Tools for Whole Model Validation of Building Simulation Programs Experience from the CEC Concerted Action PASSYS

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ABSTRACT

This paper deals with the validation methodology used within the PASSYS project focusing on the developed method for empirical whole model validation of building energy simulation programs. The paper further discusses and describes how high quality data sets for empirical whole model validation are obtained within PASSYS.

1. INTRODUCTION

In 1986 the PASSYS project was formed by the Commission of the European Communities with the aim to increase confidence in passive solar heating systems through the development of a European component testing procedure including the definition of component characteristics, the refinement/approvement of a European validation methodology for building energy models and the development of better calculation tools.

PASSYS involves research consortia from Belgium, Denmark, France, Germany, Greece, Italy, the Netherlands, Portugal, Spain and United Kingdom. The work of PASSYS is undertaken by four specialist subgroups addressing test methodology, model validation and development, simplified design tool development and test site management. The national consortia have access to 12 test sites with two or four test cells with an integrated heating and cooling system and data acquisition. Due to a removable south facing wall of these full scale test cells (8.4 x 3.6 x 3.8 m), passive solar components can be mounted for testing. In support of the model validation and development work, each consortium utilizes Unix™ work station technology on which the ESP energy modelling system (Clarke 1985) is resident. This program was selected by the Commission of the European Communities as the European reference simulation program for passive solar simulation on the basis of program comparison undertaken by the European Passive Solar Working Group (Dupagne 1986, Achard and Gicquel 1986).

The paper deals with the validation methodology being employed by the model validation and development subgroup (MVD subgroup) within PASSYS with special emphasis on the developed methodology for empirical whole model validation. The paper further describes how experiments for obtaining high quality data sets for empirical whole model validation purposes are set up in the PASSYS test cells, and how measurements are compared with predictions. As part of this, criteria for high quality data sets will be discussed.

2. VALIDATION OF BUILDING SIMULATION PROGRAMS

Many simulation programs have over the years been checked to some extent, and it is not uncommon for the developers to claim that they have "validated" them. The word "validation" is often misunderstood and has certainly been used in different senses in the past. It is often taken to mean a once and for all time check of the absolute accuracy of a program. In practice, the thermal performance of a building is dependent on a very large number of parameters (including essentially unknown quantities like user behaviour). It would be quite impossible to test all feasible combinations of these parameters in order to ensure that the program is correct, even if the true building performance was known.

Although it is not possible to validate a simulation program for all kinds of applications, correct and carefully performed validation will increase confidence in a program. It may also give an indication of the reliability of the program, at least for more common cases.

The question is then, what is a correct and carefully performed validation? Experience from the past shows that in order to perform good validation, it is most important to have a validation methodology combining different validation approaches.

3. VALIDATION METHODOLOGY

The main objective of the MVD subgroup has been to refine/approve a European validation methodology and to test this by applying it to a building energy simulation program (especially ESP).

Before the start of PASSYS two studies had been carried out with the attempt to establish such a methodology for validation of building energy simulation programs. The first study, undertaken by the US Solar Energy Research Institute (Judkoff et al 1983) had resulted in a three part methodology:

a) analytical tests,
b) inter-model comparison,
c) empirical validation.

This methodology has further been refined and extended in the second study carried out by four British research teams - the University of Nottingham, Leicester Polytechnic, the Rutherford Appleton Laboratory and the Building Research Establishment (Bloomfield et al 1988). The methodology comprises:

a) theoretical examination of the theory behind the submodels and a thorough inspection of the source code,
b) analytical verification involving a comparison of predictions with exact analytical solutions,
c) inter-model comparison involving a comparison of the target program with several other programs,
d) parametric sensitivity analysis,
e) empirical validation involving a comparison of predictions with measured data.

This was the methodology reviewed and accepted by the MVD subgroup at the commencement of the PASSYS project. The methodology was translated to:

- theory and source code checking - evaluation of alternative algorithms/models and code debugging,
- analytical tests - comparison of predicted results with exact solutions,
- inter-model comparison - comparison of target program with several other programs,
- sensitivity analysis - internal consistency and quality assurance checks,
- empirical validation - comparison with carefully planned and measured data,
- uncertainty evaluation - determine confidence intervals on predicted data sets,
- based on the activities above - recommend modifications to the models under study.

The validation methodology has, in order to test its validity and further to refine it, been applied to the simulation program ESP for a number of topics of major importance for simulation of the thermal performance of buildings (although not all topics have been, or can be, processed to the same level of detail):

- climate input data,
- external and internal surface convection,
- external and internal surface longwave radiation,
- shortwave processes,
- conduction,
- air flow,
- thermal comfort,
- controls.

The complete description of the above-mentioned work undertaken by the MVD subgroup can be found in the final report from the first phase of PASSYS (completed December 1989) (Østergaard Jensen (ed) 1989) and more condensed in (Clarke 1989).

4. EMPIRICAL WHOLE MODEL VALIDATION

In the second phase of PASSYS main emphasis has been devoted to empirical validation or more precisely empirical whole model validation. The reason for putting major emphasis on this technique is that many people consider empirical validation (comparison of a model with reality) as being **the** way to perform validation. Empirical validation should in principle compare a true model derived form experiments with a mathematical model implemented in a program. Such method is not, as analytical validation, limited to isolated processes in simple constructions, but deals with real world complexity comparable to situations as encountered when the simulation program is used in design studies. Empirical validation is, therefore, the most widely used technique for validating transient thermal simulation programs.

The problem with empirical validation is, however, that it involves experiments, with the risk that the question regarding the reliability of the predictions cannot be answered due to the unreliability of the measurements. In an analysis of existing experimental data sets for validation purposes (Lomas and Bowmann, 1986), the authors conclude that among 179 examined data sets only 2 were of a sufficiently high quality to be used for empirical validation.

Many data sets are missing important measured data eg air infiltration, the split between direct and diffuse solar radiation, etc. The uncertainty of the data is often very large eg the weather data has not been collected at the test site. Very often the physical parameters of the materials of the buildings have not been measured, and have to be obtained from handbooks. The use of such low quality data sets can only lead to the conclusion that when the predictions are within the error band of the measurements, the model is capable of reproducing the observed building performance with appropriately chosen input data. In such cases it cannot be claimed, that the model can predict the response of a given building. If the uncertainty of the input data is large, serious errors in the simulation program may remain hidden, as good agreement between measured and calculated values can be obtained by fitting the input data and not because the model is correct. On the other hand, if the results do not fit within the error band, this can be due to two reasons: 1) the algorithms in the model describing the thermo-physical processes are "wrong" in some way, or 2) the user is unable, for some reason, to accurately describe the building, system or excitation to the model.

There is, therefore, a need for high quality data sets for validation purposes. The PASSYS project is well equipped to undertake the task of obtaining high quality data sets:

- 12 almost identical test sites with highly insulated test cells spread all over western Europe,
- the test cells are equipped with a comprehensive sensor set with small uncertainties connected to an automated data acquisition system,
- the test cells are equipped with a well monitored heating and cooling system,
- a removable south facing wall of the test cells makes it possible to test different passive solar components,
- thermo-physical properties of the materials can be determined by the involved teams.

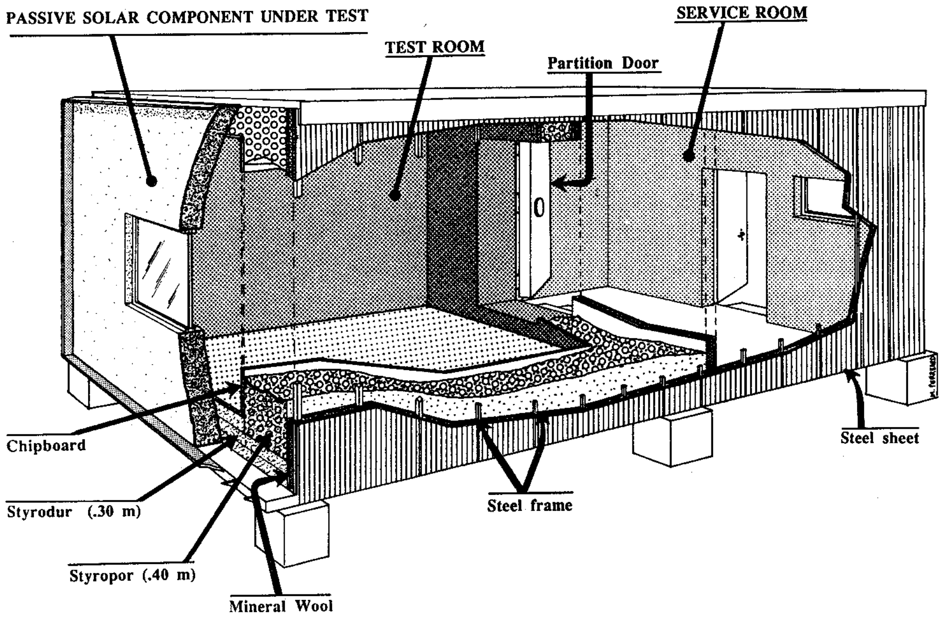

Figure 1. The PASSYS test cell. The south wall is not as shown here installed directly in a steel frame, but in an insulated frame in order to decrease the thermal bridges.

A more detailed description of the PASSYS test cell, the heating and cooling system and the basic sensor set can be found in (Wouters and Vandaele, 1989a and b).

In order to utilize test facilities like the PASSYS test sites for model validation purposes it is, however, outmost important to have strict criteria for producing high quality data sets and a methodology for performing empirical validation. Criteria for high quality data sets are necessary in order to ensure that the obtained data sets really are of high quality. A methodology for empirical validation is necessary in order to ensure the outcome of an empirical validation exercise - ensure that the comparison of measurements and predictions is as little as possible based on skill or subjective judgement, and to ensure that as much as possible information is obtained from the exercise. Criteria for obtaining high quality data sets and a methodology for empirical whole model validation have been developed within the framework of PASSYS by the MVD subgroup.

4.1. Criteria for high quality data sets

In few key words, a high quality data set for model validation purposes should:

- be comprehensive,
- be detailed,
- have small uncertainties,
- be controlled,
- be fully documented.

The comprehensiveness should allow that all important input parameters are known with a low uncertainty, and thereby it is avoided that good agreement between measurements and predictions can be obtained by data fitting. The detail should ensure that, in the event of differences between measured and predicted results, the source of discrepancies can be pin-pointed. The small uncertainties should decrease the uncertainty band on the measured values and thereby decrease the overall uncertainty on the validation study. The control should ensure that the data sets are without errors. The documentation is the primary condition for future use of any recorded data.

How these requirements are fulfilled within PASSYS is described in the following.

4.1.1. Comprehensiveness. All input data to the model are measured with a high level of accuracy. This goes for the weather conditions (solar irradiation, ambient temperatures, wind speed and direction, ambient humidity and longwave radiation to the sky), thermo-physical properties of materials, air infiltration of the test cells (if the heat loss by ventilation/infiltration exceeds 5% of the transmission loss continuous infiltration rate measurements are required), etc. The model is, as explained later, used to detect which parameters are critical and should be measured with the highest level of accuracy.

4.1.2. Detailed. The PASSYS test sites (and test cells) are equipped with a basic sensor set which consists of:

- 7 air temperatures in the test room,
- 1 dry resultant temperature sensor in the service room,
- 21 internal surface temperature sensors,
- 21 external surface temperature sensors,
- 1 heat flux meter at the removable south wall,
- 1 air velocity meter (indoor)
- 3 external air temperatures (ventilated south, shielded north, unshielded below the test cells),
- 1 wind speed and direction (at 10 m),
- 3 solarimeters (global horizontal, diffuse horizontal, global vertical south),
- 1 pyrradiometer (horizontal),
- 1 relative humidity meter (ambient),
- 1 meter for measuring of heating power to the test room,
- 1 meter for measuring of cooling power to the test room.

Most of the test sites and test cells are equipped with more sensors than the basic sensor set. When used for obtaining high quality data sets for validation purposes the model is used to investigate the necessary sensor set and the location and accuracy of the sensors. Extra sensors for validation purposes are eg temperature sensors located in the south wall, extra surface sensors and heat flux meters, sensors for determination of the micro climate around the test cell, continuous air infiltration measurements (a pressurization/depressurization test is always performed before and after a test), etc.

Most of the sensors are scanned each minute and stored this way, others eg the pyranometers (measuring solar irradiation) are scanned every 3 seconds and averaged into one minute values. The measured data is averaged to 10 minute and 1 hour mean values. When storing both the one minute, 10 minute and 1 hour data it is always possible to go back to the one minute raw data if something is wrong in the averaging or in the data, or discrepancies between measurements and predictions cannot be explained from the 1 hour values.

The above-mentioned averaging acts more or less as a low-pass filter. Information about high frequency variations is, therefore, lost. Furthermore, the sampling technique may cause aliasing problems of the sampled signal. The problem is, however, handled by using presampling filters which have been developed within PASSYS.

4.1.3. Low uncertainties. Low uncertainties on the measurements are obtained by using sensors with a high accuracy, and by maintaining and calibrating the sensors at regular intervals. The Test Site Management subgroup, which is in charge of the test sites, has developed procedures for maintaining and calibrating the sensors at the test sites.

The conditions during the tests have been designed in order to minimize the uncertainty of the measurements. Well known initial conditions inside the test cell, high temperature difference between inside and outside, only heating or cooling during the test, constant heating or cooling power rather than constant temperature, etc. The test conditions are controlled by the data acquisition system, which gives a more precise control and an exact knowledge of what is happening during the experiment.

4.1.4. Control. A data set cannot be called high quality before it has been checked for errors and missing data. A control procedure for manual daily check of the raw data at the test sites has been developed within PASSYS. The aim of the procedure is mainly to check if the experiment is running as planned, but gives also a first control of the data set. It is expected, by the end PASSYS, to have a software based procedure for final control of the data sets. It should be controlled if the measured values are within the expected range, if the trend is within a defined range, if data is missing, etc. Missing data should, if possible, be filled with flagged realistic data. Statistical tests as eg principal component analysis should also be applied in order to detect if one or more sensors, of several sensors measuring almost identical values (eg the 7 air temperatures), are malfunctioning or influenced by external sources resulting in a bias.

4.1.5. Fully documented. Data sets are documented in such a way that future use of the data sets is possible, even if the user has no knowledge about the experiment or of PASSYS.

The documentation contains a comprehensive description of the component being tested, with detailed information of the design (including detailed drawings), materials used (including thermo-physical properties), locations of sensors, etc. On file: Location, time and duration of the experiment. Detailed description of the sensors with name, location, uncertainties, calibration factors, conversion factors, measuring or averaging problems, etc. Condensed information on weather conditions during the experiment. Information on the micro climate. Information on obstructions causing shade. Description of the used data averaging, data filling and data correcting routines. A logbook with any event during the experiment eg adjustment of sensors, entrance to the test cells, snow on the sensors, etc. Strategy for heating and/or cooling during the test cell. Results from pressurization/depressurization tests, etc.

4.1.6. Data sets. It is the aim of the MVD subgroup to obtain up to 20 high quality data sets for empirical whole model validation purposes. The tests are divided into three groups:

1) common experiment,
2) different passive solar components,
3) parameter variations.

The common experiment is aiming at demonstrating the feasibility of the concerted action, validation of the calibration procedure and ensuring climatic diversity. The common test will be performed at several test sites and is performed with an insulated, lightweight reference wall with a 1.15 m^2 window with double glazing.

The tests with different passive solar components are aiming at characterising the spectrum of passive solar components and to show to which extent ESP or any other simulation program can handle passive solar components. The tests will comprise sunspaces, solar walls with transparent insulation and a Trombe wall.

The tests with parameter variations are aiming at testing the sensitivity of the thermal performance of passive solar components. Experiments with the reference wall with added thermal mass and added solar blind, and variations of a sunspace are planned.

4.2. Methodology for empirical whole model validation

The aim of performing empirical whole model validation is to detect if a model is capable of describing the reality correctly. This is, however, a non-trivial task to perform, as it requires expertise in experimental design, modelling principles and simulation techniques. In many earlier validation studies, comparisons have been performed for relatively few physical parameters (eg only the total heat demand), making it difficult to identify the cause of the observed discrepancies between measured and predicted values. In some cases, discrepancies have been reduced by adjusting one or more of the determining parameters without knowing the real cause of the deviations, as the number of accurately measured parameters was insufficient. In such cases one cannot claim that the model has been proven valid.

An empirical validation study should be carefully planned before starting. The experiment should be devised so that the necessary data is available in terms of eg scanning interval, location and accuracy of sensors. Guidance in this area can be obtained by modelling the phenomena before doing the experiments. Also the expected analysis of the data should be planned before the study.

There is thus need for an empirical whole model validation methodology. Such a methodology has been developed by the MVD subgroup. A methodology which ensures that one can rely on the results from the validation and that a maximum of information is obtained from the validation study. The methodology comprises six stages:

1) definition of scope, type and nature of the physical and numerical experiment,
2) implementation of the physical experiment on site,
3) process of measured data,
4) perform simulations,
5) analyse results and assess the sensitivity,
6) document data set and validation work.

The empirical whole model validation methodology is shown graphically on figure 2 and is described in more detail in the following. A validation study should always be carried out by at least two teams: A leading team performing the exercise and a reviewing team. In this way the performing team can receive input and criticism and the calculations are checked by somebody else. This should ensure the quality of the validation study.

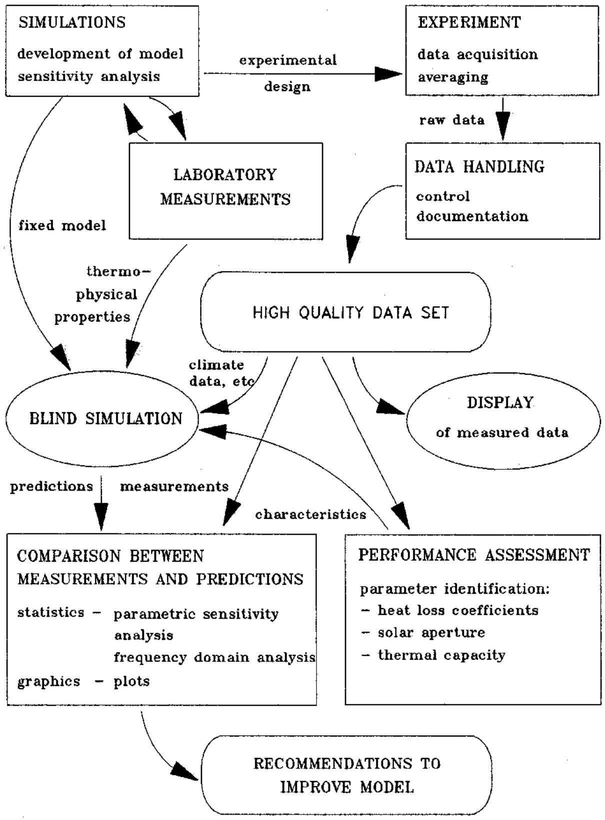

Figure 2. Outline of the empirical whole model validation methodology.

4.2.1. Definition of scope, type and nature of the physical and numerical experiment. At this stage of the validation study, the purpose of the study should be very clearly defined: Select type of component and define the field of interest. Identify and isolate thermal processes in both the physical and the numerical experiment. Define a test cell model, with an appropriate level of detail for the envisaged analysis. Define the critical (and sensitive) parameters for the selected test cell model. The critical parameters can be found by performing sensitivity analyses with the test cell model. It is very important that the model is fixed before the experiment is carried out, as the validation then can be called "blind". Performing blind validation ensures, that the modeller is not influenced by the actual measurements, and is, therefore, unable to fit the input data to the measured data.

4.2.2. Implement the physical experiment on site. Based on stage one: Design the passive solar component in question if not already done. Select an appropriate set of instrumentation. Assess the accuracy of the experiment. Select an appropriate control strategy. Select an appropriate period and desired range of climate variation. Make sure that the wall is constructed according to the specifications, that samples of materials are obtained for measuring of thermo-physical properties and that sensors are located correctly.

4.2.3. Process the measured data. Consider only high quality data sets. Pre-process the data set if necessary - control, averaging, etc. Match experimental data with model inputs, parameters and outputs. Transfer the measured data to a database for display purposes and for later comparison with predicted values.

4.2.4. Perform simulations. Clarify modelling assumptions and adapt if appropriate. Refine defined test cell model if necessary - based on obtained information and experience from the construction of the wall, the test and measured thermo-physical properties. Perform simulations with measured climate data and measured test cell conditions.

4.2.5. Analyse results and assess the sensitivity. Identify uncertainties on model inputs and model parameters. Use statistical techniques to assess resulting uncertainties on selected model outputs. Identify uncertainties on measured outputs. Compare measurements with predictions.

This stage of the methodology is very important. Comparison between measured and predicted values has often been performed in a very subjective way by eg comparing a curve showing the measured values with a curve showing the predicted values and then by looking at this, stating whether the agreement is satisfactory or not. This kind of comparison is of course unacceptable, and the method gives only little information on what may cause deviations between measurements and predictions. It is necessary to apply statistical techniques in order to increase the quality of and confidence in the validation result and to obtain valuable informations about the model.

There exist several statistical techniques for comparison between measured and predicted values, testing the goodness of different aspects of a model. Within the MVD subgroup two different kinds of statistical tools have been applied: Parametric sensitivity analysis and frequency domain analysis.

Parametric sensitivity analysis. In this field it is mainly the differential sensitivity analysis that has been applied. In this method perturbed runs, where each model input parameter is changed by ± their standard deviation, are performed. Based on the perturbed runs the overall uncertainty band of the simulation is calculated. The agreement is stated to be good if the measured values fit within this uncertainty band. The advantage of this method is that it is very clear when good agreement is obtained. Furthermore the sensitivity of the model for each input parameter is obtained giving a hint on the cause of discrepancies between measurements and predictions. The disadvantage of the method is that the standard deviation of the input parameters mainly is based on subjective judgement and experience, and that the parameters have to be independent.

Another parametric sensitivity analysis which has been investigated within PASSYS is the Monte Carlo method. Here the parameters of the model are changed simultaneously according to a given probability distribution function. The advantage of this method, compared to the differential sensitivity analysis, is that the parameters do not need to be independent. The drawback is, however, that it is only the global uncertainty that can be derived. It gives no information of which parameters that have major influence on the global uncertainty.

Common software for performing the two above-mentioned parametric sensitivity analyses has been developed. The software has, however, to be modified by the user in order to fit the actual validation exercise.

The parametric sensitivity analyses only compare measurements and predictions in the low frequency area. They do not test the highly dynamic parts of the model. Other statistical methods have therefore also been incorporated in the procedure for comparing measurements with predictions.

Frequency domain analysis. If the considered model in the validation exercise is of the correct functional form, the true parameter values have been substituted and the assumption about noise is correct, the residuals of the model will be white noise and its estimated autocorrelation will be distributed mutually independently around zero with the variance $1/m$ (where m is the degree of freedom). Serious model inadequacy can usually be detected by examining:

a) the autocorrelation function or the power spectrum of the residuals of the fitted model,
b) certain cross correlation functions in the time and frequency domains, involving inputs and residuals.

Software for detection of any kind of autocorrelation in the residuals or cross correlations between inputs and residuals of a model has been developed within PASSYS. The theory behind the software and the software itself are described in a paper called "Methods for comparing measurements and calculations" by Palomo (E) and Madsen (DK) presented at the same conference as the present paper.

4.2.6. Document data set and validation work. The validation study should be documented comprehensively and published. Publication is essential in order to increase the confidence in simulation based methods. Further documentation should be added to the data set if necessary. On basis of stage 5, recommendations for improvements to the model or the simulation program should be given.

4.2.7. Conclusion. Using a comprehensive methodology for empirical whole model validation (eg the one described above) in connection with high quality data sets, is the only way to prevent, that results from empirical validation studies will not be rejected in the same way as many earlier empirical validation studies have been (or should have been).

In this way a well documented empirical whole model validation methodology in connection with relevant high quality data sets is to be considered as a substantial contribution towards increasing the confidence in thermal modelling of buildings.

4.3. Empirical validation environment

The national consortia within PASSYS are equipped with almost identical test sites, Unix work stations and common software - the simulation program ESP, software for data acquisition and to some extent for processing the raw data from the test sites and for transferring it into databases, and statistical software for comparing measurements and predictions using the above-mentioned statistical methods. Common equipment and procedures decrease the number of potential errors and speed up the validation studies.

It is felt, that this is a step towards what could become "online validation facilities", where the empirical validation of a simulation program is carried out more or less simultaneously with its development. The PASSYS facilities are well fitted for this. A paper on this subject called "Towards an interactive model validation facility" by Strachan and Clarke (UK) is presented at the same conference as the present paper. The subject will, therefore, not be discussed further here.

5. CONCLUSION

Validation of a building energy simulation program is a non-trivial task. It is in fact not possible to perform a complete validation of a program, as many parameters remain unknown and it is impossible to test all kinds of applications of the program. It is, however, possible to increase the confidence in a simulation program by applying it to a well documented and comprehensive validation methodology combining several different validation approaches.

Such a validation methodology has been further refined and approved within the CEC concerted action PASSYS. Based on already performed studies a validation methodology has been selected and further developed. Although the validation methodology has been tested and further developed in connection with the validation of the simulation program ESP, it is a non-program specific validation methodology, which can be applied to any building energy simulation program. ESP has simply been used to test the methodology.

A well documented and reliable validation methodology is valuable for developers of simulation programs in order to test their products, but we believe that the main application of such a methodology is in the field of "Software Accreditation". As the confidence in simulation programs increases, the concept of

"Simulation Based Building Energy Standards" will become more and more accepted. When Simulation Based Building Energy Standards become a reality, there will be a need for Software Accreditation Procedures based on well documented validation methodologies.

Simulation Based Building Energy Standards are not far away. A working group within the European standardization body CEN has, based on collaboration with PASSYS, recommended to accept the concept of Simulation Based Building Energy Standards, and has worked out a "draft" standard on the calculation of the internal temperature of the room in the warm periods including a Software Accreditation Procedure as reported in (van de Perre 1991). This is not only considered a major breakthrough in European standardization activities, but can also be seen as an indication that research is increasing the confidence in thermal modelling of buildings. The MVD subgroup within PASSYS accepts the challenge to prove that its major product - a well documented validation methodology - may be of use for future European standardization activities.

The final products from the PASSYS program are expected to be officially available by the middle of 1992.

REFERENCES

Achard, P. and Gicquel, R. (eds). 1986. *European Passive Solar Handbook.* Commission of the European Communities, DGXII.

Bloomfield, D. et al. 1988. *An investigation into analytical and empirical validation techniques for dynamic thermal models of buildings.* Final Grant Report. Science and Engineering Research Council. Polaris House, Swindon, England.

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

Clarke, J.A. 1989. The Model Validation Activities of Project PASSYS. In *Proceedings from the 2nd European Conference on Architecture* (Paris, France, December 4-8). pp. 403-406.

Dupagne, A: 1986. *Final Report of Passive Solar Modelling Subgroup.* Commission of the European Communities, DGXII.

Judkoff, R. et al. 1983. *Methodology for Validating Building Energy Analysis Simulations.* Report TR-254-1508, Solar Energy Research Institute.

Loman, K.J. and Bowman, N.T. 1986, The Evaluation and Use of Existing Data Sets for Validating Dynamic Thermal Models of Buildings. In *Proceedings from the 5th CIB/CIBSE international symposium on the use of computers for environmental engineering related to buildings* (Bath, United Kingdom, July 7-9). pp 100-117.

Strachan, P. and Clarke, J.A. 1991. *Towards an interactive model validation facility.* Building Simulation '91 - IBPSA conference (Sophia-Antipolis, Nice, France, August 20-22).

Palomo, E. and Madsen, H. 1991. *Methods for comparing measurements and calculations.* Building Simulation '91 - IBPSA conference (Sophia-Antipolis, Nice, France, August 20-22).

van de Perre, R. et al. 1991. Simulation Based Environmental Building Performance Standards - a Case Study: European Harmonization. In *Proceedings from the International Workshop on Computers and Building Standards* (VVT, Espoo, Finland, May 27-29).

Wouters, P. and Vandaele, L. (eds). 1989a. *The PASSYS Project Phase 1. Subgroup Instrumentation - Final Report Part 1. 1986-1989.* Commission of the European Communities, DGXII.

Wouters, P. and Vandaele, L. (eds). 1989b. *The PASSYS Project Phase 1. Subgroup Instrumentation - Final Report Part 2. 1986-1989.* Commission of the European Communities, DGXII.

Østergaard Jensen, S. (ed). 1989. *The PASSYS Project Phase 1. Subgroup Model Validation and Development - Final Report. 1986-1989.* Commission of the European Communities, DGXII.