MEETING THE RESEARCHER'S NEEDS IN BUILDING ENERGY SIMULATION

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ABSTRACT - The Building Researcher directs his efforts towards increasing the knowledge to provide cheaper and better buildings. Energy simulation software can be a useful vehicle to transfer this knowledge to those responsible for the design, construction, operation and use of the built facility. This software must lend itself to scrutinity revisions, upgrading and verification by the researchers. The available software is not generally accessible for these activities. Future previsions to accommodate these revisions are outlined.

INTRODUCTION

The researcher's objective is to help achieve better buildings at lower cost. Researchers strive to contribute to the knowledge base of the building process and as educators they strive to impart this knowledge to new professionals. Better buildings can be built and operated at lower cost if the design process is improved. This can be achieved by increasing the knowledge base and the pool of expertise from which the designer can draw.

The complexity of buildings is such that seldom does the design team have the expertise and the information base needed to cover all fields adequately and effectively. Yet the decisions made during the design stage have the greatest impact with respect to resources expended in the construction and operation of the building.

It is estimated that design accounts for 7% of the cost of a project whereas maintenance and operation accounts for 57%. The actual conceputalization stage where the highest impact on the total cost occurs is a small proportion of the design itself. More effort must be placed, at this stage, on the design process because it will reduce costs in later stages. It is important that tools be available to the designer to make him aware of the impact of his decisions at this stage of the life cycle cost of the building.

The detail design stage should enable the engineers and architects to access current standards and information to produce a design and drawings of high quality to avoid delays in the construction process.

The design process must be made more efficient to reduce delays on project duration (estimated at 25% per project) which are caused by (i) design errors (37.2%), (ii) change orders (21%) and (iii) other (41.8%).

THE ROLE OF THE BUILDING RESEARCHER

The building researcher is simultaneously user, developer and teacher.

As user, he needs a tool to analyze problems in order to better understand the phenomena, to discover and quantify correlations between parameters, and to propose new design solutions and strategies for saving energy in buildings. Programmes normally address ideal buildings because too many unknowns exist regarding the as-built physical facility. Although these toolsexist, a large majority of our buildings perform inadequately. There is water penetration as well as moisture migration through walls. There is a need, therefore to improve the knowledge base.

As developer, based on his knowledge of the limitations of available software, he can improve or develop new mathematical models or technical information on properties of building materials. The researcher in building science and building engineering looks at the programmes in energy conservation as a vehicle to transfer existing as well as newly developed knowledge to the market place.

As teacher, he transfers his knowledge of the capabilities of existing software to professionals by explaining its performance, by providing theoretical and practical analysis, comparison between programs, conclusions from validation projects or recommendations for selecting an appropriate program for a particular problem. He is therefore involved in the diffusion of these programs to potential users.

Hence, in the knowledge cycle, the researcher must be an important node in the network of communication between the other parties involved in the building process and operation. The end purpose of their activity is to provide an appropriate built environment in which people can live and work within a reasonable energy budget.

LIMITATIONS OF PRESENT SOFTWARE

The search for better building design and operation in terms of energy consumption, requires the analysis of new concepts and solutions. Several phenomena such as heat storage effect in the building mass, moisture migration, tri-dimensional transient heat transfer or air movement within and between rooms, are problems which have been neglected in past practice but which could be solved today using existing computer methods.

The available software on building energy analysis has limited capabilities to simulate such complex phenomena.

In 1981 the participants at a roundtable on building energy analysis methods (1) mentioned several weaknesses in energy analysis methodologies, especially related to inter-zonal interactions, daylighting, air infiltration, underground heat transfer, passive solar systems and moisture migration through the building components.

In April 1983 the participants at the Workshop on Sophisticated Models for Building Energy Analysis and Performances Prediction (2) concluded that work must be done to improve algorithms in areas such as air infiltration, mixing between daylighting and artificial lighting, daily and seasonal solar effects on buildings or mass effects on heat storage, thermal bridges and moisture effects.

A new software structure, able to handle simultaneously the calculations for loads, systems and controls, thermal comfort and air distribution was also suggested. The work recommended by the 1983 Workshop should be carried out in association with the building researchers. It is good, for example, to improve algorithms to model thermal bridges, but a much better solution is to eliminate them through better building design.

In recent years remarkable effort has been made to improve and develop new capabilities of simulation programs such as:

- thermal performance of multiple rooms;
- distribution of solar radiation on interior surfaces, eliminating the assumption of uniform distribution;
- passive solar techniques (direct gain, Trombe wall, water wall, sunspaces, movable insulation);
- effect of daylighting on building energy consumption;
- dynamic control of HVAC systems.

It is difficult for researchers to obtain the actual models and computer listing to carry out validations and comparison between the results of those models and the actual behaviour of the building. It is not feasible for researchers to purchase all these programs in order to have access to the computer codes. The existing software is not yet able to simulate several complex phenomena occurring within buildings which were mentioned at the above meetings.

This situation may be due to various reasons:

- lack of adequate mathematical models or experimental data;
- limited information transfer from building researchers;
- priority given to the development of micro-computer software, based on simplified models or modified algorithms from detailed energy analysis programs.

NEW TRENDS

Building energy simulation must improve the efficiency of the design process by:

(i) providing a vehicle of communication and transfer of information and technology between the various agents of the construction process;

(ii) providing a knowledge bank which would grow with the contribution of:

- experiences from the field and performance of the built facility;
- research results from the researcher, universities, builder, other research programmes;
- extended education to the professions. 50% of building problems occur in the building envelope; and
- innovation from the designer.

In order for this to be achieved, simulation software must be open to assessment by the researchers so improvement can be made to the algorithms; it must carry updated information and state-of-the-art technology at all times, intermediate packages should be distributed to interested reserchers during the development of the programme.

Through this software, the knowledge base becomes accumulative, it does not die with the disappearance of contractors or consulting firms. It grows because it's continuously shared among the participants in the cycle. Once the information is placed in the cycle it remains there because it's common to all who wish to avail themselves of it. Educators will draw from it to train engineers and architects, etc.

Researchers at a number of universities and research labs are already carrying out research programmes which can contribute to better simulation models of the building. For example, at the Centre for Building Studies, Concordia University, Montreal, current research projects which can interface with energy simulation programs deal with the building envelope, HVAC systems, solar passive systems, energy analysis in the retail sector and commercial building, and economic analysis. These areas interact and their variables are included in models which can be expressed in computer programmes.

Research - Oriented Software

In the past energy analysis programs, software developers and researchers have directed great efforts in similar directions, in parallel activities and have developed a large number of programs having similar capabilities.

The researcher needs a tool for detailed analysis of new concepts, involving phenomena usually neglected or approximated. Consequently, a research oriented software is required. Programs such as GEMS and HVACSIM + are the first examples of such software.

The development of a research software in building energy analysis implies a new software structure and new or improved mathematical models.

The new modular structure will allow the researcher to built a code for a particular probem but using the available modules from library and by adding new modules.

During the symposium on Modular Programming held in Boston in July 1968, several viewpoints on the nature and purpose of modular programming were presented. However, the only common conclusion was the recognition of the high cost of producing correctly functioning software and the conclusion was expressed by the saying: "divide et impera".

Since 1968 the modularization concept in software development was applied especially in Electrical and Civil Engineering, and less or no related activities were observed in Building Energy Analysis (20).

The Microsoft company is pursuing the modularized approach which enables each user to build his own code using the available modules. This software has been named "Windows" (18).

At the Centre for Building Studies, Concordia University, research into software with a modular structure includes several aspects related to the building science, such as thermal comfort, air quality as well as energy conservation.

A large package of modules, similar to the Scientific Subroutine Package (SSP) will be created using the state of the art in building energy simulation software, and new modules will be based on the most recent research results.

With this structure different algorithms can be compared within the same general conditions such as:

- solar radiation models;
- distribution of solar radiation on interior surfaces;
- window models;
- one-dimensional against three-dimensional heat transfer.

The research oriented program will provide, upo user request, besides the custom results (e.g. space loads, room air temperature, energy consumption), relevant data about the thermal behavior of the building such as temperature distribution in walls, relative and convective heat flows or solar radiation on the exterior and interior surfaces.

In developing this package it was found that some areas require additional research for developing or improving mathematical models:

a. Transient heat and mass transfer through the building envelope, in two- or three-dimensions, including the effects of thermal bridges, air infiltration through the envelope and air cavities.

a. Heat storage effect in building mass, especially for complex configurations of interior surfaces.

c. Indoor comfort including thermal, visual and air quality aspects.

d. Pattern of air movement in rooms, for both active and passive systems.

e. Air infiltration in multi-story buildings

f. Thermal properties of conventional or new materials (e.g. phase change materials) under diurnal and seasonal variation of ambient conditions.

g. Effect of built environment (reflected solar radiation, concentration of air polutants, air movement around buildings).

Analysis of Simulation Results

..e results of existing energy simulation programmes are generally limited to deterministic approach can be more adequate when analyzing the thermal behavior of the building under random meteorological conditions or uncertain thermal performance of the building or HVAC system.

This analysis module of the simulation results should be included in the standard configuration of a research oriented software.

Software Validation

The aim of these computer programs, as mentioned by ASHRAE Handbook 1981 (3) was to provide quantitative energy and cost comparisons among design alternatives, and not accurate prediction of utility bills, due to the large number of uncontrolled and unknown factors. However, the most utilized approach to validate the building energy analysis programs is to compare the estimated against the measured energy consumption (8,9,10).

The disadvantages of this validation are the following:

- Large number of different buildings and systems should be evaluated to generalize the results;

- Although the estimated and measured energy consumption are comparable for particular conditions, the confidence cannot be achieved on the algorithms accuracy. The consensus of the Workshop on sophisticated models (2) was that in terms of acceptance by the design community, all the energy analysis programs rate very high, but at the algorithm level the acceptance is at an intermediate point because there is confidence in some algorithms, but not in others.

Within another approach, the predicted indoor air temperature or the cooling/heating load are compared against the measured values (7,10,11, 13, 14) or the analytical solution to particular cases, such as response of the interior temperature to a step function in the ambient temperature (4,6).

The comparisons of the global results can cover weaknesses at the algorithm level, which have not been discovered during the validation for particular cases, as in the following examples.

In an exercise carried at the Centre for Building Studies, it was found that major programmes concluded some discrepencies in the module that calculates the shading such as negative sunlit ratio for a configuration of the exterior shading devices involving overhang and side fines having different widths. Because the code was available it was possible to find this discrepancy. The first version of DEROB code was validated against results from seven test rooms at Los Alamos Scientific Laboratories (5), but a detailed analytical analysis done by Judkoff et al. (4) has shown the program is insensitive to building mass due to errors in interactive solution technique. Walton has shown a radiation imbalance will occur in BLAST-2.0 program when interior surfaces have different emissivities or the room geometry is not a simple cube (12).

During a research project carried out at the Centre for Building Studies (19), differences less than 10% have been obtained between the estimations of DOE-2.1B program and the utility bills of two commercial buildings. The uncertainties of specifying input data related to people habits (thermostat settings, window and door openings, use of appliances) or to the real thermal performance of building components and HVAC systems, have been observed as having a great effect on the estimation of energy consumption. Since the assignment of such factors involves some subjective estimations, it becomes relatively easy to fit the utility bills, by iterative runs, without a high accuracy in simulation of other phenomena, such as air infiltration, heat storage in building elements or effect of adjacent buildings.

To create confidence in the performances of building energy analysis software, a standardized validation procedure should be established based on software testing techniques. It is well known that complete testing, in the sense of the "proof", is not possible (20). However, the goal should be to provide sufficient testing to assure that the probability of failure is sufficiently low to be acceptable. A combination of structural and functional testing procedure can provide the necessary analysis framework.

A software validation package, based on standardized procedures, would be a helpful tool to assess the real performances of the energy analysis programs, to validate the authors' claims and to avoid expenses for obtaining the required experimental data.

CONCLUSIONS

1. The scientific competition and the information transfer between researchers as users of the building energy analysis software must be increased.

2. More emphasis must be placed on the building research itself for the development of better mathematical models of complex phenomena.

3. A highly modularized structure of the energy analysis software will create the framework for better use of existing algorithms and the implementation of new developments in mathematical models.

4. The analysis of the simulation results, using non-deterministic methods, should be integrated in the new software structure.

5. The researchers should be involved in the development of a software validation package for the building energy analysis programs.

6. The results of current projects should be reflected in new simulation software so that the user may have the benefit of current research.

7. By the interaction with the educational and research institutions, the level of use and confidence of the programme will be increased.

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