Thermal performance programs

How good are the currently available computer programs for calculating the thermal performance of buildings? *D P Bloomfield* describes the research findings from a recent BRE collaborative project.

There are many computer programs available for assessing thermal performance, at the building or services design stage, or for assessing retrofit measures. They can cost from £50 to £10 000, can run on low cost pc micro-computers or on large mainframe computers. How is the user to make a sensible choice?

The research project in question was co-ordinated by BRE[1] and conducted by BRE, Leicester Polytechnic (LP), Nottingham University (NU) and the Rutherford Appleton Laboratory (RAL), and from International Energy Agency (IEA) Task 8[2].

What is validation?

It is not possible to check every path through a detailed program, to investigate every assumption and approximation and to take account of every situation for which it might be used. It is therefore not possible to validate a program in an absolute sense. The accuracy or adequacy of a program is dependent on the purpose for which it is being used.

Similarly it is not possible to make a simple statement to the effect that a program has been validated; such statements must be accompanied by more detailed information describing the circumstances for which the validation has been performed, eg building type, climate, operating conditions etc.

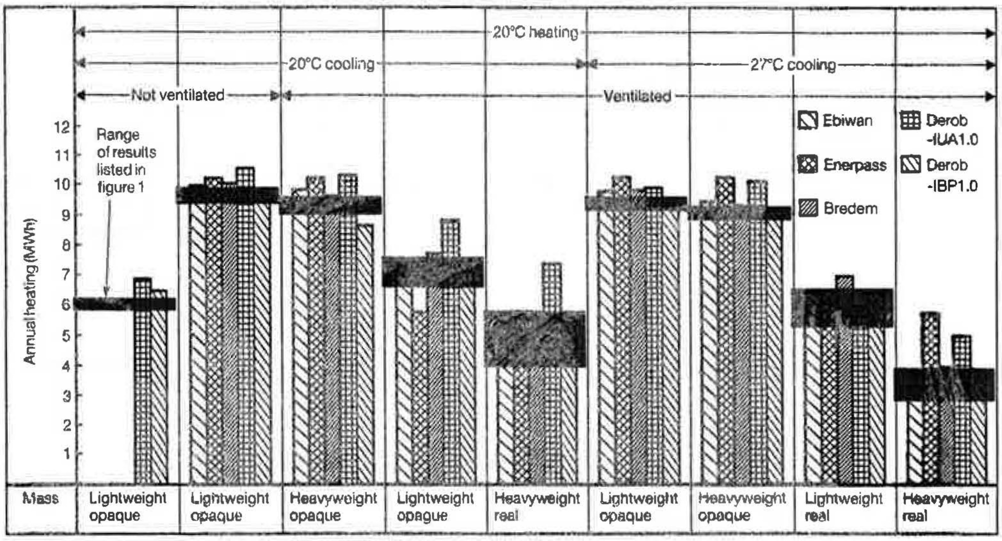
In the BRE/SERC work emphasis was placed on developing a methodology for evaluating the magnitudes of errors within a program. Additional errors will arise from the data selected when it is used.

The most commonly used validation techniques are inter-model comparisons and comparisons with experimental results (empirical validation). Much of the past work was found to be inconclusive, mainly because the tests used were too complex and the data were incomplete. Little attention had been given to the interpretation of results on a sound statistical basis.

The BRE/SERC group adopted the general approach developed by the Solar Energy Research Institute (SERI) in the USA, refining and extending the techniques where necessary; these techniques were used to;

- □ investigate and document the program's theoretical basis and examine the algorithms implemented;
- □ test individual thermal processes, using sensitivity analyses, and simple input excitations which allow comparison with analytically derived solutions (analytical tests);
- □ compare programs in such a way as to stress individual processes;
- □ compare against high quality measured datasets, using appropriate statistical tests.

These techniques need to be used together within an overall methodology tailored to the objectives of the evaluator as shown in figure 1.



Above, figure 1: IEA Task 8 benchmark tests. Five design tools are compared against the ranges in results obtained from careful use of detailed simulation programs.

Empirical validation

Although empirical validation provides the only real "truth test" and seems the obvious technique to use, it suffers from some shortcomings. All too often the data are incomplete (for example missing infiltration rates) or imprecisely known (insufficient measurement accuracy or unknown occupancy patterns).

Leicester Polytechnic reviewed existing experimental data-sets and documented the most suitable. Data from the Polytechnic of Central London test cell were compared with predictions from ESP, HTB2 and SERIRES. This exercise was conducted blind, ie without knowledge of the experimental results. It demonstrated the difficulties inherent in empirical validation, highlighting the need for very good quality data, for an appropriate and well documented building, and for uncertainties in program input data to be allowed for.

Very few such datasets exist and the cost of obtaining and documenting such information is extremely high. It is unrealistic to suppose that enough quality datasets covering the wide range of building types, climates etc, necessary to validate a program, will become available soon.

Leicester Polytechnic used relatively simple statistical techniques to obtain estimates of error bands, while RAL conducted research into the development of more advanced techniques. Such techniques may eventually allow better use to be made of existing datasets.

The empirical validation work indicated some errors in the programs under test. The need for improved algorithms for the calculation of surface heat transfer coefficients was highlighted, as was the need for more "mechanism level" experimental data and for more good quality test sets for a wide range of building types, etc.

The program user can have a large influence on the predicted results. One study[3] demonstrated this well: 25 consultants using a single simulation program predicted annual energy consumption with a range in absolute values of 4:1 for the same building!

Validation is always of the combined system of model-plus-user, and user effects should be considered very carefully, not only in inter-model comparisons, but in all of the techniques used for validation.

Review of techniques

The BRE/SERC project highlighted the need for understanding the theoretical basis of a program, its assumptions and approximations, both in conducting validation work and in selecting and using a program. The existing information produced by program developers was found to be inadequate for this purpose.

A questionnaire was devised and completed for four programs, allowing a standard description of theory to be given.

The questionaires revealed a significant number of errors and bugs in the programs. The understanding gained about their theoretical basis was also invaluable in completing the other stages of this validation methodology, in particular in determining the causes of differences in program predictions.

Further research into how best to document program theory and assumptions is being conducted within IEA Annex 21[4]. Thorough reviews of the theory and available algorithms for conduction, external convection, internal longwave radiation and solar radiation were conducted and guidance for future model developers is being prepared.

The major sources of errors in solar gain algorithms were found to be simplistic U-value modelling of windows and neglect of shading due to window reveals, and of diffuse radiation. Together these errors could lead to an overestimation of 20% in solar gain.

Uncertainties in the air flow regime at an external surface, together with those in wind velocity, surface roughness etc could lead to uncertainties in convection coefficient of 50%. The use of a combined convective/radiative convection coefficient (ie a U-value approach) was judged to be suitable for steady state analysis but not for assessing short-term dynamic effects.

Review and examination of source coding was an effeective way of detecting implementation errors. Statistical techniques such as cross-correlation were found to be effective in revealing the dynamics of energy flows.

Analytical tests were devised and executed for conduction and internal longwave radiation. These are suitable for verifying that the algorithms are working as intended by the developer, and proved successful in identifying errors and examining the adequacy of numerical solution schemes.

The advantage of analytic tests over other validation techniques (including empirical validation) is that the "truth model" used for comparisons is exact. They could be used for:

□ debugging, where the number of error sources should be restricted so that maximum information can be obtained;

□ testing accuracy of predictions, where all sources of error should be active in the way that they would in a normal building application.

Because of the wide range of different building types and user applications, general tests of the latter are difficult to devise. There is therefore an advantage in choosing the former approach which tests relatively extreme conditions. Exploring the conditions under which an algorithm breaks down leads to results which can be generalised more easily.

The description of a "real world" problem to a program has to be made in simple terms. These are forced partially by the program, its user interface and approximate treatment of certain features, and partially by pre-modelling simplifications made by the user. There is no unique way to describe the real world problem in terms which are suitable for all the programs. This has an important bearing on how intermodel comparisons should be conducted and their results analysed.

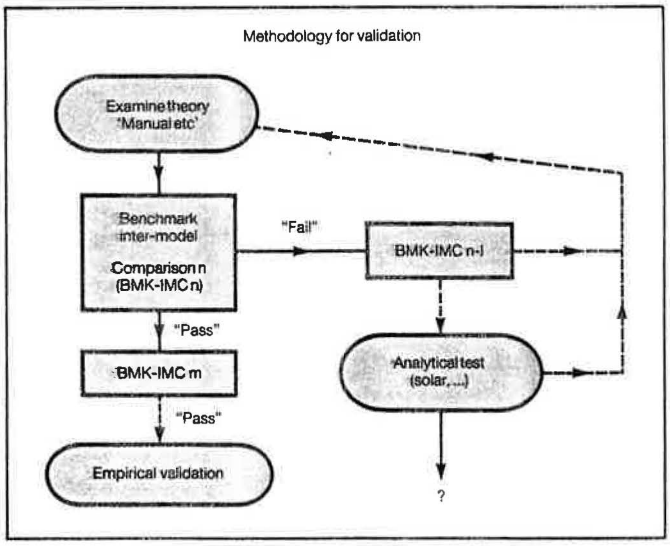


Figure 2: Schematic flowcart for a possible evaluation method.

Comparing models

As a result of this work a set of well-specified realistic building specifications has been produced and are being published by the Industry/Research club BEPAC[5]. Comparing predictions from several existing programs for these buildings showed significant differences, thus highlighting the need for validation.

A set of much more simplified building specifications was devised and tested for UK and other programs within IEA Task 8[6]. Reasonable agreement between predictions was obtained (figure 2) and a set of benchmark tests developed.

This set of tests was structured in such a way as to successively test different program features and to aid in the interpretation of results. Work is underway to develop this into a design tool evaluation procedure both within ASHRAE and IEA Annex 21.

It is considered that a great improvement in the quality and credibility of thermal modelling could be made by producing and disseminating guidance on how models should be used, by making appropriate data available, by improving the human computer interface, and by subjecting models to a basic set of evaluation tests.

Conclusions

One of the main factors emerging from this work is the importance of the program user. The opportunities for mistakes, misunderstandings, and misuse of programs are legion, quite apart from the inherent difficulties arising from the need to perform pre-modelling to fit the real world to the program.

In the absence of a more direct feedback of the consequences of mistakes in building design to the perpetrators, this situation is likely to continue.

There is no one technique for validating models, and each one discussed above has both strengths and weaknesses. Used in combination and with proper thought and quality control, they can form a powerful approach.

The BRE/SERC and IEA groups have laid the foundations for a set of test procedures which should be considered as the minimum to ensure a basic level of quality control in the field of dynamic thermal modelling.

A great improvement could be made by adopting and extending such an evaluation methodology and in increasing quality control over the process of program use.

Important advances could be made by:

□ producing and disseminating guidance on how programs should be used - improved program documentation, understanding what results are required and what accuracy is needed;

□ making appropriate data available in a standard format, for use in certain applications;

□ improving the user interface -perhaps developing a standard interface, using agreed terms;

□ subjecting all programs used to a minimum set of evaluation tests, based on the IEA 8 evaluation approach.

These issues are currently being addressed within the International Energy Agency Building & Community Systems project Calculation of Energy & Environmental Performance of Buildings (Annex 21). The Building Research Establishment will be publishing the existing evaluation tests through the Building Environmental Performance Analysis Club (BEPAC).

References

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4 D Bloomfield, *IEA Annex 21 - calculation of energy & environmental performance of buildings:* Annex text, BRE.

5 Building Environmental Performance Analysis Club - newsletters and information available from the Building Research Establishment.

6 D Bloomfield, *Design tool evaluation benchmark test cases,* IEA Report T.8.B.4, May 1989, BRE.