SOLAR MODELLING OF COMMERCIAL BUILDINGS

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ABSTRACT

A number of computer programs have been developed over the last 20 years that are capable of modelling the thermal response of buildings. There have been two major obstacles precluding these programs from becoming commonly used by practitioners when designing buildings. Firstly, The high cost of the mainframe computer that was required to run the program. Secondly, The data models required by these programs can be quite complex, and very difficult for the designer to master. New Zealand has also faced an additional obstacle in the lack of comprehensive weather data files (containing the information required by the programs).

With the advent of increasingly more powerful personal computers, DOE2 and SUNCODE have been adapted to run on these cheaper computers. The Ministry of Energy sponsored this project, that has seen the development of "standard" data models describing various types of commercial buildings, from the corner dairy to a multi-storey building. Using these standard buildings as a base, the practitioner should be able to adapt them to model their design. In order to increase the applicability of the programs, suitable weather data files for over 30 New Zealand locations have been produced.

1 PROJECT OBJECTIVE

The objective of the research was:

"to develop two energy thermal simulation programs as design tools for New Zealand buildings."

The two simulation programs are SUNCODE (1981) and DOE2.1C (1981). They have been available for a number of years, originally on main-frame and latterly on personal computers. However, successful use of these programs has not been a simple task. They have been used primarily by researchers. Designers generally have not had the time to learn how to use the program, to find all the data required (building, weather and location) and then to model successfully the building that is to be tested.

The research is predicated on the notion of the numerate designer: the member of the design team who can manipulate mathematical models of a building in order to study its performance. As such, the results are not targeted exclusively at any particular member of the building design team. Rather, they provide the team with easy access to two programs which can simulate the energy performance of alternative design ideas at an early stage in the design process.

In order to simplify the use of these programs, and thereby assist designers to include these design tools in their design process, the tasks of this project were to:

a) Provide standard data on building materials used within New Zealand, applicable to both programs.
b) Develop standard weather files for extreme and typical design conditions in all the climate regions of New Zealand.
c) Define and provide computer models of standard building types as a starting point for designers modelling their own buildings.
d) Test all three data sets (separately and combined) for consistency and ease of use.

The architect, engineer or scientist involved in the early strategic design decisions for a building will find the files from this project of most use. This designer must still learn to operate and understand the limitations of whichever of the programs they decide to use as a design tool.

In this paper an overview is presented of the data files and the principal assumptions on which they are based. The data files are available on disk in IBM PC format.

2 THE BUILDING SIMULATION PROGRAMS

Both DOE2.1C and SUNCODE are accepted as state of the art in the field of building simulation, having undergone extensive validation by the International Energy Agency. They have been widely accepted by the international research and design communities.

The two programs approach the modelling of buildings in different ways. SUNCODE uses a relatively simple building model compared to DOE2.1C. Two of the main differences between the programs are:

2.1 HVAC Systems

SUNCODE assumes that an HVAC system provides what energy is needed by the building (as specified in the building input model), but does not concern itself with the details of what that system is. A services engineer or the designer must ensure that a suitable system is incorporated into the building design.

DOE2.1C provides the option of including plant and systems simulation when modelling the building. However, the base buildings developed for this research have not utilised this option because the aim of this project has been to assist in the design of the building fabric, rather than the services. Adequate definition of a detailed HVAC system was not within the range of expertise of the research team.

2.2 Location of Spaces

The SUNCODE building model does not concern itself with the precise location of rooms (zones) within the building. The SUNCODE building model is concerned with the thermal relationship that each space (zone) has with each other and with the outside wall. However, DOE2.1C requires that the precise spatial location of each space be recorded, in addition to these thermal relationships.

Both programs are able to adequately model every type of building. However, DOE2.1C is more suited to large buildings because:

a) it is more capable of modelling the HVAC services, which have a major impact on the energy performance of large buildings;

b) it is less capable of modelling the thermal storage which can dominate the energy performance of small buildings.

3 BUILDING DESCRIPTION LIBRARY

An extensive (though not exhaustive) list of building materials and component descriptions has been compiled for the library database. The database includes:

a) individual materials (e.g. 100mm thick concrete);
b) system components comprising two or more of the materials (e.g. 100mm thick timber stud wall with insulation);
c) types of glazing (e.g. wooden or aluminium framing);
d) shape descriptions (e.g. 500mm eaves overhang);
e) weather station location data (e.g. height above sea level);
f) defined seasons (e.g. winter, spring, etc);
g) heating and ventilation regimes (e.g. heating to 20°C from 7 a.m. to 6 p.m.).

All these data types are used by each program as part of the building description. The components that make up the library are described in greater detail in Appendix I of the project report (Donn et al, 1990).

We expect that the database will continue to grow over time, as other users of the programs find a need to use materials and components that have not previously been coded.

We recommend that users provide the supplier of the information with data about new materials they decide to code. Users of the building database should provide the supplier of that information with data about new materials they decide to code. The supplier would then be able to check the figures and to share them with other users. The International Energy Agency is undertaking a project to determine and collate data on new materials and innovative building components (e.g. transparent insulation) which will also be added to the libraries (Solar Energy Group, 1981).

4 STANDARD WEATHER FILES

The aim of this part of the project was to develop standard weather files for New Zealand sites from the raw weather files already held by the School of Architecture.

The 22 raw weather files held by the School of Architecture contain unprocessed weather information from the Meteorological office, with hourly values collected for 21 facets of the weather at the site. Most of these weather files contain data for a period of 26 years.

They contain no solar radiation data as very little was available outside the main centres until recently. The cost of obtaining up-to-date solar data precluded obtaining readings to supplement the files. The original weather files are stored in a binary format with several sites' weather data compressed onto one tape.

4.1 Weather File Conversion

Appendix III of the project report (Donn et al, 1990) describes the weather file conversion process in detail. In summary, the following steps were necessary:

a) convert from binary format to processable format (ASCII) using SAS;

b) interpolate between missing data and remove "spikes";

c) check for missing data values, and put in simulated weather data at these points.

d) use SAS to pick "good" years:
   i) sort and print monthly averages, highs and lows for each year;
   ii) calculate monthly heating and cooling degree days for each year;
   iii) determine long-term mean temperature, wind speed and cloud cover;
   iv) calculate normalised temperature, wind speed and cloud cover to help in selection of particular "design weeks": hot windy, hot no wind etc.

e) create a Test Reference Year (TRY) format dataset for entry to the DOE2.1C weather processor for generation of synthetic solar data from available cloud data;

4.2 Conversion Assumptions

In order to complete these steps the following assumptions had to be made:

a) where a particular year fitted all the selection criteria yet had a large number of missing values, the next closest fit was found;
b) In some cases, ground temperatures were not recorded for some of the sites for which we had hourly data. In this case the closest location that recorded ground temperatures. For some sites, ground temperatures were only collected at 0.3 metres depth, and not the 1 metre depth we sought. In these cases the 0.3 metre values were used. For some sites, records of ground temperatures were started at a later date than some of the years data we were selecting. In these cases, later years' ground temperature data was used for the earlier years' data.

Table I Source of Ground Temperature Data

Location	Solution
Kaikoura	Used Rangiora data for all years
Nandi	Used Nandi 1974 data for 62, 65, 66, 67. 68
Nasouri	Used Nandi, Fiji data for all years
Ohakea	Used Levin data for all years
Paraparaumu	Used Levin data for all years
Raoul Island	Mixed values for 71, 73, 74 to get full monthly data for these three years
Rarotonga	Used Rarotonga 1977 data for all years

c) Some of the weather data spans only a few years. In all cases where there is less than 20 years data there is not enough data to calculate average, hot and cold years. The sites affected by this problem were Campbell Island, Chatham Island, Raoul Island, Rarotonga, Nasouri, Alexandra and Hamilton.

d) The generation of solar radiation data from the cloud cover information in the weather files was the most difficult part of the exercise, and remains the most problematical data in the output files. After consulting the literature (ASHRAE, 1981; DOE2.1A, 1982; Harkness and Mehta, 1978; Kimura and Stephenson, 1969; Leslie and Trethowen, 1977; Parmelee, 1954; Threlkeld and Jordan, 1958) to find a definition of clearness numbers (Threlkeld and Jordan, 1958), and analysing the depth of precipitable water in the air, and comparing the results to USA data, we concluded that New Zealand clearness numbers would most likely follow the numbers found along the west coast of the USA. The only exceptions to this would be at Christchurch where the winter smog would give lower clearness numbers in winter, and at sites at high altitudes, like Alexandra or Waiouru. This gave us the following list of monthly clearness numbers for sites in New Zealand:

Table II Clearness Numbers Calculated for New Zealand

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NZ	1.03	1.02	1.00	0.98	0.97	0.95	0.97	0.98	1.00	1.02	1.03	1.05
Chch	1.02	0.98	0.95	0.92	0.88	0.85	0.88	0.92	0.95	0.98	1.02	1.05
High	1.08	1.07	1.05	1.03	1.02	1.00	1.02	1.03	1.05	1.07	1.08	1.10

e) Initial attempts at calculating values for missing data in the weather files, through the generation of sinusoidal patterns that followed the daily variations in temperature, lead us to seek a better method of calculating values for missing data. After consultation with the New Zealand Meteorological Service (Reid, 1990), we developed an algorithm that calculated missing data in the following fashion. For each month of every year we created a temperature profile for that month which consisted of the hourly average temperatures for that month. This profile was scaled to the first valid value before the missing data and an increment added to each successive hour so the profile would match the first valid data after the stretch of missing data. This technique produced very realistic weather curves for periods with missing data.

4.3 Weather File Analyses

With the processed weather files, analyses were done to find years of weather data which are average. The average hot and cold years of weather data were also identified. At this stage we analysed the weather data to find weeks of weather data that met certain specific criteria:

(a) hot and windy;
(b) hot and calm;
(c) cool and windy;
(d) cool, calm and sunny;
(e) cool, calm and no sun.

The one percentile week of these types were selected and a year of weather data extracted around each of these weeks. This produced a suite of weather data files for each location which would allow a designer to test a building with average and with extreme periods of weather.

With the years of data selected, the next step required extracting the data from the weather files and formatting it in a manner acceptable to the simulation programs. The problem encountered at this point was that SUNCODE required radiation data in its weather files and none came with the raw weather data. We overcame the problem by using the weather calculation program of DOE which in the process of creating its own binary weather files, calculates radiation data. This calculated radiation data was extracted from the DOE weather files and incorporated into the data files used for the SUNCODE simulation program. The major caveat that must be placed on radiation data generated in this manner is that it relies on correlations between long-term average data and has thus not been `verified' for hour by hour data.

This has produced 8 years of weather data for each simulation program for each site along with some database files in case further work is required, a total of 16 simulation files for each site, totalling about 8 megabytes of data for each site.

5 STANDARD MODEL BUILDING DESCRIPTIONS

This part of the project devised a simple list of building models which was comprehensive enough to be representative of commercial building `types'. The standard building model descriptions provide an easy method for designers to start using either simulation program. We anticipate that these standard building models will be used by the designer in the following manner:

a) initially, one of the models forms the basic building file that, when modified, becomes the actual building model to be input to the program;
b) during the performance analyses by the simulation program, the performance of the "standard" building file from the library will provide a benchmark of performance;
c) incremental changes to various model parameters allow the designer to explore the value of each parameter in the energy performance of the proposed building.

The standard descriptions also guide the designer in the best ways to model the various aspects of a building.

In order to define the basic computer models, we determined a range of different building types representative of commercial buildings in New Zealand. The types of occupation as well as the types of construction of a building are important, so they have been incorporated into each basic computer model. The following range of building and occupation types was defined:

5.1 Building Types

a) Small shop (eg diary).

b) Small shop with house attached.
c) Small shop within a row of shops.
d) Two storey office/retail building.
e) A single floor within a multi-storey building.
f) Barn or warehouse building (eg. supermarket)

5.2 Occupation Types

a) Retail
b) Office (eg. clerical)
c) Consultancy (eg. legal, medical)
d) Public (eg. art gallery, museum)

Twelve different combinations of building type and occupation type were determined to be representative. Each building and occupation type is described in detail in Appendix II of the project report (Donn et al, 1990). The combinations that have been modelled are shown in 3:

Table III Combinations of Building and Occupation Modelled

Building		Occupation		
	Retail	**Office**	**Consultancy**	**Public**
Small Shop	Yes		Yes	Yes
Shop/House	Yes		Yes	
Shop in Row	Yes		Yes	
Two Storey	All combinations combined in one model type			
Multi Storey		Yes	Yes	
Warehouse	Yes			Yes

These twelve combinations are further subdivided according to their "construction type". This was required because the varying construction types each cause a significant change in the model that is used as input for each of the computer programs. This subdivision therefore simplifies the designer's use of the base models.

In the final analysis, 27 base computer models were created for each program.

6 TESTING OF MODEL BUILDINGS

The data in the building construction and weather libraries was checked for inconsistencies. While we have a comprehensive collection of weather data, we expect that the building construction database will expand over time. The standard building models are less likely to change. They were also tested, and all of them were successfully compiled and run.

7 SUMMARY

The project described above has shown the feasibility of the library approach to use of programs. However, another major problem with each of these programs is that the user manuals are not very "friendly". A simplified version is required to enable the designer to get his/her "feet wet", thereby gaining confidence in use of the program. They could then make reference to the existing manuals with more confidence as they progress to modelling more complex buildings. In order to fully exploit the data produced by this project, we recommend that simplified users manuals be produced for DOE2.1C and SUNCODE.

ACKNOWLEDGEMENTS

We would like to thank the following people for their help and suggestions in this project.

Dr Steve Reid Meteorological office for the algorithms for replacing missing data, and checking of our raw weather data to the real Met. office tapes.
Mark Bassett (BRANZ), Tony Isles and Brian Weston for help with radiation calculation
Craig Thompson Met. office for help with precipitable water statistics.
Silvia Nichol, Rees Basher and Stuart Burgess for help with radiation calculation.
Harry Trethowen for help with methods of generating accurate data to fill periods of missing data.

REFERENCES

ASHRAE (1981). ASHRAE Handbook, Fundamentals, ASHRAE Inc.
DOE2.1A (1982). Engineers manual, Lawrence Berkeley Laboratories, University of California, Berkeley, California 94720.
DOE2.1C (1981). Building Energy Simulation Group, Lawrence Berkeley Laboratories, University of California, Berkeley, California 94720.
Donn, M., van der Werff, I. and Amor, R. (1990). Passive/Hybrid solar low energy design, Unpublished report, CBPR, School of Architecture.
Harkness, E. L. and Mehta, M. L. (1978). Solar Radiation Control in Buildings, Applied science publishers.
Kimura, K. and Stephenson, D. G. (1969). Solar Radiation on Cloudy Days, ASHRAE Transactions Part I, pp 227-233.
Leslie, S. F. and Trethowen, H. A. (1977). A Computer File of New Zealand Climate, Building Research Association of New Zealand, Report No. 21.
Parmelee, G. V. (1954). Irradiation of vertical and horizontal surfaces by diffuse solar radiation from cloudless skies, ASHRAE Transactions, pp 341-358.
Reid, Dr. S. (1990). Personal communication with School of Architecture.
Solar Energy Group (1981). Group Q-11, Los Almos National Laboratory, "DOE-2 Reference Manuals", reproduced by National Technical Information Service, US Department of Commerce, Springfield, VA 22161, USA.
SUNCODE (1981). Ecotope Group, 2812 E. Madison, Seattle, WA 98112.
Threlkeld, J. L. and Jordan, R. C. (1958). Direct Solar Radiation Available on Clear Days, ASHRAE Transactions, Vol. 64, pp 45-68.