the CR one of the most polluted countries in the world. The last few years have seen an increase in activity aimed at improving the energy situation and the associated impact on the environment by introducing more energy efficient technologies and installing emission control devices. There is a drive to switch to other fuels like natural gas. Emissions have already been reduced significantly; for example SO_2 emissions reduced from 2.16×10^6 tons/year in 1987 to 1.09×10^6 tons/year in 1995.

The energy used in buildings for heating, ventilation and air-conditioning represents about 50% of total national energy consumption. It is therefore essential to reduce the energy consumption and improve the efficiency in buildings and HVAC systems. We feel that computer modelling and simulation of building and HVAC energy performance can play an important role in this respect (Hensen, 1996).

In spite of rapid improvement in the computational tools in use in the CR, the more sophisticated modelling and simulation techniques are not yet used nor are they commonly known. Specialised design programs are used for specific purposes (e.g. cooling or heating load calculation, duct sizing, etc.), but these are based on many significant simplifications.

In higher education the methods of building energy simulation are just being introduced into the curriculum (ESP-r (ESRU 1996) was first installed in 1993 at CTU) and the results of first case studies have only recently become available.

This paper illustrates the current situation by describing three recent case studies.

The first case study analyses the variation of energy consumption for heating in panel houses with different parameters. This study deals with the general problem of high heating energy consumption which affects a significant group of flat owners (Drkal - Dunovska, 1996).

The second study considers the energy efficiency of an existing HVAC system in a new archival building. An improved HVAC control strategy is proposed, simulated and finally applied in practice (Skrlant, 1996).

The third case study involves the analysis of the indoor-climate in a large ventilated industrial hall under extreme summer conditions. The influence of skylight size and thermophysical properties of the floor on thermal comfort are presented. The results provide an insight in indoor environment of large ventilated enclosures which can be used for design purposes (Neuzil, 1996).

I. PARAMETRIC STUDY OF HEAT CONSUMPTION IN FLATS

Problem Description

The amount of energy used for residential heating is relatively high in the Czech Republic. This problem is evident especially in the case of prefabricated apartment buildings which represent about 70% of the present housing stock. The flat owners were not aware of energy control and reduction since the energy consumption for heating of the flat was calculated only according to the floor area and not the real energy consumption. Even today when energy consumption measuring devices are being introduced to the flats, the most common reaction when it gets too warm is to open a window. As shown in the following, the variation in heat consumption of similar flats can be very high.

Objective

The objective of this study was to estimate the influence of different parameters on the heating energy consumption of the flat.

The parametric analysis of the energy consumption of an average flat was carried out using ESP-r.

Model Description

The analysis of four different parameters having an influence on the residential building heating energy consumption was carried out. The parameters under consideration were as follows:

- location of the apartment in the building (A)
- set-point increased up to 24°C (B)
- heating pattern of neighbouring flat (C)
- excessive continuous ventilation (D)

The “standard” prefabricated house, typically built from the 60s to the 80s, was selected as an object of investigation. The average apartment size is 45 m^2 floor area. The buildings were built from the pre-fabricated concrete panels with almost no insulation (external walls U-value = 1.09 W/m^2K, roof U-value = 0.5 W/m^2K, windows U-value = 2.6 W/m^2K, internal walls U-value = 2.9 W/m^2K) and therefore relatively high energy consumption.

---

[1] *Faculty of Mechanical Engineering, Czech Technical University, Technicka 4, 166 07 Prague 6, Czech Republic*

Simulations and Results

The simulation was run through the period of one typical winter week in the Czech Republic (10 to 16 January) when external temperature reaches -5°C during the day and -12°C at night (Dunovska, 1995). The resulting heating energy consumption obtained by simulation for different cases are graphically shown in Figure 1. To make the case study more "realistic", the cost of one-week of heating expressed in KC (1 US$ ≃ 29 KC) is presented. When calculating the heating cost, a price of 163 KC per GJ (Czech official price for district heating in 1996) was assumed. The heating consumption of all the cases are stated relative to the 100% base-case heat consumption.

The base-case (A1) denotes the space heating energy consumption of the flat situated in the middle of the building when heated up to 20°C. The heating energy consumption for the base-case during the simulation period was 323 kWhrs and is referred to as 100%. Case A2 shows an increase in energy consumption of up to 217% when the same flat is situated under the roof and in the corner of the building, i.e. about 50% of the walls are external.

Case B1 had a heating energy consumption of 128% which was caused by the set-point increase to 24°C (internal air temperature).

The effect of the heating pattern of the neighbouring apartment was modelled in case C1, which had a resultant energy consumption of 110%. In case C1 it was assumed that the neighbouring apartment on one side (partition wall of 20 m^2) was not heated at all.

In case D1, the natural ventilation rate was assumed to be 1.6 ACH which is double that of the base-case value, and the heating energy consumption was found to be 162%. This represents the situation when, for example, a small "ventilation window" is opened during the whole period.

The cases denoted by suffix number 2 illustrate the combination of the flat location (corner) and the other factor's influence on the heating consumption with the reference case A2 (of 217% energy consumption). For the case B2, the energy consumption was 253% when the flat under roof was heated up to 24°C. The unheated neighbouring apartment increased the energy consumption to 234% (case C2) and in case D2, the energy consumption increased by excessive ventilation to 279%.

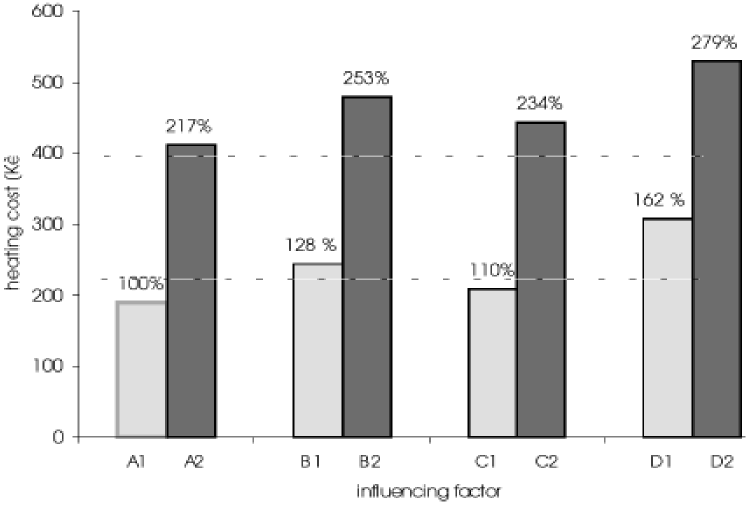


Figure 1 Variation of costs and energy consumption for heating the flat

The effect of higher desired internal air temperature on the length of the heating period was analysed. The simulation was run through the whole year period with heating set points of 20°C and 24°C respectively for the flat located in the centre and in the corner of the building. The energy consumption for heating, and the length of the heating period, were compared for different cases and are summarised in Table 1 together with the cost of heating in KC. It can be seen in Table 1 that the length of the heating period differs from the base-case situation by 1,398 hours only because of the location of the flat in the corner position. Setting the internal air temperature to 24°C instead of 20°C increases the heating period by 916 hours for the central flat and by 1,076 hours for the corner flat.

Conclusions

From comparing the above simulation results it can be concluded that the most significant parameter influencing the heating energy consumption (out of the investigated ones) is the location of the flat. The second most important parameter is excessive ventilation ("ventilation window" opened), a result of overheating, which is a common problem today. On the other hand the heating pattern of neighbours had a surprisingly low influence on heat consumption. However, it must be noted that these results were obtained for the specific case and for a one week-period.

It follows from the whole year simulation that in the same building the heat consumption of a flat can vary from 100% to 400% depending on its location and the desired internal air temperature (4°C variation in this case), and the heating period can be 1.6 times longer as a result of that.

II. ENERGY CONSERVATION AND EFFICIENCY OF HVAC SYSTEM IN AN ARCHIVAL BUILDING

Problem Description

The new building of the State Archives was constructed in Prague in 1995. Separate HVAC systems for each floor were installed which use recirculation air only. To ensure the special internal conditions for archival purposes (i.e. internal air 15 ± 1°C, relative

Table 1 The annual energy consumption and hours of heating for the flat

Flat location	t_i (°C)	heating energy consumption (GJ)	(%)	heating period (hours)	cost of heating (KC)
central	20	16.0	(100%)	3,674	2,609
	24	24.3	(152%)	4,590	3,976
corner	20	45.3	(283%)	5,072	7,384
	24	64.2	(401%)	6,148	10,475

humidity 55 ± 5%) the HVAC system was designed to work continuously during the whole year. During the first year of operation it was observed that the cooling was on continuously, even during winter. This is because the actual heat losses of the building are much lower than was assumed when designing the HVAC system. It was found that the heat gains from the fan of the designed HVAC system would be sufficient to cover all the heat losses of the building in winter.

Objective

The objective of this study was to propose a new control strategy for the existing HVAC system in the archival building to achieve energy conservation while maintaining the required special internal conditions.

A dynamic simulation model of the building and HVAC system was constructed using ESP-r. 12-hours cycled "On/Off" control strategy was proposed, applied and analysed to achieve efficient use of energy.

Model Description

The State Archives building studied is a medium-heavy building with no windows, consisting of 13 floors, with minimized heat gains and losses. The external walls have a U-value = 0.2 W/m^{2}K and the internal surfaces (floors) have a U-value = 2.49 W/m^{2}K. The middle five floors were modelled as being representative for the building.

The indoor-air quality requirements for archival purposes were in this case defined as an air temperature of 15 ± 1°C and a relative humidity of 55 ± 5%.

Casual heat gains from electrical equipment, occupants and lighting were neglected. The building construction also allowed infiltration to be neglected.

Artificial hourly climate data derived from long-term average monthly weather data for Prague was used (Dunovska, 1993).

Simulations and Results

The energy consumption for the current situation was obtained by whole-year simulation with the HVAC system operating continuously in each floor — here called the "continuous operation" case. As outlined above, cooling was available even during the winter period. The simulation results for the middle floor (3rd) are discussed in detail below.

The cooling load for *continuous operation* of the HVAC system shows a maximum value of 2.6 kW in the summer period and a minimum of 1.1 kW in the winter period.

The "On/Off" operation was modelled with 12 hour operating cycles alternating between floors:

floor	0 - 12 h	12 - 24 h
1	ON	OFF
2	OFF	ON
3	ON	OFF
4	OFF	ON
5	ON	OFF

Figure 2 shows the cooling loads of the middle floor (3rd) for the case of 12-hour cycles *On/Off operation* with a minimum of 0 W and a maximum of 3.1kW in summer and 0.3 kW in winter. The instantaneous value of cooling required is higher in this case than in case of continuous operation, as a result of warming up during the 12-hour Off period.

The simulation results presented in Figure 3 prove that the internal air temperature variation is within the temperature limits of 15 ± 1°C when 12-hour cycles *On/Off operation* would be used during the whole year. The extreme values of internal air temperature occurring in a typical winter month (January) and a typical summer month (July) for both HVAC continuous and *On/Off operation* strategies are summarised in Table 2. In the assumed climate, the diurnal external temperature fluctuates between 5°C and 2°C in January and between 18°C and 25°C in July. The energy consumption for January and July for the different cases is also included in Table 2. It can be seen that by applying the *On/Off operation* strategy the energy consumption can be reduced to 17% during January and to 56% during July.

The predicted annual energy consumption is 83,040 kWh for continuous HVAC operation and 38,630 kWh for 12-hour cycles *On/Off operation*. This suggests that the current annual HVAC energy consumption can be reduced to 47%.

Table 2 Minimum and maximum internal air temperature, and energy consumption, for continuous and 12-hour cycles *On/Off operation* in selected months.

	operation	$t_{i\,min}$ (°C)	$t_{i\,max}$ (°C)	**energy** (kWh)
January	continuous	15.1	15.1	4,259
	On/Off	14.1	15.1	745
July	continuous	15.1	15.1	9,740
	On/Off	15.1	15.9	5,445

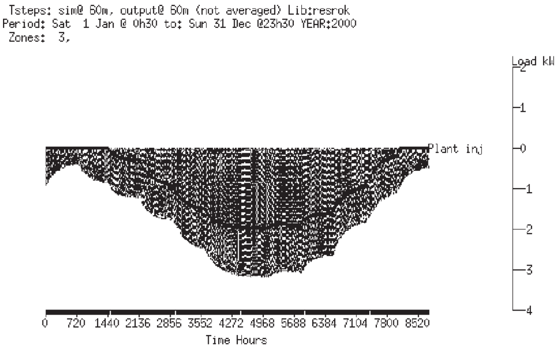


Figure 2 Cooling loads for12-hour cycles *On/Off operation* (i.e. proposed situation)

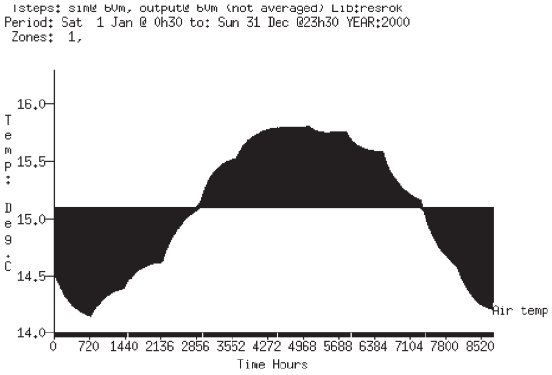


Figure 3 Internal air temperature fluctuation for 12-hour cycles *On/Off operation* during the whole year

Conclusions

By employing a dynamic model of the State Archives building, it was possible to propose the 12-hour cycles *On/Off operation* of HVAC system instead of *continuous operation*, while satisfying indoor air requirements. It follows from the results that the energy consumption can be reduced dramatically to 47% when this On/Off control strategy is used. The most significant energy conservation can be achieved during the winter period; the energy consumption can be reduced down to 17%.

The On/Off control strategy proposed in this paper was applied in the investigated building and proved its relevance in practice.

III. THERMAL COMFORT ANALYSIS IN AN INDUSTRIAL HALL

Problem Description

The internal environment of industrial halls may have an impact on the thermal comfort of workers, on the productivity of workers, on the quality of the products and on the number of workplace accidents. The internal environment of industrial halls is influenced by external and internal factors. During the summer period external factors are: outdoor air temperature, solar radiation and ground temperature. Internal factors are: ventilation operation, thermal insulation and thermal capacity of the hall and casual heat gains. From the energy consumption point of view we want to use the minimal outdoor air flow rate for ventilation, on the other hand we don't want to disrupt thermal comfort of the internal environment. By simulation it is possible to optimise the operation of the ventilating system in relation to the construction of the building (integral approach).

Objective

The objective of this study was to estimate the influence of the area of skylights and the floor construction on the thermal comfort in an industrial hall ventilated during the summer period by displacement system.

The building and ventilating system were modelled and simulated with ESP-r.

Model Description

The mounted hall type HARD Jeseník was used as an example of an industrial hall. The hall consists of modules with dimensions 18 x 6 x 7.2 m (length x width x height), slope of the roof is 11° (Figure 4). The external walls and roof consist of thermally insulated sandwich panels. The floor is made of concrete and has thermal insulation. The U-values are presented in Table 3. The ground temperature was assumed constant at 10°C. The flat polycarbonate skylights allow for natural lighting. The hall is used for welding of large support constructions. The casual heat gains of each module are 3360 W. The displacement ventilation system provides ventilation of the hall. The working period starts at 6.00 and finishes at 22.00. The air flow rate is constant during this period (10.8 air changes per hour) and suffices to eliminate external heat gains. The polluted air (welding) is exhausted and filtered. The infiltration rate during the night period is 0.5 changes per hour.

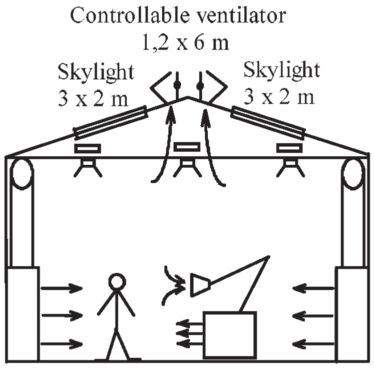


Figure 4 The displacement ventilation system and its operation in summer in an industrial hall

Table 3 U-values of the industrial hall

Structure	U-value (W/m^{2}K)	
Floor - light, thermally insulated	0,38	0,36
Floor - heavy, thermally insulated	0,61	0,44
Floor - heavy, non-insulated	0,44	0,85
External wall - sandwich panel	2,90	
Roof sandwich panel		
Door		
Skylight		

The basic central module of the hall was used as a single zone model for simulation purposes. The central line of the roof is in an East-West direction. The above indicated climate for Prague was used (Dunovska, 1993). The maximal external air temperature was expected to be 30°C and minimal external air temperature was expected to be 16°C.

Simulation and Results

The indoor climate conditions were predicted for the summer period. In the central part of the hall they are represented by the internal air temperature, surface temperature of the floor and thermal comfort sensation (PMV, PPD).

The external heat gains (solar radiation) through the skylights seriously affected the thermal comfort in the working zone. The skylights have to provide the visual comfort which is essential for the type of work. The oversized skylights cause glare problems during the summer period and increased energy consumption during the winter period. The optimised skylights (Neuzil, 1996) have an area of 6 x 2 m (two skylights each 3 x 2 m). The oversized skylights 6 x 3 m and 6 x 5 m which are very often used in practice were used as an example.

The impact of various constructions of the floor was tested too. Three types of floor (upper concrete layer, thermal insulation) were used: light floor (120 mm concrete layer) with thermal insulation, heavy floor (270 mm concrete layer) with thermal insulation and heavy floor without thermal insulation (see Table 3).

Figure 5 shows the behaviour of the following temperatures: external air temperature (t_e), internal air temperature (t_i) and surface floor temperature (t_s) during the working week (0 — 120 h, during working time ventilation equals 10,8 air changes, and during the night the infiltration equals 0,5 air changes) and weekend (120 - 168 h, infiltration equals 0,5 air changes). The optimised skylights (6 x 2 m) and the thermally light and insulated floor were used.

The internal air temperature rises when the ventilation is stopped because the infiltration rate is very small and the heat (solar radiation) accumulated in the floor cannot escape from the hall. After that the internal air temperature decreases very similarly to the external air temperature which is caused by transmission heat losses of the hall. The internal air temperature drops when the displacement ventilation starts because the external air temperature (supplied air) is lower than the internal air temperature and causes ventilation heat losses.

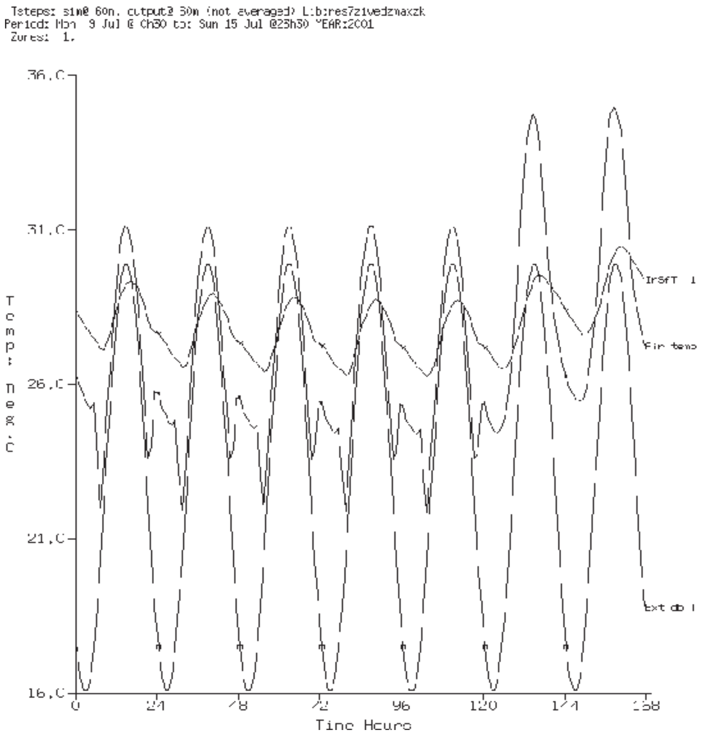


Figure 5 Internal air temperature t_i and floor surface temperature t_s as a function of external and internal conditions during the working week and weekend (external air temperature t_e)

Table 4 Maximum values of internal air temperature t_i and floor surface temperature t_s (in °C) as a function of the skylight area and the floor construction

	1	2	3	4	5
t_i (Mon - Fri)	31,3	35,0	29,3	28,6	30,6
t_i (Sat - Sun)	31,4	39,0	32,1	30,7	33,8
t_s (Mon)	31,4	38,7	31,4	31,0	33,0
t_s (Fri)	32,1	44,7	36,0	34,0	39,5
t_s (Sun)	32,0	42,8	35,3	34,0	36,9

1 - Skylights 6x2 m, floor light, thermally insulated
2 - Skylights 6x3 m, floor light, thermally insulated
3 - Skylights 6x3 m, floor heavy, thermally insulated
4 - Skylights 6x5 m, floor light, thermally insulated
5 - Skylights 6x5 m, floor heavy, thermally non-insul.

The accumulated heat in the floor construction has an impact on the amplitude of the floor surface temperature which is smaller than the air temperature amplitude. The ventilation system is out of operation during the weekend and external heat gains increase the maximal value of internal air temperature because the infiltration is too small to remove the heat gains.

The temperatures in the case of 6 x 3 m and 6 x 5 m skylights are similar but the maximum values of the internal air temperature and floor surface temperature are higher (see Table 4).

The skylights of 6 x 3 m increase the maximum internal air temperature by 0.1 K during the working week and by 4 K during the weekend (light floor, thermally insulated). The skylights of 6 x 5 m increase the maximum internal air temperature by 0.8 K during the working week and by 7.8 K during the weekend (light floor, thermally insulated). The skylights of 6 x 3 m increase the maximum value of floor surface temperature by 2.8 K on Monday, by 2.1 K on Friday and by 3.2 K on Sunday (light floor, thermally insulated). The skylights of 6 x 5 m increase the maximum floor surface temperature by 6.7 K on Monday, by 5.4 K on Friday and by 8.9 K on Sunday (light floor, thermally insulated).

The impact of the various types of floor (light, heavy) on the maximum inside air temperatures during a hot summer working week is negligible (see Table 4). Also the impact of the various types of floor on the maximum floor surface temperature is very small (see Table 4).

The simulation results confirm the practical experience, i.e. that temperature changes resulting from a 24 hour cycle of outdoor climate do not penetrate in the concrete floor deeper than approximately 100 mm, and concrete thicker than 100 mm is not necessary from the point of view of summer thermal accumulation.

The impact of various skylights and floor constructions on the thermal comfort and discomfort during the Monday is presented in Figure 6 (Predicted Mean Vote - PMV) and in Figure 7 (Predicted Percentage of Dissatisfied - PPD). The assumed average air speed was 0.3 m/s, the activity level 120 W/m² A_{Dubois} and the clothing level 1.0 clo. The critical situation occurs at 14.30.

Conclusion

From the simulation results it was possible to predict the summertime indoor environment in an industrial hall equipped with a displacement ventilation system. Two constructional variables were studied. The *area of skylights* has a significant impact on the indoor environment of the industrial hall. The *floor construction* has a small impact on the indoor environment.

It is obvious that during the summer period the predicted sensation of the hall indoor air quality has mostly discomfort character (see Figures 6 and 7).

The halls with smaller skylights (6 x 2 or 6 x 3 m) have of course more favourable microclimate than those with oversized skylights (e.g. 6 x 5 m) at the same ventilation and internal heat gains conditions see Table 4.

For a given skylight nearly the same thermal comfort can be reached regardless of the floor mass (see Figures 6 and 7).

Only during the night when the ventilation rate is lower, the PMV and PPD values show some merit of a heavy floor.

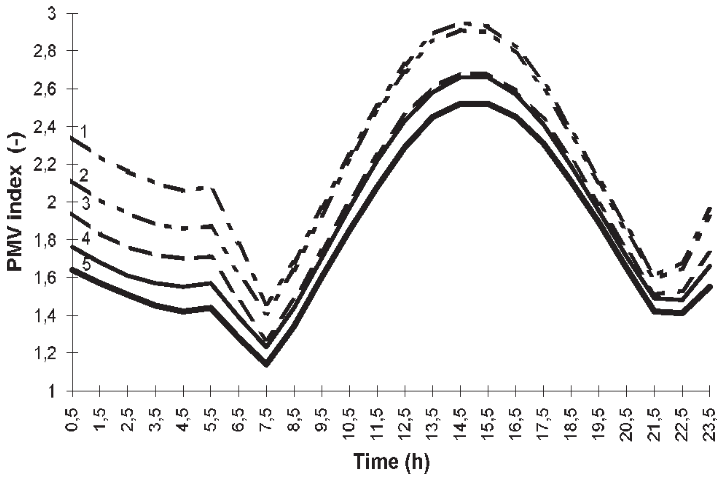


Figure 6 Thermal comfort sensation - PMV index - as a function of skylight area and floor construction during the working day

1-Skylights 6 x 5 m, floor light, insulated
2-Skylights 6 x 5 m, floor heavy, non-insulated
3-Skylights 6 x 3 m, floor light, insulated
4-Skylights 6 x 3 m, floor heavy, insulated
5-Skylights 6 x 2 m, floor light, insulated

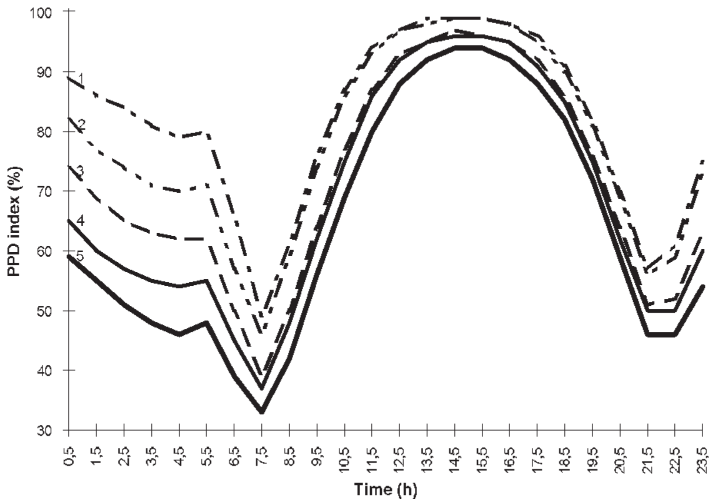


Figure 7 Thermal discomfort - PPD index - as a function of skylight area and floor construction during the working day

1-Skylights 6 x 5 m, floor light, insulated
2-Skylights 6 x 5 m, floor heavy, non-insulated
3-Skylights 6 x 3 m, floor light, insulated
4-Skylights 6 x 3 m, floor heavy, insulated
5-Skylights 6 x 2 m, floor light, insulated

CONCLUSIONS

This paper describes three studies by graduate and postgraduate students at CTU in Prague. Computer modelling and simulation was only recently incorporated in the curriculum.

From our initial experiences some general conclusions can be drawn:

- The interest of students in computer modelling and simulation increases as their theoretical knowledge of environmental engineering grows.
- ESP-r is very useful for education, particularly for many hands-on exercises and assignments, using also e-mail. The courses for postgraduate students lectured at CTU in Prague by Dr. Jan Hensen, visiting professor at CTU, are the foundation for wider uptake of modelling and simulation methods in the higher education of mechanical and civil engineers.
- Problems with the practical usage of modelling and simulation at CTU in Prague concern:
  - lack of hardware (teaching laboratory, workstations)
  - lack of data (including climate)
  - relatively low English language skills by a number of students.

Future work at CTU in Prague will concentrate on:

- further integration of modelling and simulation in the curriculum
- dissemination of information about computer modelling and simulation possibilities for HVAC systems and buildings and promoting this technology in practice (in journals, at seminars)
- continuing education courses for introduction of modelling and simulation in practice

REFERENCES

Drkal, F.: “Energy and Mass Flow Simulation and its Impact on the Design and Operation Evaluation of the Air Conditioning, Ventilation and Heating Systems”, Proceedings Low Energy Ventilation Systems, Prague, Society for Environmental Technology (STP), 1995 (in Czech)

Drkal, F., T. Dunovska. “Sensitivity analysis of thermal balance of block panel house VVU-ETA”, Prague, CTU, 1996 (in Czech)

Dunovska, T.: “Computer simulation application for energy building performance”, MSc thesis, Prague, CTU, 1995 (in Czech)

Dunovska, T.: “Energy conservation and comfort improvement for a house in Prague via computer simulation”, FAGO technical report 93.22.K, Eindhoven, TUE, 1993

Hensen, J.L.M.: “Building simulation”, Lecture notes and personal communications, Prague, CTU, 1996

Hensen, J.L.M.: The Building Approached as an Integration of Energy Systems (HVAC), VVI, vol. 3, No.1,Prague, Society for Environmental Technology (STP), 1994 (in Czech)

Skrlant, V.: “HVAC system energy conservation in archival building”, MSc thesis, Prague, CTU, 1996, (in Czech)

ESRU 1996: “ESP-r A Building Energy Simulation Environment; User Guide Version 9 Series”, ESRU Manual U96/1, Glasgow, University of Strathclyde, Energy Systems Research Unit, 1996.

BS'97

A complete list of papers

Plenary Sessions

Thermostat strategies for discretionary heating and cooling of dwellings in temperate climates *Williamson, T J, P Riordan*

Simulation tools for the exploitation of renewable energy in the built environment: the EnTrack-GIS system *Clarke, J A, M S Evans, A D Grant, N Kelly*

EnergyBase - the merger of BLAST and DOE-2 *Pedersen, C O, D E Fisher, R J Liesen, R K Strand, R D Taylor*

Experience from a design advice service using simulation *McElroy, L B, J W Hand, P A Strachan*

Communicating performance assessments of intermediate building design states *Augenbroe, G, S De Wit*

An illustration of automatic generation of zonal models *Gagneau, S, J M Nataf, E Wurtz*

Decision making through use of interoperable simulation software *Papamichael, K, J La Porta, H Chauvet*

Software Demonstration Session

Simulation-based features of the compressed air system description tool "XCEED™" *Curtner, K L, P J O'Neill, D Winter, P Bursch*

TRNSYS 14 goes Windows and Window 4.1 - tool for energetic and visual building simulation *Schuler, M, H Meyer, A Knirsch, S Holst, M Hiller, W A Beckmann, N Blair*

CA-SIS: a design tool for thermal studies with a gradual access *Tabary, L*

ENERGY-10: a design-tool computer program *Balcomb, J D*

Spreadsheet modeling of thermal and daylighting performance *Lord, D*

Building Energy Tools Directory *Crawley, D B*

COMIS 3.0 a new simulation environment for multizone air flow and pollutant transport modelling *Pelletret, R Y, W P Keilholz*

Daylight modelling with Passport-Light *Tsangrassoulis, A, M Santamouris*

ADELINE - an integrated approach to lighting simulation *Erhorn, H, J De Boer, M Dirksmoeller*

New generation of software? Modeling of energy demands for residential ventilation with HTML interface *Forowicz, T*

System and Plant Simulation

Simulation of a centralized cooling plant under different control strategies *Bourdouxhe, J-P, P Andre*

Optimisation of mechanical systems in an integrated building energy analysis program: part i: conventional central plant equipment *Taylor, R D, C O Pedersen*

Simulation and fault detection of the thermal storage system *Nakahra, N , M Zheng, Y Nishitani*

Fault modelling in component-based HVAC simulation *Haves, P*

Applications

Simulation of a complex wind and buoyancy driven building *Holmes, M J, S McGowan*

Ventilation and thermal performance of design options for Stadium Australia *Lomas, K J, H Eppel, M Cook, J Mardaljevic*

Recent Czech building energy simulation case studies *Drkal, F, T Dunovska, M Neuzil, V Skrlant*

Energy saving in office buildings. a case study in Rome through the use of DOE-2 and other simulation tools *Beccali, M, R Caponio, S Gara, L Pagliano*

Fundamentals — Solar and Daylighting

The implications of sky model selection for the prediction of daylight distribution in architectural spaces *Lam, K P, A Mahdavi, V Pal*

Image processing for urban scale environmental modelling *Richens, P*

Analysing radiation transport through complex fenestration systems *Campbell, N S, J K Whittle*

Comparison of computer and model simulations of a daylit interior with reality *Jarvis, D, M Donn*

Implementations — New Tools and Approaches

An NMF based model library for building climate and energy simulation *Vuolle, M, A Bring*

An open ended modular interface and controller library for CLIM 2000 *Murphy, K M, F Deque*

Guidance for the selection of a reduction technique for thermal models *Palomo, E, Y Bonnefous, F Deque*

A substructuring approach to 3D conduction problems: applications to buildings' components *Durmort, C, B Flament*

Electric storage heaters in building simulation *Wright, A J*

Design and simulation of HVAC systems with bond graphs *Zeiler, W*

Simulation of ventilation and indoor air conditions of agricultural buildings *Kic, P, R Chiumenti, S Bortolussi, F Da Borso*

SIMBAD: a simulation toolbox for the design and test of HVAC control systems *Husaunndee, A, R Lahrech, H Vaezi-Nejad, J C Visier*

Fundamentals - Heat Transfer

BASESIMP: a residential-foundation heat-loss algorithm for incorporating into whole-building energy-analysis programs *Beausoleil-Morrison, I, G Mitalas*

Calculation tool for earth heat exchangers GAEA *Benkert, S, F D Heidt, D Schoeler*

Parameter estimation and the use of catalog data with TRNSYS *Rabehl, R J, W A Beckman, J W Mitchell*

Education

Integration of computer based modelling and an inter-disciplinary based approach to building design in post-graduate education *Batty, W J, B Swann*

Introducing IT based energy simulation courses in Central/Eastern Europe *Hensen, J, M Janak, N Kaloyanov, P Rutten*

Forget the tool when training new simulation users *Hand J W, D B Crawley*

Quality Assurance - Validation

Validation of a building thermal model in CLIM2000 simulation software using full-scale experimental data, sensitivity analysis and uncertainty analysis *Guyon, G, N Rahni*

A comparative validation based certification test for Home Energy Rating System software *Neymark, J, R Judkoff*

Validation of HOT 2000 using HERS BESTEST *Haltrecht, D, K Fraser*

Applications — Controls

Predictive optimal control of fabric thermal storage systems *Ren, M J, J A Wright*

Rational operation of a thermal storage tank with load prediction scheme by ARX model approach *Yoshida, H, T Inooka*

A fuzzy control adapted by a neural network to maintain a dwelling within thermal comfort *Egilegor, B, J P Uribe, G Arregi, E Pradilla, L Susperregi*

Fundamentals — Weather Data

Examination of the concept of using “typical-week” weather data for simulation of annualized energy use in buildings *Degelman, L O*

Modelling of the heat island generated by an urban unit *Pignolet-Tardan, F, P Depecker, F Garde, L Adelard, J C Gatina*

Multi-Year (MY) building simulation: is it useful and practical? *Hui, S C M, K P Cheung*

Weather sequences for predicting HVAC system behaviour in residential units located in tropical climates *Adelard, L, F Garde, F Pignolet-Tardan, H Boyer, J C Gatina*

Integrations — Thermal and Lighting

Aggregate space-time performance indicators for simulation-based building evaluation procedures *Mahdavi, A, P Mathew, K P Lam*

Simulation of visual and thermal comfort related to daylighting and solar radiation in office buildings *Laforgue, P, B Souyri, M Fontoynont, G Achard*

Dynamic link of light and thermal simulation: on the way to integrated planning tools *Herkel, S*

Coupling building energy and lighting simulation *Janak, M*

Fundamentals — Air Flow

Guidance on the use of computational fluid dynamics for modelling buoyancy driven flows *Cook, M J, K J Lomas*

A comparison of wind tunnel and CFD methods applied to natural ventilation design *Alexander, D K, H G Jenkins, P J Jones*

Predicting natural ventilation air velocity using deterministic and non-deterministic methodologies *Santamouris, M, E Dascalaki*

Numerical and experimental assessment of a flow field in a ventilated industrial hall *Denev, J, P Stankov, D Stoyanov, P Spassov*

Fundamentals — Moisture

Development of a simulation tool for mould growth prediction in buildings *Clarke, J A, C M Johnstone, N J Kelly, R C McLean, A E Nakhi*

The selection of appropriate flow potentials for moisture transport models *Galbraith, G H, R C McLean*

A systematic method for hygrothermal analysis of building constructions using computer models *Geving, S*

Applications — Regional

The simulations of the thermal performance of retrofitted existing residential buildings in Istanbul with Micro-DOE 2.1 computer program *Tavil, A, N Sahal, E Ozkan*

The use of a simulation tool in order to obtain the thermal performance of passive solar houses in Portugal *Goncalves, H P, M N Oliviera, A M Patrício*

Sensitivity analysis of a traditional round hut in the tropical upland climate *Malama, A, S Sharples*

Practice — Present and Future

An application manual for building energy and environmental modelling *Bartholomew, D, J Hand, S Irving, K Lomas, L Mcelroy, F Parand, D Robinson, P Strachan*

A survey of users of thermal simulation programs *Donn, M*

What next for building energy simulation - a glimpse of the future *Crawley, D B, L K Lawrie, F C Winkelmann, W F Buhl, A E Erdem, C O Pedersen, R J Liesen, D E Fisher*

Quality Assurance — Calibration

An inverse model to predict and evaluate the energy performance of large commercial and institutional buildings *Abushakra, B*

Calibration of hourly energy simulations using hourly monitored data and monthly utility records for two case study buildings *Soebarto, V I*

A hybrid monitoring-modeling procedure for analyzing the performance of large central chilling plants *Troncoso, R*

Poster Papers

The implementation of industry foundation classes in simulation tools for the building industry *Bazjanac, V, D B Crawley*

Design of air conditioning systems for efficient life-cycle operation using the ZEBRA software package *Marshallsay, P G, R E Luxton*

Integration of building design tools in Dutch practice *Plokker, W, L L Soethout*

Numerical simulation of air flows — an essential tool of comfort optimization of modern buildings and HVAC systems *Ochocinski, B*

Validation of displacement ventilation simplified models *Manzoni, D, P Guitton*

A numerical analysis of flow and dispersion around a cube *Scanlon, T J*

Predicting foundation heat losses: neural networks versus the BASESIMP correlations *Beausoleil-Morrison, I, M Krarti*

Simplified method for underground heat transfer calculation *Choi, S, M Krarti*

Heat transfer in block walls *Hassid, S, E Levinsky*

Evaluation of the finite control volume method in simulating thermal fire resistance of building elements *Chow, W K, C M Ho, N K Fong*

Natural convection in a superposed air and porous layer when heated from below *Serkitjis, M*

Integrated building simulation tool — RIUSKA *Jokela, M, A Keinanen, H Lahtela, K Lassila*

Toward a simulation-assisted dynamic control strategy *Mahdavi, A*

Control strategies for heating systems *Björsell, N*

Moisture permeability data presented as a mathematical function applicable to heat and moisture transport models *Galbraith, G H, R C Mclean, Jiansong Guo*

New educational software for teaching the sunpath diagram and shading mask protractor *Oh, J K W, J S Haberl*

Optimisation of design criteria for solar space heating systems through modelling and simulation *Michaelides, I M, D R Wilson*

Computer model of the apartment building from the panel system T06b *Rabenseifer, R*

A user-friendly tool for the integrated simulation of building HVAC control performance *Mathews, E H, E Van Heerden*

Comparative study of sky luminance models in the tropical context *Lam, K P, A Mahdavi, M B Ullah, E Ng, V Pal*

Sun and climate modeling for thermal simulation. Parametric models relevant at early design stages *Rudy, M*

Simulation of solar gains through external shading devices *Alexander, D K, K A Ku Hassan, P J Jones*

SOMBRERO - shadow calculations on arbitrarily oriented surfaces as a preprocessor for simulation programs *Schnieders, J, A Eicker, F D Heidt*

The use of a simple simulation tool for energy analysis *Kosonen, R, J Shemeikka*

Role of the model user in results obtained from simulation software program *Guyon, G*

A comparative assessment of two HVAC plant modelling programs *Underwood, C*

Influence of modeling uncertainties on the simulation of building thermal comfort performance *Wit, S De*

A study on the thermal performance simulation to evaluate the prefabricated radiant floor heating panels *Yeo, M S, K W Kim*

The optimal insulation detail of the thermal bridge adjacent to hot water pipes in apartment building slabs *Song, S Y, K W Kim*

The main features of a new generation building simulation tool *Tuomaala, P, K Piira, M Vuolle*

Methodology for modelling/simulation of an office building equipped with an air-conditioning system *Milcent, F, L Lapenu*

Optimisation of mechanical systems in an integrated building energy analysis program: Part II: thermal storage-based central plant equipment *Taylor, R D, C O Pedersen*

A randomised approach to multiple regression analysis of building energy simulation *Hui, S C M*

Application of system simulation to WCH boiler selection *Hensen, J, K Kabele*

Application of simulation in design and operation of refurbished buildings and heating systems *Felsman, C, G Knabe, A Kremonke, A Perschk*

A new system for accessing transfer function coefficients for an architectural computer-aided thermal optimization tool *Malkawi, A M, J Wambaugh*

The verification of Radon protective measures by means of a computer model *Jiranek, M, Z Svoboda*

Reproducing thermal coupling between components in a generic environment like MATLAB *Lefebvre, G, E Palomo, M Izquierdo*

CASCADE: a novel computational design system for architectural acoustics *Mahdavi, A, G Liu, M E Ilal*

Acoustic rendering of buildings *Rabenstein, R, O Schips, A Stenger*

The simulation of photovoltaic-integrated building facades *Clarke, J A, C Johnstone, N Kelly, P A Strachan*

Simulation of a photovoltaic hybrid facade *Gutschker, O, H Rogass*

Building thermal simulations using a new tool — Passport Plus *Santamouris, M, C A Balaras, E Dascalaki, S Alvarez, J F Coronel, E G Rodriguez*

Computer-aided energy use estimation in supermarkets *Orphelin, M, D Marchio*

An advanced glazing case study from the IMAGE project *Clarke, J A, M Janak, P Ruyssevelt, R Cohen, J Bates*

Building thermal models reduction: improving existing methods by taking spectral inputs characteristics into account *Palomo, E, S Dautin, A Ait-Yahia, F Deque*

Physical system modelling languages: from Allan to Modelica *Jeandel, A, F Boudaud*

Monitoring system for distributed energy and heat supply complex *Bila, J, K Broz, V Jirovsky, H Rodic*

◆

Minutes of IBPSA Board Meeting

11 September 1997
Czech Technical University, Prague

Board members present: *Joe Clarke (Chair, UK), Larry Degelman (USA), Frantisek Drkal (Czech Republic), Philip Haves (UK), Jan Hensen (UK), Curtis Pedersen (USA), Roger Pelletret (France), Per Sahlin (Sweden), Dan Seth (Canada), Ed Sowell (USA), Jeff Spitler (USA), Terry Williamson (Australasia)*

Guests: *Deon Arndt (South Africa), Ardeshir Mahdavi (USA), Lam Khee Poh (Singapore)*

AGENDA

1. Introductions and setting of agenda
2. Taking stock and a forward look
3. Report on BS'97
4. IBPSA Treasurer's report
5. BS'99 Planning
6. Regionalization and International Activities
7. New board structure
8. Publications — Newsletters, Web, International Journal
9. Old business
10. New business
11. Adjourn

PROCEEDINGS

The meeting started at 10:15 a.m.

1. Introductions: President **Clarke** called the meeting to order and proposed an agenda and asked for additional items. Attendees introduced themselves.

2. Taking stock of IBPSA: The current membership in IBPSA is estimated to be in excess of 400. There are 37 in France, 250 in the UK, 40 in the US, and more than 100 members in Australia, Canada, Czech Republic, and France, though exact membership numbers were not available. Membership in Greece is not known at this time.

Each board member briefly described what he thought were important issues that IBPSA needed to address. Discussions centered on:

a) **Relevance:** There was concern over the current focus on "energy" simulation in the face of worldwide declining concern over energy? It was concluded that we need to become more active in simulation areas other than energy. Possibly having board members as liaisons to outside societies and organizations to help foster interest in other simulation areas and give IBPSA more visibility. The board plans to establish more formal, and informal, connections to outside groups to maintain relevance. The board charged itself with the task of addressing the issue of relevance and the issue of international focus.

b) **Regionalism:** Concern was expressed over the emphasis on regionalization and that it may cause a loss of focus on international concerns. It was felt that we don't really know what's going on within the other regions because we don't participate in, or even communicate, activities between the regions. There is a perceived need for more exchange of information about regional activities between the affiliates. The board decided to discuss and determine the regional affiliate structure and relationship to IBPSA.

c) **Conference management issues:** It was felt that we need more frequent meetings with the conference organizers so the conference issues get scrutinized more closely so as to avoid any financial problems. It was reported that the Prague conference was highly successful, but it is also a high-risk activity for IBPSA. It was agreed that closer examination of procedures will be undertaken for the '99 conference.

d) **Conference technical issues:** Discussions centered on the timing of paper processing for Building Simulation conferences and the makeup of the Scientific Committee. The organizers felt that the committee needs to have an appropriate mix of "science" vs. "application" interests and that deadlines for paper submittals need to be moved to earlier dates.

e) **Membership benefits:** Newsletter and educational outreach issues were discussed. The board concluded that it needs to address educational outreach as an action item, and that we need more networking to other groups, administrators, etc. The board also decided to: (1) determine content and frequency of the newsletter, (2) determine and clarify what the board's executive functions are, and (3) broaden simulation topics to attract people from other industries to IBPSA activities and conferences.

3. BS'97 Report: Hensen gave a report summarizing the conference schedule and its attendance statistics. The attendance was as follows:

Region of origin	No.	%
Europe	94	54
Eastern Europe	30	17
North America	26	15
Australia-Asia	13	8
Other	10	6
Total	173	100

He described several new innovations that were accomplished by BS'97 —

- Electronic communications for paper submittals and review
- Web site advertisements and logistical communications
- Proceedings put on CD-ROM
- Variety of presentation formats
- Multiple software sessions
- Panel sessions
- Public was invited to the exhibitions

Lessons learned or suggested —

- Need more electronics for the presentations
- Need longer breaks
- Presenter should be asked for their presentation format preference
- Paper due dates need to be earlier

Drkal presented the conference financial information that was available at the time of the board meeting. The income exceeded the known expenses by about $3000 not accounting for any sponsorship. The anticipated sponsorship amounts to around $19,000. Conference organizers are to send the final conference accounting to Treasurer **Sowell**, who will organize it and report it to the board members.

4. Treasurer's Report: Sowell presented a summary of annual profit and loss statements and balance sheets for each year from 1994 to the present. Prior end-of-year balances were around $79,000 to $80,000. The current balance is about $74,000, though the final proceeds from the BS'97 conference are not accounted for. It was noted that during the early part of 1997, IBPSA has spent a significant amount ($8,400) on publishing of the IBPSA News. The annual budgeting of IBPSA operations will be taken up later after the BS'97 conference accounting is finalized. The board decided to undertake annual IBPSA budget planning related to the newsletter efforts.

5. BS'99 Conference Planning: Under consideration for BS'99 is the Pacific Rim area, including Hong Kong, Japan, Korea, and Singapore. The board members showed no particular preference toward any one of these possible locations. The board unanimously decided to send an invitation to all four countries to submit a site host proposal by November 30. **Jan Hensen** was named as liaison to the conference coordinators for BS'99, and agreed to develop the RFP for BS'99. The board agreed that IBPSA should fund a nominal level of liaison expenses.

Liaison and scientific chair duties were discussed. These are to include:

- Proactive paper solicitation
- Organize and plan the conference execution with the site coordinators.
- Promote exhibitions
- Initiate methods of attracting special groups from other countries that have not been well represented at the IBPSA conferences.

6. Regionalism and International Activities:

- Need autonomy of regions but also need procedures for monitoring — Secretary function.
- Region would be required to provide their by-laws, evidence of bank account, periodic report, membership directory, planned regional activities, and structure of organization.
- A membership directory should be a "living document" that members could access at any time to determine who and how many members there were. Regions will be requested to provide specific services to IBPSA.
- Encourage expansion of topics, activities and membership in the regions.

- A discussion ensued on whether IBPSA should limit the total number of regions and the amount of support to be provided. The board agreed that at this time, no limits should be set. If the society expands such that the number of regional representatives on the board exceeds what is specified in the by-laws, then the issue of by-law changes would have to be considered.
- **Pelletret** presented a formal proposal from IBPSA-France for $1500 of start-up funds for their region. The request was approved unanimously. [This is the third region to receive start-up funding from IBPSA.]

7. **New Board Structure:** By-laws specify that the board size cannot exceed four (4) elected officers, the past president, and ten (10) board representatives of the members, and terms of office are to be two years. Based on board resolutions made at Ross Priory in March of 1996, the board is to be made up of the Executive (President, Vice President, Treasurer, and Secretary), Regional Representatives (one from each region), and Members-at-large. The past president is automatically a member of the board. Members-at-large are to carry on liaison duties to other organizations. **Clarke** presented the results of the nominations he received by e-mail from various former board members. This slate of nominees will be placed on a ballot and distributed by the current Secretary by 1 November on which the whole membership will vote. This election will be effective for 1998-1999.

Some discussion took place on the desirable meeting frequency of the board. The minimum, of course, is that the board will meet once every two years (at the BS conferences), after which minutes will be published. More frequent meetings could take place on call by the president or another officer perceiving the need to debate a critical issue. Generally, it was agreed that there needed to be more regular meetings (frequency to be determined by the criticality of the issue) of the board with the liaisons. Much of this could take place by e-mail and conference phone calls.

8. **Publications — Newsletters, Web, International Journal:** The board discussed several ways that might gain visibility for IBPSA and/or gain regional participation in its efforts. These included:

- Getting more articles from the regions for the newsletter.
- Consideration of an IBPSA Journal (future plans). **Haves** agreed to investigate other magazine publishers and find out more on publishing costs.
- **Spitler** agreed to give several BS'97 papers to the editor of Energy and Building and also the Journal of Building and Environment.
- **Sahlin** agreed to participate in finding a permanent home for the IBPSA home page and a web master. Most likely this would move to a commercial site.

9. **Old Business:** The old business centered mostly on the financial affairs of the IBPSA Newsletter. Currently, IBPSA has no mechanism to receive money back from the regions for each region's consumption of the newsletter. IBPSA's treasury is sound at this time, but each issue of the newsletter diminishes the amount of funds in the treasury and there is no recovery of this cost. Charging the regions for their newsletters seemed that it may be counter-productive to the mission of IBPSA, so it was decided that at a minimum, the IBPSA secretary would investigate means of reducing the publishing costs. This issue will be re-visited at a future date.

10. **New Business:** No new business.

11. **Clarke** adjourned the meeting at 3:30 p.m.

Submitted by: **Larry Degelman**, IBPSA Secretary

❖

IBPSA Worldwide

IBPSA-Australasia
Terry Williamson
The University of Adelaide
Faculty of Architecture and Urban Design
ADELAIDE SA 5005, Australia
Phone: 618 8303 4591 Fax: 618 8303 4377
e-mail: twilliam@arch.adelaide.edu.au

IBPSA-Canada
Dan Seth
Public Works & Government Services Canada (PWGSC)
Sir Charles Tupper Building
Room C 456, Riverside Drive
OTTAWA, Ontario K1A 0M2, Canada
Phone: 1 613 736 2233 Fax: 1 613 736 2764
e-mail: sethd@pwgsc.gc.ca

IBPSA-Czech Republic
Frantisek Drkal
Department of Environmental Engineering
Czech Technical University in Prague, Technicka 4
166 07 PRAGUE 6, Czech Republic
Phone: 42 2 2435 2480 Fax: 42 2 2435 5616
e-mail: drkal@fsid.cvut.cz

IBPSA-France
Roger Pelletret
CSTB
BP 209, Sophia-Antipolis F-06904, France
Phone: 33 4 93 95 67 11 Fax: 33 4 93 95 67 33
e-mail: pelletret@cstb.fr

IBPSA-Greece
Constantinos Balaras
National Observatory of Athens
Institute of Meteorology and Physics of the Atmospheric Environment
P O Box 20048, GR 118 10 ATHENS, Greece
Phone: 301 32 57 961 Fax: 301 34 21 270

IBPSA-UK (BEPAC)
Marion Bartholomew
BEPAC
16 Nursery Gardens, Purley on Thames
READING RG8 8AS, UK
Phone/fax: 44 118 984 2861
e-mail: dba@compuserve.com

IBPSA-US
Ed Sowell
Fullerton State University
P O Box 939, Placentia, CA 92634, USA
Phone: 1 714 773 4092 Fax: 1 714 449 7168
e-mail: sowell@fullerton.edu

IBPSA Membership Application

Dues for IBPSA are paid directly to the regional affiliate to which the member belongs. At this time, there are affiliates in Australasia, Canada, Czech Republic, UK, and the US. Members of the affiliate organization are automatically considered full members of IBPSA-Central. Please inquire as to the affiliate organization in your region, or contact the representative shown elsewhere in this Newsletter. If joining an affiliate is not in your best interest because of your location, you may join IBPSA directly by completing the application below.

MEMBERSHIP CLASSIFICATION DESIRED (check one): (Effective dates: Jan. through Dec.)

- Sustaining member US$ 500/year [ ]
  An individual, company, or institution in related practice.
- Member US$ 75/year [ ]
  A graduate from a college or university, or a registered professional engineer or architect.
- Student Member US$ 25/year [ ]
  An individual who is a full-time student.

Amount Enclosed: US$ _________

PERSONAL DETAILS

Name: ____

Title: ____

Organization: ____

Street Address: ____

City, State, Zip: ____

Country: ____

Telephone: ______________________ Fax: ______________________________

e-mail address: ____

Please pay by **Check** or **M.O.** to: **IBPSA** c/o Larry Degelman, Dept. of Architecture, Texas A&M University, College Station, TX 77843-3137, USA. Tel: (409) 845-1015, Fax: (409) 862-1571, e-mail: larry@archone.tamu.edu.

or by **Purchase Order** by faxing this signed form to **IBPSA** c/o Larry Degelman (409) 862-1571:

Purchase Order Number: ____

Date: ______________________ Signature: ______________________________

The Integration of Computational Fluid Dynamics into Building Simulation

Joe Clarke[1] and Ian Beausoleil-Morrison[2]

BACKGROUND

To address the complex nature of real-world design problems the building simulation (BSim) field has been evolving towards higher resolution, integrated heat and air flow modelling. Although earlier tools considered the *thermal* impact of user prescribed infiltration and ventilation, the interdependency of heat and air flow was not considered. Consequently, important configurations in which heat and air flow are strongly coupled-Hensen et al (1991) provide some examples-could not be accurately simulated.

Network air flow modelling was therefore integrated into BSim in the 80s to address this shortcoming. In the case of the ESP-r system, the coupling between heat and air flow is achieved by iteratively solving a thermal model and an air flow network. The air flow network is composed of nodes (representing air volumes such as rooms), components (representing the leakage paths and pressure drops associated with doors, windows, supply grills, ducts, fans, etc.), and connections (joining nodes by components). A mass balance is performed at each time step, using the temperatures calculated for the previous time step, to solve the air flow through each connection. The air flow results are then used to establish the infiltration and ventilation loads for the thermal equations for the current time step. These steps are repeated at each time step of the simulation with iteration used for the case of strongly coupled flows.

Although the integration of network air flow modelling has advanced BSim towards higher resolution, there are limitations to this approach:

- large air volumes are represented by a single node, implying well-mixed conditions;
- and temperature distributions within air volumes cannot be determined;
- momentum effects are neglected;
- insufficient resolution exists to accurately determine local surface convection and so simplifying assumptions and techniques must be applied.

Computational Fluid Dynamics (CFD) has been used to predict air motion and heat transfer in buildings for nearly a quarter century. Whittle (1986), Nielsen (1989), and Jones and Whittle (1992) provide a thorough review of the applications. The quality of CFD predictions, however, depends greatly on the accurate prescription of boundary conditions (wall temperatures and air flows into and out of the CFD domain), which, in general, are not known *a priori*: wall temperatures and air flows through openings are dynamic and dependent on the external weather excitations and the states prevailing throughout the rest of the building. As such, simplifying assumptions are usually made, and the boundary conditions often treated as steady.

There is therefore a synergistic potential between BSim and CFD: BSim can establish more realistic boundary conditions for CFD, while CFD can produce higher resolution modelling of flow patterns within air volumes and surface convection for BSim. This synergistic potential provided the motivation to implement a CFD capability within ESP-r (Negrao 1995).

THE BSim-CFD CONFLATED SYSTEM

The conflated BSim-CFD system was achieved by developing a CFD code (the *domain flow solver*, dfs) and integrating this into ESP-r's *building and plant simulator*, bps. The bps and dfs structures operate in tandem (within a single executable), exchanging information on a time-step basis. Three different conflation mechanisms currently exist to allow bps and dfs to "handshake". These are described conceptually in this article, while the reader is referred to Negrao (1995) and Clarke et al (1995a, 1995b) for a detailed description.

Figure 1 shows a montage of an ESP-r session involving CFD.

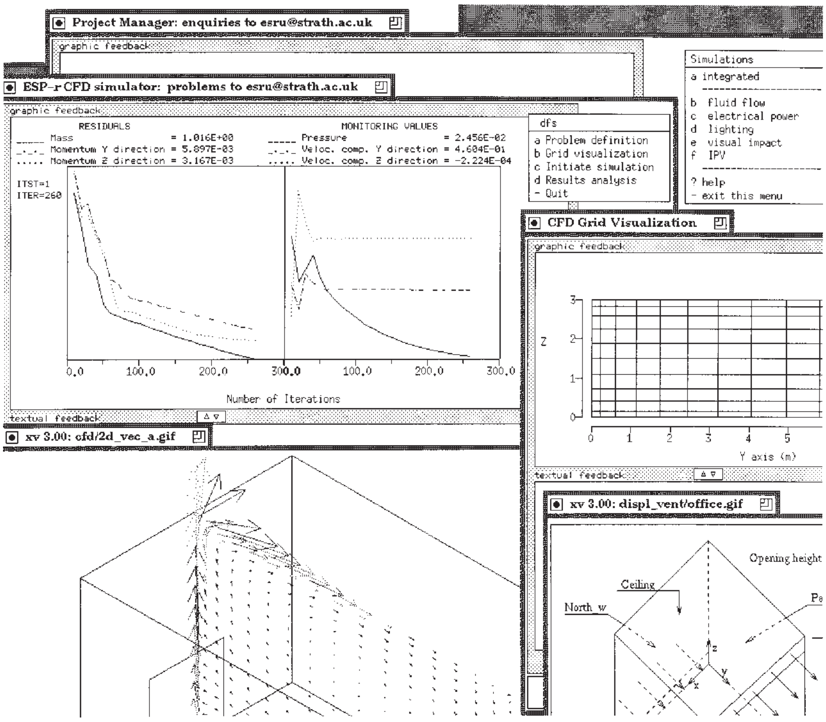
With *Type 1* conflation, bps and dfs handshake on a thermal level. Rather than calculate convection coefficients between solid surfaces and the zone air-point in its usual manner (a number of methods are available, the default being the Alamdari and Hammond, 1983, empirical correlations), bps uses dfs to determine the convection coefficients. Bps establishes the boundary conditions for dfs using the surface temperatures calculated during the previous time step. Bps then invokes dfs, which is driven to convergence. Air-to-surface heat transfer is then determined from the dfs-predicted flow and temperature fields through the use of wall functions. Surface averaged film coefficients for each surface of the zone are then calculated and passed back to bps, where they are used to establish the zone energy conservation matrix equation. Bps then solves this matrix equation in its normal fashion (Clarke 1985) to determine the zone air-point, surface and intra-construction temperatures for the current time step. Again, iteration may be employed for the case of strongly coupled flows.

Bps and dfs also interact on the thermal level with *Type 2* conflation but now bps uses dfs to solve the zone air-point temperature directly. Rather than calculating the air-point temperature with its usual technique, bps invokes dfs and establishes its boundary conditions as in Type 1. Once dfs converges, its temperature field is averaged to determine the zone air-point temperature and the wall functions are used to

---

[1] *ESRU, James Weir Building, University of Strathclyde, Glasgow G1 1XJ, Scotland, UK*

[2] *CANMET Energy Technology Centre, Natural Resources Canada, Ottawa K1A 0E4, Canada*



```
RESIDUALS                                   MONITORING VALUES
_____ Mass                 = 1.016E+00      _____ Pressure                   = 2.456E-02
_._._ Momentum Y direction = 5.897E-03      _._._ Veloc. comp. Y direction = 4.604E-01
..... Momentum Z direction = 3.167E-03      ..... Veloc. comp. Z direction = -2.224E-04

ITST=1
ITER=260
```

Figure 1 Montage of an ESP-r session involving CFD

determine the convection heat transfer to the surfaces. The surface convection values are passed back to bps where they are used to solve for the surface and intra-construction temperatures. In application, the handshaking occurs every 10 dfs sweeps, so that dfs' boundary conditions are updated a number of times each bps time step.

With *Type 3* conflation, bps' air flow network and dfs interact, although there is no interaction at the thermal level. A single air flow network node is replaced by a CFD domain, thus dropping the assumption of well-mixed conditions for that zone. New connections are added to bps' air flow network to connect the CFD domain to the remaining network nodes while the connections to the node replaced by the CFD domain are removed. Bps establishes boundary conditions (mass flow and thermal) for the CFD domain, then invokes dfs, which is driven to convergence. The CFD-predicted air flows into and out of the zone are then passed to bps' network air flow solver, where they are treated as sources or sinks of mass. Bps then determines the flow through the remaining connections in the network, before solving the thermal system for the current time step.

A fourth conflation type is planned by which the features of Type 2 and 3 may be combined: i.e. dfs estimates the zone air-point temperature and surface convection coefficients on the basis of a fully interacting (whole building) air flow network and CFD domain.

Dfs' COMPUTATIONAL APPROACH

The job of CFD is to approximate and solve the coupled and non-linear set of partial differential equations (PDEs) that describe the conservation of mass, momentum and energy of a fluid domain. Dfs applies a finite volume approach and a three-dimensional, Cartesian, staggered grid to discretise and transform the PDEs into a system of algebraic equations.

The widely applied standard *k*-e model of turbulence is used to estimate the turbulent diffusion of momentum and heat while the log-law wall functions are used to account for viscous effects in near-wall regions. Buoyancy forces are included in the momentum equations using the Boussinesq approximation.

The SIMPLE pressure-correction solution approach is used, in which the transport equations for velocity, pressure, temperature, kinetic energy of turbulence, and dissipation rate of kinetic energy are sequentially solved until the system of equations is driven to convergence. (This approach is currently being refined to improve the speed of convergence.) The transport equations are solved with a combined TDMA/Gauss-Siedel solver.

Dfs' approach shares much in common with CFD codes that have been applied to room air flow modelling (for example, see Lemaire et al 1993 and Liddament 1991).

Dfs has undergone analytical, empirical and inter-program validation. Negrao (1995) compared dfs predictions to an analytic solution for a simple laminar flow situation. He also compared dfs and PHOENICS for a number of natural and forced convection cases. In addition, Loomans (1995) simulated the two-dimensional test cases of IEA Annex 20 (Lemaire et al 1993) and found favourable agreement in both the isothermal and non-isothermal cases.

APPLICABILITY OF THE CONFLATED SYSTEM

There can be little doubt that the integration of CFD has increased the resolution of BSim: detailed predictions of the flow and temperature fields within zones can be predicted, enabling flow visualisation, studies on pollutant dispersion, and thermal comfort assessments. However, significant questions remain regarding the accuracy and applicability of the technology.

As mentioned, CFD has been used to predict air motion and heat transfer in buildings for nearly a quarter century. The standard *k*-e model has been employed in the majority of these analyses to characterise the effects of turbulent motion. Upon reviewing the various turbulence modelling approaches, Chen and Jiang (1992) concluded that this method remains the most appropriate for predicting room air motion.

However, the standard *k*-e model, as described by Launder and Spalding (1974), is only valid for high Reynolds Number (fully turbulent) flow. Adjustments are made in regions adjacent to solid walls to account for low Reynolds Number (viscous) effects. Consequently, the application of the standard *k*-e model implies an important assumption: that the flow is fully turbulent (notwithstanding wall regions) or at least behaves like a fully turbulent flow.

In general, room air flows are not fully turbulent. Baker et al (1994) characterise room air motion as typically turbulent, although only weakly so. According to Chen and Jiang (1992), room air flows may be laminar unsteady, locally artificially induced turbulent, transitional or fully turbulent. Measurements indicate that the flow in the main body of ventilated rooms may be transitional (Jones and Whittle 1992).

Given that room air flows are rarely fully turbulent, can the thermal simulation of buildings really be improved by the BSim-CFD conflated approach? Will CFD-predicted temperature and velocity fields result in better estimates of surface convection? Is the technology limited to the few building configurations which are truly fully turbulent?

These questions are being addressed in a research project which is currently underway.

IMPROVEMENTS TO THE CONFLATED SYSTEM

A number of developments are planned to improve the accuracy and applicability of the bps-dfs conflated system. These are outlined in this section.

Improved Surface Convection Prediction

When BSim and CFD are conflated on a thermal level, the prime job of CFD is to accurately estimate surface-to-air convection heat transfer. Recent work (Chen, Moser and Huber 1990; Chen and Jiang 1992; Yuan, Moser and Suter 1994) has shown that log-law wall functions (the approach used by dfs) can lead to significant errors in predicting surface convection. Consequently, alternatives to the log-law wall functions-low Reynolds Number models and new wall functions-are under examination and improvements to dfs will be made in this regard.

Integration with Bps' Multi-Gridding Approach

Nakhi (1995) has implemented multi-dimensional construction modelling within ESP-r and a marriage with dfs is envisaged. This will allow a more resolved description of boundary conditions for dfs, and facilitate the use of local surface convection coefficients (as opposed to surface averaged values) by bps.

Adaptive Control of Bps-Dfs Conflation

The most significant development planned is an adaptive control system, which will control how and when the bps and dfs structures interact. At each time-step, the controller will assess the qualitative behaviour of a flow (laminar, fully turbulent, partially turbulent, etc.), by examining non-dimensional groupings such as the Rayleigh Number and Reynolds Number. Drawing upon a knowledge base, the controller will then decide whether CFD should be applied and, if so, how it should be applied. The controller will examine the resulting dfs predictions and compare them against empirical predictions of surface convection. If the use of CFD is rejected, the controller will choose amongst a suite of empirical correlations to predict surface convection, again drawing upon the knowledge base.

REFERENCES

Alamdari F and Hammond G P (1983), 'Improved Data Correlations for Buoyancy-Driven Convection in Rooms', *Building Services Engineering Research and Technology*, 4(3), pp106-12.

Baker A J, Williams P T and Kelso R M (1994), 'Numerical Calculation of Room Air Motion - Part 1: Math, Physics, and CFD Modelling', *ASHRAE Transactions*, 100(1), pp514-30.

Chen Q, Moser A and Huber A (1990), 'Prediction of Buoyant, Turbulent Flow by a Low-Reynolds-Number *k*-e Model', *ASHRAE Transactions*, 96(1), pp564-73.

Chen Q and Jiang Z (1992), 'Significant Questions in Predicting Room Air Motion', *ASHRAE Transactions*, 98(1), pp929-39.

Clarke J A (1985), *Energy Simulation in Building Design*, Adam Hilger Ltd, Bristol and Boston.

Clarke J A, Dempster W M and Negrao C (1995a), 'The Implementation of a Computational Fluid Dynamics Algorithm within the ESP-r System', *Proc. Building Simulation '95*, International Building Performance Simulation Association, pp166-75.

Clarke J A, Hensen J L M and Negrao C O R (1995b), 'Predicting Indoor Air Flow by Combining Network Approach, CFD and Thermal Simulation', *Proc. 16th AIVC Conf.*, pp145-53.

Hensen J L M, Hand J and Clarke J A (1991), 'Building Design Assessment through Coupled Heat and Air Flow Simulation: Two Case Studies', *Proc. 12th AIVC Conf.*, pp239-49.

Jones P J and Whittle G E (1992), 'Computational Fluid Dynamics for Building Air Flow Prediction -Current Status and Capabilities', *Building and Environment*, 27(3), pp321-38.

Launder B E and Spalding D B (1974), 'The Numerical Computation of Turbulent Flows', *Computer Methods in Applied Mechanics and Engineering*, 3, pp269-89.

Lemaire A D, Chen Q, Ewert M, Heikkinen J, Inard C, Moser A, Nielsen P V and Whittle G (1993), 'Room Air and Contaminant Flow, Evaluation of Computational Methods', *IEA Annex 20 Subtask 1 Summary Report.*

Liddament M (1991), 'A Review of Building Air Flow Simulation', *AIVC Technical Note 33.*

Loomans M (1995), 'Comments on and Simulations with the Domain Flow Solver', *FAGO Report 95.45.W*, Eindhoven University of Technology, The Netherlands.

Nakhi A E (1995), *Adaptive Construction Modelling within Whole-Building Dynamic Simulation*, PhD Thesis, ESRU, University of Strathclyde, Glasgow UK.

Negrao C O R (1995), *Conflation of Computational Fluid Dynamics and Building Thermal Simulation*, PhD Thesis, ESRU, University of Strathclyde, Glasgow UK.

Nielsen P V (1989), 'Airflow Simulation Techniques -Progress and Trends', *Proc. 10th AIVC Conf.*, 1, pp203-23.

Whittle G E (1986), 'Computation of Air Movement and Convective Heat Transfer Within Buildings', *Int. J. Ambient Energy*, 7(3), pp151-64.

Yuan X, Moser A and Suter P (1994), 'Wall Functions for Numerical Simulation of Turbulent Natural Convection', *Proc. 10th International Heat Transfer Conf.*, Brighton UK, pp191-6.

*IBPSA welcomes contributions to ibpsa*NEWS. *If you would like to submit an article or other material, please contact Marion Bartholomew on:*

phone/fax: +44-118-984-2861

e-mail: dba@compuserve.com

IBPSA reserves the right to reject papers submitted, and to edit those that are published.

This edition of *ibpsa***NEWS** was designed and produced by David Bartholomew Associates, 16 Nursery Gardens, Purley on Thames,
Reading RG8 8AS, UK   Phone/fax +44-118-984-2861 email dba@compuserve.com

ibpsa NEWS

VOLUME 9 NUMBER 2 DECEMBER 1997