Next-Generation Building Energy Simulation Tools—A Vision of the Future

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Many building energy simulation programs developed around the world are reaching maturity—using simulation methods (and even code) that originated in the 1960s. Without substantial redesign and recoding, expanding their capabilities has become difficult, time-consuming, and expensive. Over the last thirty years, substantial research in analysis methods and advances in computational power have increased the opportunity for significant improvements in these tools.

In the United States, the Departments of Energy and Defense are planning to jointly develop a new building energy simulation tool. Although this new program will build on the collective experience of the development community, it is intended to go substantially beyond the capabilities of existing programs. To help in the planning effort, a workshop was sponsored in late 1995 on next generation building energy simulation tools—focusing on energy simulation developers and expert users. A second workshop planned for June 1996 will focus on user needs. The goal of the workshops is to generate and rank applications, capabilities, methods and structures, and interface ideas for next generation simulation environments. The scope was simulation of building life-cycle processes that influence energy performance and environmental sustainability.

This paper describes the vision for next generation simulation tools that evolved from the meeting of simulation developers from around the world. The methods used in the workshops as well as the resulting recommendations are also described.

BACKGROUND

In August 1995, the U.S. Departments of Energy (DOE) and Defense (DOD) cosponsored a workshop on next generation building energy simulation tools. Earlier in 1995, DOE and DOD began planning to develop a new building energy simulation tool that builds on their experience developing existing programs—DOE-2 (Winkelmann et al. 1993) developed by Lawrence Berkeley National Laboratory (LBNL) and BLAST (BLAST Support Office 1992) developed by Construction Engineering Research Laboratories (CERL) and University of Illinois (UI). This project is anticipated to take approximately 24-30 months to complete. In 1997, they will also begin planning development of next-generation building simulation tools that go substantially beyond the capabilities of simulation programs available today.

The focus of the first workshop was intentionally limited to energy simulation developers and expert users[1] . A second workshop that focuses on users is planned for June 1996. This paper reports on the results from the first workshop.

STRUCTURE OF THE EXPERTS WORKSHOP

The goal of the experts workshop was to generate and prioritize applications, capabilities, and methods and structures for next-generation simulation environments. The scope was simulation of building life-cycle processes that influence energy performance and environment sustainability. Participants were told that this workshop was not: a forum to discuss pros and cons of any existing tool, to decide who might perform any development work for any potential U.S. next-generation simulation tools, nor a place to discuss platforms or user interfaces.

The workshop was organized into three breakout sessions: Applications, Capabilities, and Methods and Structures. The participants were divided into five groups facilitated by a team member from DOE, LBNL, CERL, or UI. The facilitators used a five-step process for each of the breakout sessions: brainwriting, grouping and eliminating duplicate ideas, brainstorming, prioritizing and pareto voting, and summarizing. Each is described briefly below.

At the beginning of each breakout session the workshop leaders described the general subject of the session (applications, capabilities, or methods and structures). Then, each group began brainwriting—each workshop participant writes down ideas on 3 x 5 cards (one idea per card), then passes each card to their right. Over the next 10-15 minutes, the group reviews each idea as they are passed and continue to generate new ideas. Brainwriting encourages idea-generating through individual creativity and brainpower. Then the groups organized the cards/ideas into general groups while eliminating duplicate ideas. To make sure no important ideas were missed, the groups then spent 10-15 minutes brainstorming—group generation of new ideas. After brainstorming, each group counted their cards/ideas and multiplied by 0.2 to get number of votes allowed each participant. Each participant then selected their top 20% of the ideas (pareto voting). Votes (using dots) were applied to the cards only after all participants in the group had selected their top 20%. The groups then rank-ordered the cards from highest priority (most votes) to lower priorities (fewest votes). It should be noted that all the ideas are considered important. Voting only provides a relative ordering of the ideas within each group. Last, each facilitator prepared a summary, presented below, that was presented to the entire workshop at the end of each breakout session.

SUMMARY OF APPLICATIONS BREAKOUT SESSION

Group 1

The group recommended a range of applications going far beyond simply calculating energy use. This indicates that any future program or suite of programs should be able to do quantitative simulation of many issues related to energy use such as lighting, indoor air quality, and exterior environmental impact. Another key result was that future programs should not just be aimed at designers, but are also needed in such areas as research, education, and standards development. Also, it was concluded that the program should be useful not only for the initial design of a building, but should also be applicable throughout the building life cycle, including construction, commissioning, operation, and retrofit.

Group 2

Group 2 had a large percentage of professors, and the suggestions for applications reflected that fact. The top choice for application of the new program was for student education. The other top choices were to provide equipment sizing capability and system operation optimization. Generally the group took a broad systems view for applications by including such topics as parameter estimation, indoor air quality determination, and fault diagnosis as high priority choices.

Group 3

During initial discussions for the breakout, Group 3 decided not to limit its ideas to the domain of current energy simulation programs, but to open itself up to further-reaching applications. After the prescribed idea formation (56 individual items generated), the group attempted to group the ideas. Eight categories (design, operations, database, life cycle costing, controls, codes and standards, education and training, and other) encompassed the ideas generated. Potential applications for a new tool are widespread throughout the building/construction area.

Group 4

There was strong consensus in prioritizing the applications of next generation tools. Although the group was comprised almost entirely of researchers, the focus was clearly on applications that would benefit practicing mechanical engineers and architects. Research applications received low marks, while building industry applications such as thermal comfort, productivity, controls, optimization, and code compliance were considered top priorities. Thus the group perceived the primary beneficiaries of the next-generation tool to be the building design, operations, maintenance and construction communities.

Group 5

This group swayed from wanting everything in the world fundamentally modeled to having simple inputs for users and not having them worry about fundamental models. At first the group thought about the user and discussed options that a user would like to see in a simulation tool. The group believed that the interface was the key link between having the accessibility of sophisticated algorithms and user manageability of the large amount of building information. The group also concluded that having objects that could be easily interfaced with each other to form custom models was crucial. In other words if some group in the world updated a system model or a component of the zone model you could replace that object with the updated object quickly. Key technical concepts supporting this idea are: interoperability, object-oriented or -based, and sharing of common data or databases. This is a natural extension of concurrent engineering or collaborative technologies.

SUMMARY OF CAPABILITIES BREAKOUT SESSION

Group 1

Here, the group discussed areas where additional research and/or better models were needed rather than simply repeating the capabilities of current programs (which, of course, the group assumed would be carried over into future programs). Additional work is needed in two broad areas: (1) fundamental physics and (2) processes that traditionally received little emphasis but are now important. In the first category the members of the group were surprised by the number of basic heat transfer mechanisms that are still poorly understood, are not well modeled, or have not been incorporated in the mainstream whole-building programs, but which are important in any future program. These mechanisms include foundation heat transfer, moisture absorption/desorption, phase change materials, outside air film conductance, and inside air flow. The second category—processes that previously were not emphasized but are now of concern—includes issues related to indoor air quality, such as indoor pollutant production and transport, and pollutant mitigation processes, such as ventilation control.

Group 2

The system orientation of the group carried through into the capabilities session. The top vote went to: coupled interzone air flow and thermal processes incorporating moisture/contaminant transport and infiltration. The academic orientation also came through in many of the high-vote suggestions which included: first principles system and plant models, and fundamental room air heat balance models. Receiving lower numbers of votes, but still popular, were such things as 1-, 2- and 3-dimensional conduction, and stratification. All the suggestions were oriented toward including more basic or fundamental process models.

Group 3

Our group assumed that the current capabilities inherent in several of the simulation codes would remain and focused on areas that need more definition, research or both. Categories of ideas included air flow, lighting and fenestration, moisture, model flexibility, heat transfer, building information structure, weather and uncertainties, and ''other.'' Some categories represent improvements needed in current models; some are entirely new areas for building simulation.

Group 4

Although there was also a strong group consensus in prioritizing next-generation tools' capabilities, the focus of the group was in this case clearly driven by an interest in fundamental research rather than end use. The group considered the research community—not the user community—best positioned to make decisions related to the modeling of physical processes. It was agreed that issues related to the room air flow field (such as intrazone air flow and mixing) and issues related to solar radiation (glazing and shading systems, internal radiant exchange and daylighting) are areas where current models are deficient.

Group 5

During the second session the group made a distinct shift back to fundamental physics and total generality. They wanted all heat transfer in 3-D and transient with simultaneous heat and mass transfer. They also wanted fully flexible system and plant modeling, daylighting and ray tracing, and 3-D radiation modeling—''all physical processes should be modeled at the most detailed level possible.'' Then they made a slight concession in that yes, several simpler levels of models for quicker execution time and input simplicity should also be available. This is just the schizophrenia of researchers who may develop software or want simulations tool that are usable by practitioners.

SUMMARY OF METHODS AND STRUCTURES BREAKOUT SESSION

Group 1

It was unanimously agreed that a future program should have three basic elements:

- A common product model for the building. This model (building description) should be object-oriented, standardized so that different programs can read from it and write to it, and persist through the building life cycle to avoid reentering data for different applications.

- A modular calculation—modular means that the calculation comes in pieces that can be connected to simulate the problem at hand or are interoperable, i.e., can work together on the common building model.

- Databases of component product information—databases of generic or actual products that contain the input needed to simulate these products. Such databases are needed for envelope components (windows, walls, light fixtures, etc.), HVAC components (coils, heat exchangers, chillers, cooling towers, etc.) and whole HVAC systems.

In addition to these basic elements, a number of supporting features were listed. The most important were: integration with CAD, visualization of complex outputs, and case study databases.

Group 2

The group here issued a call for interoperability, and friendly interfaces coupled with modularity and open program structure. A category the group deemed important was that of product modeling and in this category they thought standardized data structures for product databases should be a goal. In the area of interfaces, the suggestions were quite typical and included graphical inputs and on-line help. One interesting suggestion was the concept of ‘‘meters’’ to assist with tailoring output. The suggestions for advanced techniques included such interesting topics as: modal reduction, inverse modeling capability and error propagation analysis.

Group 3

Four important categories emerged: modeling, solving, interface, and architecture. Fundamental to the discussion in the group was that the architecture of the software should be open to allow for most flexibility from all concerned. It should be built around an object-oriented environment to help smooth the model translation problems prevalent in current software. Inherent knowledge of building systems should be available for the user to have intelligent defaults when modeling a facility. The environment should be able to simulate in variable time steps to take advantage of the response time in the various building elements. Interfacing to the software is a key issue and ‘‘easy to use’’ is the keyword.

Group 4

Predictably, there was not a strong consensus on the methods and structures that should be utilized in the new tool. There was some agreement on methods at the most general level: extensible libraries and modularity of components. General agreement was also reached that every effort should be made to model processes in the most fundamental way possible (simultaneous systems and plants, adaptive time steps). There was not a clear consensus on specific techniques. There was not only great diversity, but also strong opinions on which solution technique should be used to solve various problems.

Group 5

Finally during the last session the concentration was on user interfaces with knowledge-based defaults and rules, algorithm and module communications, and verification. The participants wanted to put it all together: sophisticated models with graphical and knowledgeable shells for the users, all algorithms able to communicate with all others, a standard format completely verified. This culmination will allow everyone to be able to access these powerful integrated algorithms with ease of use or excruciating detail.

DETAILED CONCEPTS FROM THE BREAKOUT SESSIONS

The following tables and figures present a summary of the concepts and ideas that were generated in each of the three breakout sessions. The top five items for each major category are included in each table. In total, the five groups generated 225 ideas for the Applications breakout session, 242 ideas for the Capabilities breakout session, and 201 ideas for the Methods and Structures breakout session. Table 1 shows the ranked ideas by major category from the Applications session; Figure 1 the applications-related total votes by major category; Table 2 the ranked ideas by major category from the Capabilities session; Figure 2 the capabilities-related total votes by major category; Table 3, the ideas generated in the Methods and Structures session; Figure 3, votes by major category related to methods and structures.

SUMMARY

A somewhat surprising outcome of the workshop (at least to the authors) was that not many new or unusual ideas were brought up—even with a group of international building energy simulation experts. The hundreds of ideas generated during the workshop showed instead that the field of building energy simulation still has many fundamental problems that need to be addressed. Even the experts were not willing to stretch the boundaries and capabilities of simulation (even in their own minds) until more of these basic issues are resolved. The authors hope that the workshop was a beginning for the building simulation field—to start them talking about the future, instead of focusing on where they are today.

NEXT STEPS

The authors have initiated a project to combine the best capabilities of the DOE-2 and BLAST building simulation programs. In 1997, the team will begin formulating a plan to develop the next generation of building energy simulation tools in the United States. The plan will propose development of new building energy tools that go substantially beyond the capabilities of currently available simulation tools with a broader scope in the building simulation arena. It is our intent to structure development of the next generation tools as an open process so that a number of contributors from around the United States and the world can and will participate.

The complete list of ideas generated during the workshops is available from the authors.

Table 1. *Ranked Ideas from the Applications Breakout Session*

Design	Votes
Collaborative, integrated, facilitated building design	39
Building code compliance—energy and environmental impact	18
System selection and equipment sizing wizards	16
Lighting/Daylighting (selection of products, performance assessment)	7
Aid in selecting retrofit strategies	7
Performance Evaluation	**Votes**
Comfort evaluation	21
Economic, life cycle, and cost-benefit analysis	14
Optimal operation and control	14
Control strategies/optimization/supervisory	13
Indoor air quality	12
Research	**Votes**
Policy formation code development	9
Solution of inverse problem to calibrate model for existing building	6
Basic research	5
Sensitivity and error analysis	5
Provide basis for simplified tools	4
Information Repository	**Votes**
Electronic owner's manual (all life cycle)	9
Feed intelligent database for future designs	5
Need for structural libraries of models, object-oriented programming	3
No gap between description and behavior; i.e. performance data immediate after object selection	2
Use of historical data files, previous work/ buildings	2
Education	**Votes**
Student and practitioner education	23
Make it fun	2

Table 2. *Ranked Ideas from the Capabilities Breakout Session*

Physical Process Models	Votes
Air flow modeling	25
Moisture absorption/desorption in building materials	17
1-, 2-, and 3-D transient conduction	15
Daylighting	14
Full generality 3-dimension shading, lighting, and solar geometry	14
Building Systems and Controls	**Votes**
Flexible system and plant modeling	18
First principles system and plant models	14
Imperfect mixing of zone air	13
Zones, systems, plants coupling	8
Passive/active solar	6
Component Models	**Votes**
Advanced fenestration	11
Energy storage in buildings including phase change	8
Advanced lighting system modeling	4
Dynamic coil models	3
Duct losses	3
Input and Output Capabilities	**Votes**
Variable time step	5
Uncertainty analysis	4
Economic Analysis	3
Costs based on utility rate schedules modular interchangeable features	2
Shell to facilitate the combining of components into a system	2
Environment Models	**Votes**
Occupant comfort	9
Typical, extreme and site-specific weather	5
Wind pressure distribution	4
Modeling of terrain and surrounding obstruction	2
Long-term climates with special peak conditions and microclimates	1

Figure 1. Applications of Next Generation Building Simulation Tools

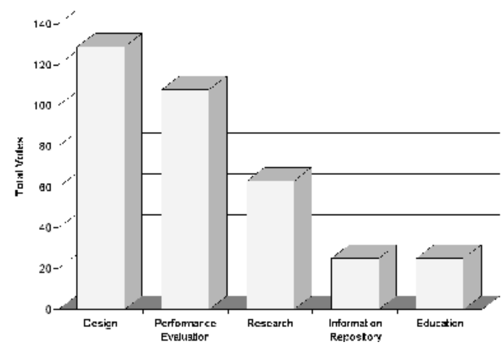

Figure 2. Required Capabilities of Next Generation Building Simulation Tools

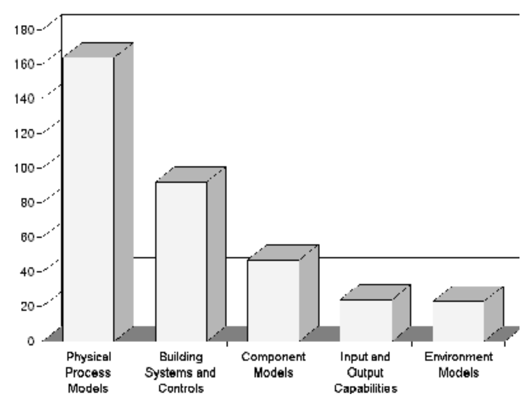

Figure 3. Proposed Methods and Structures For Next Generation Building Simulation Tools

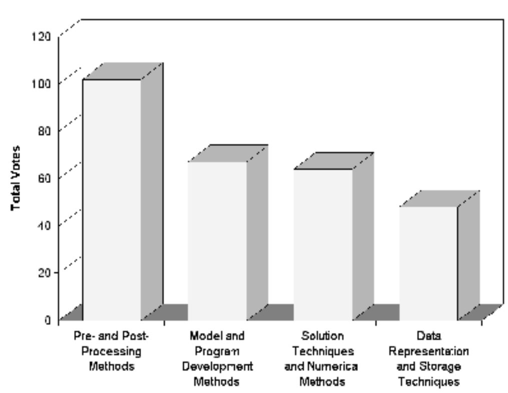

Table 3. Ranked Ideas from the Methods and Structures Breakout Session

Solution Techniques and Numerical Methods	Votes
Simultaneous solution of loads plant and controls	5
Stochastic methods	5
Macroscopic air-flow modeling (non-CFD)	4
Numeric nodal approach for maximum future flexibility	4
Powerful differential-algebraic equation solvers	4
Data Representation and Storage	**Votes**
Extensive and extensible libraries of building components and systems	13
Online documentation, structuring information	6
Flexible structure to allow quick change in systems configuration	5
Standardized data structures	5
Case studies database for decision-making	4
Model and Program Development Methods	**Votes**
Object-oriented representation	12
Model reduction	6
Modularity of components	6
Equation-based models—NMF format	5
Tool able to be used by a team (concurrency)	5
Pre and Post Processing Methods	**Votes**
Adaptable interface according to user type and stage of design process	21
Knowledge-based front end with intelligent defaults	15
Visualization of complex outputs, including virtual reality display	10
CAD integration	7
Validation by empirical, analytical, and comparative techniques	7

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ENDNOTES

1 The workshop followed Building Simulation '95 (Mitchell and Beckman 1995), a biannual conference organized by the International Building Performance Simulation Association (IBPSA).

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