AN APPLICATION MANUAL FOR BUILDING ENERGY AND ENVIRONMENTAL MODELLING

D. Bartholomew[*], J. Hand[#], S. Irving[&], K. Lomas[%], L. McElroy[#]
F. Parand[$], D. Robinson[$] and P. Strachan[#]

[*]DBA,[#]University of Strathclyde,[&]Oscar Faber Applied Research,
[%]De Montfort University,[$]Building Research Establishment
(Contact: P. Strachan, ESRU, Dept. of Mechanical Engineering,
University of Strathclyde, Glasgow, Scotland)

ABSTRACT

This paper describes the contents of an application manual for building energy and environmental software to be published in the UK. The purpose of the manual is to provide advice to practising engineers on the selection and appropriate application of such software. This is believed to be the first such manual. UK organisations involved in the project are the Department of the Environment, CIBSE, the Building Research Establishment and BEPAC. Topics covered in the paper include the reasons why the manual was considered necessary, a summary of the overall contents of the manual, and a discussion of the implications for the future development of simulation programs.

INTRODUCTION

In response to the increasing need for the use of building energy and environmental software in the course of building design, a CIBSE Application Manual is being written to provide guidance on the selection and appropriate use of such software. The manual is being produced under the UK Department of Environment's Partners in Technology Scheme led by the Building Research Establishment (BRE). BRE, the Chartered Institution of Building Services Engineers (CIBSE) and IBPSA's UK affiliate BEPAC are the main partners of the project, with funding provided by the Department of Environment and CIBSE. In producing the manual, the partners were assisted by a number of contract authors with considerable input from practising CIBSE members in the form of reviews and comments.

In the case of traditional methods, detailed guidance is given in the guides produced by CIBSE and ASHRAE. However, no comparable information is available for users of simulation software. The objective of the application manual was, therefore, to give general advice to practitioners on program selection and application in areas where the use of simulation is particularly beneficial. Major topics within the manual include:

- the role and coordination of modelling in the design process;
- the applicability of simulation programs;
- guidance on selection of programs;
- guidance on program use;
- illustrative case studies.

The sections in this paper summarise each of the individual chapters in the manual: the role of models in the design process; establishing a simulation capability; the effective use of software; and case studies. Before this, the perceived need for the manual is discussed. At the end of the paper, the implications of the manual for the future development of simulation programs is discussed.

NEED FOR GUIDANCE

The rationale for this manual stems from two main premises:

- an interest in energy saving in buildings as a result of concern for the environment and in particular the recognition that in the UK, as elsewhere, buildings are responsible for a significant proportion of total CO_2 emissions; and
- a recognition that traditional steady state and simplified dynamic calculations, while sufficient for sizing air-conditioning systems for design conditions, may not be adequate for innovative designs incorporating natural or mixed mode ventilation or other passive features. They also cannot provide sufficient information for designers to fine tune the design of a building, its systems and controls.

There is a move in modern buildings to greater interaction with the external climate and increased variation in internal conditions compared to traditional buildings, particularly those with full air-conditioning systems. The increased responsiveness is a result of several factors such as greater use of natural ventilation and natural daylighting, more advanced glazing technologies, higher levels of insulation and airtightness, higher levels of internal gains from equipment, and a greater capability for control of heating and cooling equipment and lighting.

Building Energy and Environmental Modelling (BEEM) software can potentially be used to predict the performance of such buildings and to study different design options and "what if" questions. Although the potential for simulation is large, there has not been a large uptake, with significant barriers being uncertainty regarding the capabilities of the programs and, with the exception of a limited number of experts, no general understanding of how and when to use such programs. There is a lack of coherent guidance on the selection and application of suitable software.

The CIBSE application manual was therefore targeted at two main groups:

a) Partners, managers, or engineers who decide the firm's quality and capability strategies as well as the development of staff resources and training, and who would be responsible for deciding whether or not to use modelling.

b) Engineering and modelling specialists whose day to day job it is to carry out design and modelling.

The overall aims of the manual were to:

- raise the awareness of the building services engineers, architects and clients to the capability of energy and environmental software;
- give a brief, but practically sufficient, account of most of the issues of importance in the selection of such software for those who wish to establish in-house modelling capability;
- give practical guidance to users of BEEM software to carry out the modelling in an appropriate way with due regard to quality assurance.

The manual covers thermal and energy modelling, lighting and daylighting modelling, and airflow modelling, although thermal modelling is dealt with in more detail than the other two areas.

ROLE OF MODELS IN THE DESIGN PROCESS

Because the manual is aimed at designers who may be considering the inclusion of modelling, some emphasis was given to discussing the role that environmental modelling can play in the design process, emphasizing that modelling is a means to an end, not an end in itself, and that, used properly, modelling can provide a focus around which the design develops and by which performance is assessed.

The objectives for this chapter of the manual are thus:

- to identify the benefits of using environmental models;
- to explain how models can help different classes of user;
- to describe the applications to which modelling is best suited;
- to provide examples of how modelling can be used within the various stages of the design process; and
- to give guidance on how to initiate a modelling study.

One of the key issues addressed by the manual is to clarify why and when modelling should be used. The argument is presented that many design questions cannot be addressed by traditional design methods. Two examples are given:

- In heating system design, traditional methods estimate the amount of heat that must be put into a room to maintain the desired temperature during conditions of no sun, constant external temperature and no internal gains. These approximations can lead to oversized plant, with consequences for both increased capital and operating costs due to increased running at part load. Modelling can provide the same answer, but also answers questions such as:

    a) What is the benefit of passive solar gain in offsetting heat demand?

    b) Can the heating be switched off before the end of occupancy, without affecting comfort?

    c) How should the heat emitter be integrated with the ventilation opening to avoid cold draughts in naturally ventilated buildings?

- For calculation of summertime temperatures, the CIBSE manual procedures are based on the admittance method, which is a harmonic analysis using a single frequency with a period of 24 hours. The variation in external temperature, solar radiation and internal gains are all approximated to a single sine wave with this single frequency, repeated daily. However, internal gains in many buildings now form an increasingly significant proportion of the heat gain and these gains are not well represented by a sine wave. Also, the use of high capacity structures result in the capability of storing heating and cooling energy, and this is difficult to represent with traditional calculation techniques.

Other stated benefits of modelling are:

- BEEM software can be used to analyse a much greater level of detail than traditional calculations, with fewer inherent simplifications and assumptions.
- Modelling can provide answers to questions which are completely outside the remit of methods contained in the traditional guidebooks: for example, computational fluid dynamics (CFD) can predict air velocities, turbulence intensities and temperature distributions for a given set of boundary conditions as part of optimising the positioning and performance of air diffusers.

The greatest benefit of modelling is believed to be that it provides a focus within the design team, helping all members of the team throughout all stages of the design/construct/operate cycle. The manual therefore describes how modelling can impact on each member of the design team - the client, architect, engineers, cost consultant, project manager and planning authority.

Clearly, the correct modelling tool must be used. The manual deals with the application areas of thermal, lighting and airflow, and at least for this first edition, does not address other aspects such as acoustics, fire, smoke and pollution dispersal, structural analysis or cost analysis. This restricted choice was made for several reasons - to enable the manual to give specific rather than general advice, to address domains for which a large variety of analysis methods exist, to cover what are probably the most common domains that are tackled by modelling, and to focus on those areas of most importance to “energy and the environment”.

Within each application domain covered, there are a number of tools which use methods of varying complexity and sophistication. These methods range from simple correlations of laboratory or field measurements right through to complex numerical simulations of the fundamental physical processes. Tables 1, 2 and 3 summarise the methods, typical applications and principal limitations for load calculation, plant and control simulation, and energy simulation (for energy consumption, internal thermal comfort etc.). Only the more advanced methods, shaded in the diagram, are covered in the manual. The various methods available for lighting and air movement analysis are similarly described in the manual.

One difficulty found in writing this chapter was in striking a balance between overemphasising the benefits of modelling and making the introduction of modelling into the design process a daunting task.

Method	**Typical Application**	**Principal limitation**
Elemental	Calculate thickness of insulation	Only deals with individual wall/roof constructions, not whole buildings
Steady state	Radiator/ boiler sizing	Ignores free gains and dynamic effects
Simple dynamic	Chiller sizing	All heat gains must follow repeating sine wave
Advanced dynamic	Annual heating/ cooling loads	Fixed time steps
Full simulation	Annual heating/ cooling loads	-
Design charts	Various	Fixed range of parameters

Table 1: Load calculation methods

Method	**Typical Application**	**Principal limitation**
System efficiency	Calculate heating energy from room loads	Cannot deal with air conditioned or mechanically ventilated buildings
Pre-configured system	System design	Restricted range and configuration of systems
Pseudo-dynamic component	System and control optimisation	Ignores component dynamics, control lags
Dynamic component	Analysis of control stability	Exacting input data requirements

Table 2: Plant and controls design methods

Method	Typical Application	Principal limitation
Annual	Heating energy	Only valid for simple heating systems (e.g. domestic)
Seasonal/ bin	Heating and cooling energy	Ignores building dynamics and system/ climate interactions
Hourly	Building energy use	

Table 3: Energy simulation methods

ESTABLISHING A SIMULATION CAPABILITY

This chapter of the manual gives guidance on how to set up an in-house simulation capability and discusses the costs associated with software, hardware, staff resources, training and the operation of quality assurance procedures. Because successful simulation-based analyses need both the right program and skilled operators, the chapter outlines:

- the factors to be considered when selecting the specific program(s), and
- the quality assurance infrastructure which must be put in place.

The factors to be considered are given in a detailed checklist, with the associated issues for each factor. Table 4 summarises the main areas.

Practitioners are naturally concerned with the accuracy of programs, and one problem is how this accuracy can be assessed (although it must be remembered that a similar problem also pertains to traditional methods). Clearly a manual of this type cannot address the question of validity in any depth, although it is a vital issue for potential program users. At present, there is no accreditation procedure for BEEM software - an issue which must be addressed in the future. However, a large effort has been put into checking the predictions of programs within several major validation studies. The manual discusses the issues and techniques of validation as they affect potential program users, and references recent validation work.

When discrepancies in predictions from different programs have been found, it has sometimes been shown to be as a result of user error rather than an inherent program failure. Although further work on program validity and estimation of prediction uncertainties is necessary, future emphasis should perhaps be directed towards improved user training and quality assurance.

The manual addresses the problem of establishing a suitable quality assurance infrastructure. The notion of a simulation team, consisting of a team manager who is responsible for the quality of the work undertaken by program users, is introduced. The cost of establishing a simulation capability needs to consider programs and their hardware as well as human resources, training and the operation of quality assurance procedures.

Choosing the right program	
Modelling methods	Can the program analyse your problems?
Program coding	Do you need source code?
Computer specification	Do you have the right machine?
Input interface	How easy is the program to use?
Output interface	Can results be understood?
Linked modules	Can CAD and other software help?
Associated databases	Is necessary data readily available?
User support	Can you get help easily?
User base	Are there other users who can be contacted?
Validation	How accurate is the program?
Cost	What are the costs for the program, training etc?
Producing reliable results	
Human resources	What people with what skills are needed in a simulation team?
Databases and support program	Where does the input data come from?
Training	What, when and for whom?
Quality assurance	How can you make sure a good job is done?

Table 4: Establishing a simulation capability: key issues

EFFECTIVE USE OF SOFTWARE

The chapter dealing with this subject has the aim of providing sufficient information for a relatively new user to be able to define and generate a model. The emphasis is on thermal modelling, but with some coverage of lighting and airflow modelling.

The main contents of the chapter provide:

- procedures for undertaking assessments against defined performance objectives;
- checklists for users of simulations programs;
- guidance on sources of input data; and
- guidance on results analysis and reporting.

One of the first requirements to be addressed when undertaking a modelling study is to translate the design questions into specific modelling tasks for which predictions can be made. Some examples of this are given in Table 5.

Design questions	**Modelling tasks**
Does this building require air conditioning?	Determine the peak summertime temperatures and their frequency of occurrence with a naturally ventilated scheme.
If so, which air conditioning system will be the most energy efficient?	Compare the degree of temperature and humidity control for various system configurations and evaluate the required capacity and energy consumption.
How can daylight penetration be maximised and glare sources eliminated?	Evaluate and compare daylight factors and glare indices for a range of glazing options and shading devices with and without each feature.
Will displacement ventilation be able to cope with the high levels of internal gain?	Determine the occupied zone comfort levels for a range of loadings and supply air conditions.

Table 5: Translating design questions to modelling tasks

Before the models can be created, it is necessary to make important decisions on the form of the model. The chapter discusses some of these decisions - how the reality should be abstracted, the need for a reference against which design options can be tested, the model zoning strategy, the climate sequences to be used, and the degree of modelling resolution required of various aspects of the model. In practice, there are not always easy answers, and there is likely to be some differences of opinion amongst modellers, particularly as to the level of detail required. However, the manual gives a checklist of the issues that must be addressed, with suggestions on how to proceed for new users.

Ideally an application manual should give specific instructions which could be followed to achieve the desired performance measure. For some standard performance assessments, such as overheating risk analysis, regulations compliance or energy labelling, it is possible to develop a procedure which gives the user step-by-step instructions. However, such detailed procedures tend to be lengthy and program specific, and therefore would be out of place in the manual. Also, in practice, the range of design questions asked of modellers is diverse, and it was considered that the manual should only outline general strategies.

The bulk of the chapter deals with program data input requirements. Again, the level of detail possible is limited because it is the intention of the manual that it should not deal with particular programs, and there are differences in specific requirements for each program. However, for each subject area - climate, site, geometry, construction, internal gains etc. the manual sets out in general terms what the data requirements are, the sources of the required data, issues concerning how to model, common mistakes that are made, and lastly a checklist for the user. Emphasis is placed on the need for sensitivity studies where there is uncertainty in what are the correct inputs, in order that the user can get a feel for the likely uncertainties in the model predictions.

Some examples of issues raised when clear guidance is not easy to give are:

- A restriction in program capability: ground heat losses are not generally well modelled, with the majority of programs not taking lateral heat flows into account. These can be significant for uninsulated ground slabs.
- Uncertainty in physical process modelling: there has been much debate over “correct” values for the internal convection coefficients, and there is a need for further work to generate guidance for appropriate coefficients for different heating and cooling regimes.
- Uncertainty in data inputs: over/under estimation of total internal gains and occupancy levels can seriously affect results. For new buildings, these

gains are not always known in advance, so it necessary to create a number of possible scenarios rather than attempting to define actual schedules. The resulting predictions are therefore representative rather than accurate.

CASE STUDIES

A number of case studies are given to serve as examples of procedures discussed within the rest of the manual. These case studies were chosen to show the use of BEEM software in practice, the benefit derived from its use, and examples of design decisions made on the basis of modelling results. The projects had in common the fact that the designers had to resolve questions which could not be addressed by traditional calculation methods alone.

The main selection criteria were designed to:

- ensure the case studies illustrated key points raised elsewhere in the manual - the merits of the specific buildings are less important than the way in which modelling was used in the design process;
- cover the diversity and depth of questions posed by designers;
- cover typical design projects such as extensions to existing buildings and refurbishment, as well as prestige new buildings; and
- cover both highly serviced buildings as well as those incorporating more passive approaches to environmental control.

Each case study is presented in a format which corresponds to earlier chapters of the manual dealing with how modelling should be used within design. Thus the key design questions are described, followed by the translation of these into modelling tasks, a discussion of the modelling strategy employed, details of model creation, and lastly a summary of results from the modelling studies. Where assessments were phased, the design iterations and evolution of the models and performance criteria are also discussed.

It is hoped that the detail given in the case studies will allow readers to understand the use of modelling in projects of varying complexity, and the associated nature of the interactions within the design team.

CONCLUSIONS: IMPLICATIONS FOR PROGRAM DEVELOPERS

The decision to produce an application manual for building energy and environmental software is a result of an awareness that the use of such software is increasing and is likely to become more prevalent. However, in writing the manual, it also became clear that there is still considerable scope for further development of software and the techniques for using it in design. There are many questions which do not have universally accepted answers, such as:

- how should modelling be used in the design process?;
- how can the reliability of predictions be quantified?; and
- how can quality assurance guarantee that the model created was that intended?

It was also clear that contemporary software has limitations - in its functionality as well as ease of use - and that some physical processes are not well represented. In addition, design is multi-faceted and modelling is only just starting to coherently address the problem of integration, when a design decision can affect several aspects of the performance. However, it should always be remembered that a comparison must be made with traditional methods, which in general have more simplifications and assumptions built into them.

From a consideration of the general need for software to improve, and specifically from issues arising during the writing of the manual, the following areas were identified as being of importance to program developers:

- Checklists for data inputs are given in the manual to aid program users. It is believed that developers could introduce a form of such checklists into their user interfaces to aid in model development and quality control.
- In many cases it is true that strict sequential steps for operating programs cannot yet be given except for very constrained problems, but guidance and checklists can be given. Again, it should be possible for program developers to refine the general checklists and guidance given in the manual to more specific instructions for their particular program. In some cases, these instructions could be specialised for various applications.
- If software is to become easy to use by designers, program developers must:
    a) improve interfaces and help facilities, and provide greater feedback to users;
    b) provide more comprehensive databases; and
    c) provide intelligent defaults for early stage design.
- Developers need to continue to extend the capabilities of their programs to reflect the

increasing desire for an integrated view of design.

- To improve confidence, programs should have a readily accessible history of validation studies and versioning control of the software. Preferably validation checks should be built in.
- The community as a whole should generate accreditation procedures. These may be for programs (e.g. development of benchmarks to help ensure consistency between programs of the same type), and/or for users (e.g. development of training courses and possibly user certification).

The science of modelling is continually expanding and so guidance on the best ways to use this important class of design aids will need to evolve. The Application Manual for Building Energy and Environmental Modelling provides a good foundation on which this developing guidance can be based.

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