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Progress Report on Fire Modeling and Validation

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Abstract

The nations of the world are moving toward performance based building code standards which will establish a level of safety or risk rather then the traditional prescriptive codes which specify the performance of components. Performance evaluations can then use trade offs between many factors to provide the required level of safety. Computer models are the means to ascertain the performance of buildings built with new materials and new contents. As these models progress and become more entrenched in the regulatory system, it is paramount there be a continual effort to insure their validity. The accuracy of the models of individual phenomena is, and should be, addressed during development. However, the interaction of various parts of the system are not always well understood. This paper is part of the continuing effort to test the complete system model with full scale and real scale tests and experiments. The International Standards Organization (ISO), together with the Conseil International du Batiment (CIB), is establishing a framework for deciding on the appropriateness of a model to meet the requirements of those who wish to use them in predicting the environment in a building. This paper discusses the status of this work and lays out the time table for the completion of this effort, leading to a proposal for an ISO standard.

Introduction

Computer modeling of physical phenomena is becoming an increasingly important tool for understanding the physical world. The driving forces are the increased speed and availability of computers and an increased knowledge base of the physical world. These factors have led to improvements such that model predictions are being used for actual design decisions. Zone models are the present means of choice for understanding and predicting fire growth and smoke spread in compartmented structures. In the past, such models have been used largely to determine, after the fact, what occurred in specific fires. As confidence in the capability of such techniques grows, many nations are moving toward replacing much of their bench scale testing of components with computer modeling of whole systems[1].

Several attempts have been made to answer partially the question of how close the models are to reality. As noted in Peacock, Jones, and Bukowski[2], to date the method has been to examine plots of experimental data and model predictions. Then some qualitative and often vague statement on the "goodness" of the prediction is made. No method exists for making quantitative estimates of error in predictions and there are many difficulties in developing such a method[3]. The problem concerns comparing curves of variables plotted against time. A method of comparing two curves and giving a simple report on how they fit each other doesn't exist.

Until some method exists, quantitative comparisons can not be done. Although we cannot yet provide such a quantitative comparison, it is possible to provide graphically a qualitative analysis. As is the practice, predictions have been plotted against measured values. This gives a visual sense of errors and any trends. The graphs used are included to allow examination of the data that leads to these conclusions.

Overall Project Objective

Our objective in the project is rather broad: To develop and promote an international protocol to assess the predictive capabilities and usability of computer-based fire models that includes the experimental, statistical, and analytical techniques to implement them. There are an number of areas, however, where significant technical issues must be resolved before such a process is workable.

Issues Which Must be Addressed

It is critical that the process of model evaluation addresses areas of primary interest to the users of the models. With this in mind, a number of areas of interest to model users can have an impact on future efforts in fire model evaluation:

- **Classes and uses of models** – What types of models are available (zone models, field models, special purpose models) and how are they being used (design, fire recreation, litigation)? Also included is the intended domain of models (and typical use which may be different). Several summaries exist, which list, but do not evaluate these models.

- **Scenarios for use in model evaluation** – What fire/building scenarios are important to the users of the models? The answer to this should include sufficient information to allow appropriate experiments or simulations to be conducted (building description, design, openings and connections, materials; contents, ignition scenario, environmental conditions). Any process of model evaluation should concentrate on areas which tests the limits of the models rather than areas which most models can be expected to successfully predict.

- **Developing and gaining acceptance of an evaluation method** – How can we insure that whatever process is used to evaluate a model is supported by the users and developers of the models?

- **Technical issues** – Although we should build on extensive available experimental data, it is likely that there are areas which are yet to have been studied in detail. These include non-residential fire scenarios, statistical and analytical techniques for comparing model and experimental data, uncertainty in model and experimental results, and model sensitivity.

Important Elements of a Protocol for Model Evaluation

Once the most important models and scenarios are defined, there are multiple approaches to model evaluation: evaluation of the model's theoretical basis by peer review, evaluation of the implementation and usability by model users, and evaluation of the overall predictive capability of the resulting model by comparison of the model with experimental results. A summary of these may provide a starting point for discussions towards a widely accepted protocol:

- Peer review of theoretical basis of models
- Usability and practicality of models
- Comparison of model predictions with experimental results
    - Sources and quality of data for comparisons
    - Measurement and measurement system requirements
    - Uncertainty in experimental results
    - Peer review of experimental results
    - Methodology for transforming measured data into values which may be compared with model predictions
    - Sensitivity analysis of the experimentally-based "model predictions"
    - Blind runs of the models
    - Statistical and analytical comparisons

Peer review of theoretical basis – The theoretical basis of the model should be reviewed by a group of recognized experts fully conversant with the chemistry and physics of fire phenomena. The reviewers should judge whether there is sufficient scientific evidence in the open scientific literature to justify the approaches and assumptions being used. Primarily, this group would be comprised of researchers in the field.

Issues to be resolved include who should participate in the groups, who is willing to pay for the effort, what organization should be responsible for the group, and how can the group's independence be ensured with a group composed of both model developers and users. Key to the success of such an effort, however, is some agreement on a process and criteria for submission and evaluation of models that is acceptable to the majority of the model developers and users. Such a process is critical to avoid continual philosophical arguments of the "best" model phenomena.

Practicality and usability – In addition to peer review of the physics of a model, the ease with which data can be input to the model and the outputs of the model examined can have an impact on the appropriate and correct use of a model. Like the peer review of the theoretical basis of models, a group of model users could review the documentation and use to judge the level of expertise necessary to use different models.

Comparison of model predictions with experimental results – User acceptance of predictive fire models is enhanced when the predictions of the model matches the user's experience. This may come from successful recreation of actual fire incidents or through comparison of the predictions of a model with data gathered experimentally. In addition, verifying that the entire model satisfactorily predicts the course of a fire by comparing its output against the actual full-scale fire, ensures that the inevitable assumptions and errors in the individual submodels do not combine to produce incorrect predictions. Program predictions should be made without reference to the experimental data to be used for the comparison. Of course, this restriction does not include required input data that may have been obtained by bench or larger scale tests. No attempt to adjust a fit between the measurements and the predictions should be made.

The quality of experimental data must also be assured. Any experimental data used for model evaluation must be sufficiently documented and reviewed to insure that the experiments were conducted appropriately, that the facilities, instrumentation, and experimental techniques were appropriate to the scenario investigated, that the experimental data is consistent, and that the experiments have been sufficiently characterized to allow simulation by the models without actual reference to the experimental data. Physical measurements of compartments, connections, leakage, and construction materials and techniques must be adequately described to allow accurate simulation. Uncertainties in the measurements and measurement techniques themselves should be determined in a systematic and logical manner.

Model documentation – In order to evaluate the predictive capability, practicality, and usability of any model, sufficient documentation must be provided by the model developer to enable an independent review of the theoretical assumptions and mathematical techniques used in the model. Such documentation of a computer model is the primary means for the model developer to communicate the underlying physics, chemistry, and assumptions of the model.

Sensitivity analysis – Nearly all fire models are deterministic. However, uncertainties in model inputs lead to often overlooked uncertainties in the model results. Model predictions may be sensitive to uncertainties in input data, to the level of rigor employed in modeling the relevant physics and chemistry, and to use of numerical treatments. In general, we need to develop a procedure which identifies the important steps and minimum requirements for evaluation of the sensitivity of a range of fire models for consideration by national and international consensus standards organizations, and to identify and review methods for sensitivity analysis which may be appropriate for evaluation of computer based fire models.

- Organize a working group to develop a consensus on a set of fire/building scenarios of interest to model users.

- Test a range of available fire models with these scenarios (once the scenarios are adequately characterized) to refine the range over which the models should be evaluated.

- Develop a consensus document on a protocol for model evaluation. The existing ASTM guide can provide a starting point. We are currently working to expand on this guide and would welcome cooperation. ISO CD 13389 is now being circulated.

The CIB W14 Project on Model Verification

An assessment procedure for the evaluation of deterministic fire development simulation methods has been proposed. Detailed planning is made for the first phase consisting of blind, semiblind and open numerical simulations followed by a common comparison of simulation data with experimental data. An open comparison report is produced for every scenario of the round robin.

This proposal has been prepared within a CIB W14 sub-group 'Assessment and verification of computer codes for predicting fire development and smoke movement'. The members of the group are: Michel Curtat, Centre Scientifique et Technique du Bâtiment, France, Reinhold Dobbernack, IBMB der Technischen Universität Braunschweig, Germany, Walter W. Jones, Building and Fire Research Laboratory, NIST, USA, and Olavi Keski-Rahkonen (chair), VTT Building Technology, Finland. The proposal was discussed January 12, 1995 at the CIB W14 plenary meeting at Espoo and accepted as rules for the first rounds of the code assessment round robin.

Although numerous efforts to compare fire models with fire experiments have been published, systematic validation of the plethora of existing fire codes[4] is insufficient. This deficiency has become critical by the introduction of performance based codes in several countries which place heavy emphasis on numerical fire simulations. Therefore, designers, authorities, and the end users of buildings, who may not be knowledgeable about fire simulation, should be given guidance on which codes to use and on the limits of the models. There is anecdotal information that the codes could predict whatever you want. Currently it is left up to the skills of the applicant to ensure the range of validity of a computer code applied to a particular problem.

Following several initiatives CIB W14 has set up a prenormative task group[5] to plan and organize a validation program, which is intended to provide unbiased evaluations of different deterministic fire development codes and a means to test the usability of these models. Primarily, this evaluation is intended to include zone model based codes due to existing experimental information, but other types of codes, if offered to participate in the round robin, are not excluded.

Project Objective

The objectives of this group are

(1) to increase confidence in the use of fire models as a tool for fire safety engineering,

(2) to support ISO/TC92/SC4 in its effort to produce a document on assessment and verification of calculation models (WD13389),

(3) to consider all aspects of code evaluation, including physics, numerics, documentation, use of the codes, and availability of appropriate data for the selected scenarios, and

(4) to carry out a round robin project on deterministic, numerical, fire-simulation computer codes and experiments for model evaluation.

These definitions are slightly modified from those given in [4, 5] due to opinions presented during discussion within the group.

The objectives of the evaluation are so wide, that it will require several years to reach them. It is feasible to plan in a detailed way only a project for the first phase consisting of two simple scenarios. Altogether it is foreseen that at least ten different scenarios should be considered to assess a code to the extent required for fire safety engineering. Preliminarily, these scenarios could be:

A: Single plume under a hood
B: Single room with a door opening
C: Single room with a door opening into a corridor
D: A floor in a hotel and/or in a health care facility
E: Atrium and a room opening into an atrium
F: Shopping mall
G: Staircase in a multifloor building
H: Very large room
I: Underground space, room ventilated only from above

Compartment scenarios include as subscenarios different fire load configurations and boundary conditions (natural versus mechanical ventilation). Scenarios with burning walls, complicated fire loads as well as inclusion of active extinction are left to the later part of the program because the physical basis is still under development.

Project Schedule

Assessment consisting of different tasks is carried out as field work at different participating institutions, and as expert work within the CIB W14 task group. These are indicated below by a letter after the task number. Calculations relative to experimental data are carried out as blind, semiblind or open. The final report is intended to provide a measure of the validity of the data used for comparison, and the process used for the evaluation. For the first phase of the project, the proposed schedule is as follows:

Project program accepted (January 13, 1995).

Identification of potential participants into the first round of the round robin (March 1995).

Data for the first fire scenarios (standard problems) (March 1995)

(A) smoke filling of a hood with an analytic solution to test numerics, and
(B) three sizes of compartments with a vertical opening
© worked out into a standard FDMS format [3], and design reports written.

Invitations to participation into the first round of the robin sent out (April 1995)

Announcement of acceptance fulfilling preconditions (August 1995)

Filing the blind calculation report on one-compartment fire (B). In addition to illustrating the comparability of models in actual end-use conditions, this will test the ability of the model users to develop appropriate input data for the models (ultimate deadline December 31, 1995)

Deadline for peer reviews of the codes (December 1995)

Invitation to calculation of the one-compartment fire with given rate of the heat release (B), (January 1996). As a follow-on to the blind calculation, this test provides a more careful comparison of the underlying physics in the models with a more completely specified scenario.

Deadline for filing in the first simulation (March 31, 1996)

Invitation to open calculation of problem B, (April 1996). This problem provides the model user with the most complete information about the scenario, including the results of experimental tests of the scenario. Deficiencies in available input (used for the blind calculation) should become most apparent with comparison of the open and blind calculation.

Deadline to file in problem B (June 31, 1996)

Final report on A, and B rounds {see above for a description} (September 1996).

Assessment Rules

The simulation code assessment includes five major components, which occur either explicitly or implicitly during the process[6]: documentation, verification, performance validation, sensitivity study, and usability.
Prerequisites for participation into the round robin are:

Full written description of the code

For documentation full description of the physical basis of the code, the main structure of the program, required input data, produced output data, and user instructions should be written. The physical basis should include all mathematical equations used in the code either fully written or referenced in the open literature in a unique way. Other instructions should be sufficiently detailed, that an educated practitioner in the field should be able to use the code properly following instructions, and without other knowledge of the code (usability).

Availability of the source code

The source code should be available for inspection at least in one place agreeable to peer reviewers outside the institution which has developed the code (verification).

Multiple participation in the round robin.

For a code to participate in the round robin at least two different users of the code are needed, one outside the organization where code is developed. These users should simulate the given problems independently (usability).

The First Two Standard Problems

SINGLE PLUME UNDER A HOOD: For a rough testing of numerics smoke filling of a hood is calculated using optional plume models, and compared with analytical solutions. For testing the sensitivity on the initial values, several input data sets differing from each other only marginally are supplied. For scaling, a small, medium, and large hood are to be calculated.

SINGLE ROOM WITH A DOOR: The fire scenario consists of a single room with a door, and a fire load of wood cribs. Three different sizes of rooms of approximately similar geometry are used.

Comparison of Simulations

For verification, a peer review will be carried out, listing models used. It is felt at the moment, a conclusive review prior to comparisons of calculations would be practically impossible.

During this first phase the comparison between the simulated and experimental results is made by inspection. Qualitative judgement is given for the goodness of fit. More formal statistical methods may be tested, and used if practical.

A workshop on simulations has been arranged for September 1996, in conjunction with the CIB/SFPE workshop in Ottawa, Canada to discuss the results of the round robin before the comparison report is published in a final form. That workshop will plan the continuation of the round robin exercise for the next scenarios and prepare the design reports for the precalculations of those scenarios.

Related Activities

The assessment of the fire simulation codes will be carried out in cooperation with CIB W14 task group of Engineering Evaluation of Building Fire Safety as well as with ISO/TC92/SC4/WG1 and other organizations related to the work. Since the data to carry out detailed evaluations is either insufficient or nonexistent, strong interaction is needed with organizations and laboratories carrying out experiments. The following activities should be discussed to find proper ways of carrying them out outside of the present program and project.

Use accumulating experience of round robins to develop rules for assessment and identify areas which need additional research.

Designing and carrying out all scale experiments of different scenarios to assess numerical fire codes. There exists only a limited number of relevant experimental data. Design of an experiment should be based on a precalculated scenario to define measured quantities and measurement positions in a proper way.

Use descriptions of the codes to write a handbook on simulation codes.

Conclusions

The development of performance-based building regulations will reduce barriers to international trade in building materials, products, design, and construction by providing objective criteria and means to establish compliance with these criteria that are not proprietary. This CIB effort is central with regard to fire regulations, and provides key support and pre-standardization research to the International Standards Organization effort under TC92/SC4 on Fire Safety Engineering.

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The nations of the world are moving toward performance based building code standards which will establish a level of safety or risk rather then the traditional prescriptive codes which specify the performance of components. Performance evaluations can then use trade offs between many factors to provide the required level of safety. Computer models are the means to ascertain the performance of buildings built with new materials and new contents. As these models progress and become more entrenched in the regulatory system, it is paramount there be a continual effort to insure their validity. The accuracy of the models of individual phenomena is, and should be, addressed during development. However, the interaction of various parts of the system are not always well understood. This paper is part of the continuing effort to test the complete system model with full scale and real scale tests and experiments. ISO, together with the CIB, is establishing a framework for deciding on the appropriateness of a model to meet the requirements of those who wish to use them in predicting the environment in a building. This paper discusses the status of this work and lays out the time table for the completion of this effort, leading to a proposal f as an ISO standard.

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