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BUILDING ENERGY PERFORMANCE SIMULATION – A BRIEF INTRODUCTION

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SUMMARY OF

ACTIONS TOWARDS SUSTAINABLE OUTCOMES

Environmental Issues/Principal Impacts

- Dynamic simulation is the only means available to compare the energy performance of alternate building design schemes in an *integrated* manner, i.e., impact of changes in building envelope, lighting or air conditioning systems.
- Local government authorities (particularly in NSW, Vic and Qld) are increasingly looking for evidence, in the consent conditions, that buildings having been designed according to ESD principles.
- Energy use results in greenhouse gas emissions. In NSW it is compulsory to use building simulation tools in design in order to be eligible for a higher than a four and a half star building under SEDA's Building Greenhouse Rating Scheme. For buildings aiming for a four star rating under the scheme, SEDA strongly recommends the use of building simulation tools.
- There is considerably more flexibility to change designs at the beginning of the project. In the hands of an expert user, dynamic simulation can reveal the impact of design changes in a powerful way.

Basic Strategies

In many design situations, boundaries and constraints limit the application of cutting EDGe actions. In these circumstances, designers should at least consider the following:

- It is critically important to test initial concept designs using simulation. The basic form and configuration of the design scheme will largely determine the energy performance of the final building. A suite of computer tools can be used for predicting energy performance, thermal comfort and visual comfort performance.
- Involve the simulation consultant in design decisions, particularly those that affect building form, glazing and shading, HVAC system configuration and operation, and integration of daylighting with electric lighting systems.
- Engage an experienced consultant with expertise in the use of an internationally validated dynamic simulation program. Programs that have been validated using protocols like IEA-BESTEST or ASHRAE-SPC 140 provide a measure of confidence to users and clients.

Cutting EDGe Strategies

- Consider taking an explicit decision to use dynamic energy simulation from the very beginning as one of the environmental initiatives of the project.
- Consider implementing a whole building approach to cost-benefit or feasibility studies. For example, how does installing energy efficient glazing, or a high efficiency chiller, impact the total cost-benefit of the project?
- Consider incorporating commissioning and handover activities in the project management schedule to ensure the optimised design and specification effort is realised in practise.

Synergies and References

- ASHRAE SPC 140 : Standard Method of Test for Evaluation of Building Energy Analysis Computer Programs
- *BDP Environment Design Guide*: DES 21, DES 33, PRO 19
- Contact pc.thomas@arup.com.au for information on IEA BESTEST
- Internet directory listing of many energy tools – http://www.eren.doe.gov/buildings/energy_tools/

ENVIRONMENT DESIGN GUIDE

BUILDING ENERGY PERFORMANCE SIMULATION – A BRIEF INTRODUCTION

PC Thomas

This Note provides an introduction to the analytical capabilities available through the use of building energy performance simulation. Detail about the specific programs that are available will be covered in another Note.

1.0 INTRODUCTION

Environmental concerns, such as global warming, provide an imperative for minimising energy use, and thus lowering carbon-dioxide emissions. The demand for methods of analysis, like building energy performance simulation (BEPS), which allow estimation of the energy use characteristics of a yet to be built building, are increasing.

These sophisticated methods for estimating energy use in building design only became available a few years ago. Although the algorithms for this estimation were well developed over two decades ago (ASHRAE 1975), it is only in the past few years that computers have become sufficiently powerful and affordable to be used for predicting energy use in buildings.

1.1 Understanding a building's thermal performance

Buildings for people are designed to provide a comfortable and productive indoor environment for the occupants. A building's indoor environment, though, is constantly changing. The building absorbs energy from the sun through its exterior roofs, walls and windows. It takes in air from the outside which, brings with it heat, moisture and dust. The people, electric lights, computers and other equipment within the building generate heat. All these interactions cause changes to the indoor environment, especially temperature as experienced by the occupants. Should the indoor temperature rise much beyond 25°C, or drop much below 20°C, most occupants will experience some discomfort.

If the building is designed using a 'passive solar' approach, the variations in the temperature will be small. In other cases, the way the building functions may cause the interior space temperatures to move outside a comfortable range. Then, either the occupants must bear the discomfort, or energy must be expended to heat or cool the building to restore comfortable conditions.

The amount of energy needed to restore the indoor space to a specified temperature, at that time, can be calculated by carrying out a 'heat balance' of the space. A 'heat balance' calculation accounts for all heat flows from walls, floors, windows, people, equipment, air movement etc., into and out of the designated space. To estimate the total amount of energy needed to maintain a specified temperature (and humidity) range over a year, the heat balance calculation needs to be repeated for simulated conditions over the year at selected intervals (usually hourly). Computer programs that perform this repetitive set of complex calculations are called building energy performance simulation (BEPS) tools.

2.0 BUILDING ENERGY PERFORMANCE SIMULATION

BEPS enables the study of transient (changing) responses of a building and its energy systems to the climate. To analyse the building a numerical 'model' is developed which includes:

- a description of the building geometry, for example, area and orientation of glass on a building facade, shading elements from adjacent buildings;
- a description of the building construction materials, for example, a layer-by-layer description of the materials that make up the wall, roof and floor construction. The sequence in which the materials are placed is vitally important for transient heat transfer calculations, which account for heat stored and released from every material layer;
- occupancy patterns of the building being studied and schedules for the operation of its mechanical plant, lighting, and other heat generating equipment; and
- in the case of air-conditioned buildings, a detailed description of the HVAC system and its control strategies, for example, a thermostat setting for cooling.

A climate data file which provides, for a reference year, hourly values for solar radiation, temperature, humidity, wind speed, cloud cover etc., is also required.

In an hourly BEPS study, the interaction of climate on the building is computed for every hour – that is 8760 heat balance calculations for each building element described in the model, using a new value for each climate parameter for each time step.

BEPS analysis can be used to study the energy performance of either residential or commercial buildings. Programs appropriate for simulating the energy performance of residential buildings allow detailed inputs for building construction, but calculate heating and cooling energy needs by assuming an ideal system with no allowances for inefficiencies. BEPS tools, designed to analyse commercial buildings, require detailed inputs of real heating, ventilation and cooling systems and account for energy losses in each component such as, chillers, fans, pumps, boilers, etc.

Residential buildings are generally fabric driven, for instance, there is very little heat generating activity within the building, and the problem is to keep the extremes of climate outside the building envelope (fabric), whether it be cold or hot. Commercial buildings are usually internally driven, for instance, they have significant heat generating activity within the building, such as, lighting, computers and people. In internally driven buildings in Australia the problem is usually the removal of heat energy from the interior.

3.0 THE BENEFITS OF BUILDING ENERGY PERFORMANCE SIMULATION

BEPS studies:

- offer higher accuracy than steady state estimation;
- are well validated (IEA 1993); and
- allow different 'models' to be tested cheaply.

BEPS analysis can also be used in research and development, for example, in predicting the effect of new construction materials, new mechanical equipment and their control strategies. BEPS can also be used to study:

- the cost effectiveness of refurbishment alternatives;
- the development of standards and codes for energy efficiency (for example, ASHRAE 90.1 - Energy efficient design of new buildings except low-rise residential buildings); and
- the development of simplified design tools, such as the House Energy Rating Software (Energy Victoria 1994) and RESFEN (LBNL 1996).

It would be almost impossible to give exact BEPS study predictions for building performance, because:

- Climate data files contain values that represent long term observations and the actual climate variations result in a unique actual energy use figure.
- All assumptions for building use and occupancy patterns, are just that, assumptions. The differences between assumptions and what actually occurs can result in discrepancies that are quite large.

Instead, an experienced modeller can say with some confidence that '… using R3.0 insulation on the ceiling, instead of R1.5, will result in a saving of about 15% in the annual heating energy use of the house, given the following assumptions about building use …'.

Assertions on life-cycle costs can be made using long-term climate observations and by testing a range of assumptions through the BEPS.

4.0 WHEN TO USE BEPS

Certain types of analysis can benefit substantially from the BEPS approach. This section lists some such instances, with brief comments.

4.1 Sensitivity' studies

Once the initial model has been described, and checked for accuracy, it is strongly recommended that additional runs be commissioned to study the 'sensitivity' in changing selected parameter values, for example, alternate glazing choices, increased levels of insulation, etc. Such additional runs are quick to implement, and give an idea of the range of possible energy use and its sensitivity to variations in design and materials.

4.2 Material selection

BEPS programs model heat storage and release in the building fabric due to changes in temperature and solar radiation. BEPS studies can therefore be used to predict the effectiveness of various combinations of mass and/or insulation, like the change in energy needed due to the use of a mass wall that is insulated on the outside versus one that is insulated on the inside.

4.3 Orientation and shading

The effect of rotating a specific house design within a site's boundaries on the need for heating (and/or cooling) energy is easily studied in most BEPS programs. Some BEPS programs allow the effect of shading, either by window overhangs or an adjacent building, to be studied.

4.4 Window systems

Glazing represents the greatest area of heat transfer between the outdoors and the interior space in a building. (Refer to PRO 3.) Accurate analysis of glazing contributions is particularly important in the Australian context due to our penchant for large windows designed to take advantage of expansive views in our temperate and warm climates.

Thermal performance of window systems and their effect on building energy use can be analysed in detail using BEPS by modelling the energy gained due to solar radiation (sunshine) passing through the window, and heat transfer due to the 'thermal transmittance' or 'U-value' of the window.

Solar heat gain

The prediction of the solar heat transmitted through a window as a fraction of the amount of solar energy falling on its outside surface is complicated by the angle of incidence of the light on the (usually) vertical window.

The latest generation of BEPS tools can estimate the Solar Heat Gain Coefficient (SHGC) characteristics of complex window systems for hourly values of incident solar radiation, resulting in a much more accurate estimation of heating and cooling energy use due to solar gain. This capability is particularly important for estimating energy use in commercial buildings in Australia's warm and temperate climates. Energy use (and air-conditioning system peak demand) can be significantly reduced by the use of an appropriate advanced glazing product.

Thermal transmittance

Thermal transmittance (the heat transfer due to conduction and convection) depends on the temperature differential between the outside and the interior, as well as the wind speed along the glass surface. Hourly temperature and wind speed changes are taken from the climate data file to recalculate the thermal transmittance at each hour. Complex glazing systems can be modelled accurately with special software and the results used with compatible BEPS systems.

HVAC systems

In analysing the design of air-conditioned commercial (non-residential) buildings, BEPS techniques are well suited for analysing the performance of the Heating, Ventilation and Air-Conditioning (HVAC) systems with Energy Conservation Measures (ECM) such as:

- Comparison of dual duct systems (mixed hot and cold airstreams) with variable air volume systems in different climates.
- Cost effectiveness of an economiser cycle (passing outside air over cooling coils when it's cold enough, instead of starting the chiller).
- Analysing specific component performance, for example, energy savings due to the use of variable speed drives for air-handling systems, or from the installation of two speed drives for cooling tower fans and pumps.
- Analysis of energy savings available from implementing specific control strategies, for example, resetting the heating or cooling thermostat setpoints, or load control of multiple chillers providing chilled water.

5.0 WHO SHOULD DO BEPS ANALYSIS

BEPS analysis is extremely useful, but is not a simple procedure. BEPS requires a good knowledge of building physics and heat transfer, as well as a grasp of the inter-relationships between various building systems and climate. Most BEPS programs make assumptions about hundreds of variables (DOE-2 lists over a thousand variables with default values that can be changed by the user).

6.0 THE FUTURE

Developmental activity is taking place at universities and other research centres around the world in a number of areas, some of which are:

- graphical user interfaces for these detailed BEPS tools, designed to make them accessible to the wider building design community;
- explicit modelling of three-dimensional heat transfer effects, like thermal bridging through metal frame components and edge effects;
- modelling of variable material properties (for example, DOE2.1E can model the performance of electrochromic windows whose solar transmission properties can be changed);
- modelling of combined heat and moisture transfer;
- incorporating the modelling of the interaction of artificial light and daylight; graphic ray tracing techniques are already being used to study this phenomena;
- integrated building design environments (a single interface will allow interaction between several design tools); and
- use of Computational Fluid Dynamics (CFD) flow visualisation software for studying natural ventilation in buildings.

7.0 FURTHER INFORMATION

The increase in power and drop in price of computers over the past decade has furthered the development of a myriad of BEPS programs and simplified design tools, which are available around the world. It is not possible to review all of them or indeed list them as many are continually evolving. A listing of features for five programs used in Australia is given in the Building Energy Manual (NSW Public Works, 1993). A comprehensive listing of programs developed in the USA can be found on the world wide web at //www.eren.gov/buildings/toolsdir.htm.

In Australia two tools that have been used for studies are NatHERS (for residential buildings) and DOE-2 (for non-residential buildings). These are not the 'only' programs available, but do have many of the capabilities discussed in the preceding sections. NatHERS has been used to develop the nationwide House Energy Rating Scheme and the Window Energy Rating Scheme; while DOE-2 has been used to develop the initial results for the draft Building Energy Code of Australia, and for developing design guidelines for energy efficient building envelopes of commercial buildings.

8.0 CONCLUSION

This article has provided an introduction to those involved in the design of buildings to the analytical capabilities available through the use of building energy performance simulation (BEPS). Use of BEPS analysis is an important tool in predicting energy use for innovation in new building design and refurbishment.

A later Note will discuss the 'what' and 'how to' aspects of available tools as a Practitioners Guide to BEPS.

REFERENCES AND FURTHER READING

ASHRAE 1975, *Procedure for determining heating and cooling loads for computerising energy calculations; Algorithms for building heat transfer subroutines, energy calculations 1*, ASHRAE Task Group on Energy Requirements for Heating and Cooling of Buildings.

CSIRO 1996, *User Manual* - NatHERS, (Release 2.01), May 1996.

Energy Victoria 1994, *Energy Efficient Housing Manual*, Energy Victoria, Fitzroy, Victoria.

Enermodal Engineering 1995, *FRAMEplus Toolkit, Version 4.0 - User's Manual*, September 1995.

IEA 1993, *Empirical validation in International Energy Agency Annex 21/Task 12: Final Report*, IEA Report No. IEA21RN372/93, August 1993, Building Research Establishment and DeMontford University (Leicester), U.K.

LBL 1994, *WINDOW 4.1: Program Description*, Lawrence Berkeley Laboratory report no. LBL-35298, March 1994, USA.
(LBL is a Microsoft Windows based program for calculating residential fenestration heating and cooling energy use and costs - applicable only for US climates.)

NTIS (National Technical Information Service), *DOE2.1E - Supplement*, 5285 Port Royal Road, Springfield, VA 22161, USA.

Yazdanian, M & Klems, J, 1993, *Measurements of the exterior film coefficient for windows in low-rise buildings*, LBL.

BIOGRAPHY

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