BRITA in PuBs

Energy Simulation Tools for Buildings

EU framework programme

eco buildings

Guidelines

2007

1 Introduction

01 Why use this technology

Building energy simulation is playing an increasingly important role in building design. To achieve the energy efficiency goal, architects and building designers require effective design tools for analysing and understanding the complex behaviour of building energy use. Building energy simulation is important for the study of energy efficiency in buildings either in new or in retrofit projects.
The use of building simulation techniques in the design process not only aides a designer to confirm his technical assumptions, but also helps nontechnical people involved in a project to understand the issues through graphical or illustrative examples of what will happen once a building is built.

The increase in computing speed and memory is allowing more sophisticated and complex tools to be used in building design. For example, full hourly energy analysis (8,760 hours in a year) and detailed dynamic thermal models can now easily be used in building energy simulation programs running on personal or laptop computers.

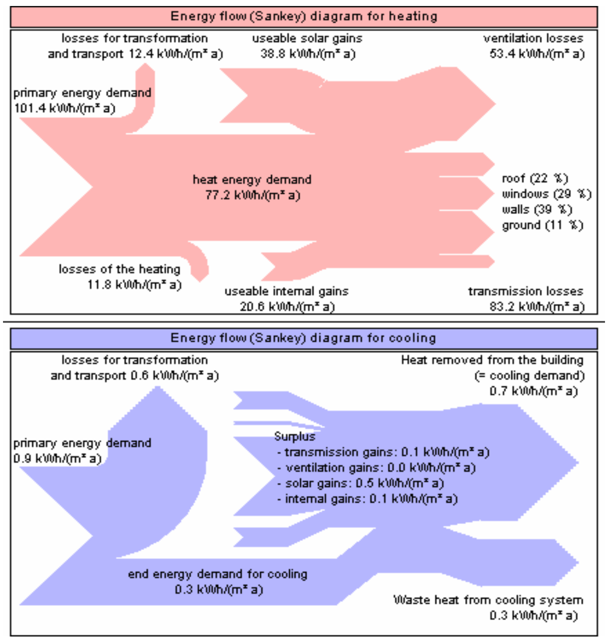

Figure 1 Energy flow. From “Casanova” and Educational Software for Heating and Cooling of Buildings [Clemens, Benkert, Braeske, Univeristy of Siegen, DE]

02 Requirements in regulations

To promote energy conservation and control building design, many countries have developed or upgraded their building energy codes in the past decade. In Europe a new and important regulation activities related to buildingn certification is in act. New procedures for calculation of energy performance of building and HVAC will probably require an increasing effort by the designers. Very often, building energy simulation tools are being used for analysing the energy consumption in buildings so as to establish the basis for the building energy codes and their energy efficiency requirements. Moreover, in order to holistically consider the building’s energy performance, building energy simulation is also taken as the evaluation method for determining code compliance under a performance-based approach.

An important trend for modern building energy codes is to move towards a greater use of building energy simulation and modelling techniques. This can help people understand the complex issues of building energy performance and improve the flexibility, clarity and effectiveness of the regulatory documents. However, as building energy simulation is a complicated process involving modelling and analytical skills, the building designers and practitioners often find it difficult to carry out the building energy analysis and comprehend the simulation results.

2 Current practice

Detailed building energy simulation programs, although powerful and sophisticated, are seldom used by practising building designers like architects and building services engineers. Many building designers are reluctant to use the simulation software because of the lack of confidence in the simulation results and the time and effort needed to learn how to use them.

The building energy simulation software available in the market ranges from the simple and approximate to the detailed and sophisticated. Selecting a program for a particular job requires matching the tool to the task. Usually, building designers will select a specific software based on their own experience and familiarity, the type of features to model, the required level of detail, the contract requirements and any regulatory guidance. At present, program users must rely on the documentation and verification provided by the software developers or large independent bodies, since they do not have enough resources to carry out extensive validations. Even if the program is regarded as verified at some acceptable level, questions may still arise concerning the validity of results obtained by users who are not familiar with the limitations of the program.

3 Innovative solutions

To conduct the analysis properly and effectively, the aims of the study and the intended use and possible limitations of the simulation tool must be fully understood. The level of technical knowledge needed to correctly use the simulation tools are often high so that mis-applications and mis-interpretations are not uncommon in building energy studies. In the past (and still with some simulation tools at present), the user interface is the weakest part of a building energy simulation program. With increasing popularity of graphical user interface (GUI) and windows-based approach, the problem with user friendliness has been partly resolved.

However, although some percentages of the possible mistakes have been eliminated, there are still many opportunities for an unwary user to make significant errors when performing the simulation, for ex in problem definition and key assumptions. Therefore, proper guidance and quality control are essential for ensuring meaningful results and reasonable judgement. Some guidelines and manuals have been published in recent years to provide assistance to building energy ‘simulators’.

For the past 50 years, a wide variety of building energy simulation programs have been developed, enhanced, and are in use throughout the building energy community. The major building energy simulation programs are: BLAST, BSim, DeST, DOE-2.1E, ECOTECT, Ener-Win, Energy Express, Energy-10, EnergyPlus, eQUEST, ESP-r, IDA ICE, IES <VE>, HAP, HEED, PowerDomus, SUNREL, Tas, TRACE and TRNSYS.

The most used of them are described in the following.

31 DOE-2.1E

DOE-2.1E (Winkelmann et al. 1993) predicts the hourly energy use and energy cost of a building given hourly weather information, a building geometric and HVAC description, and utility rate structure. Using DOE-2.1E, designers can determine the choice of building parameters that improve energy efficiency while maintaining thermal comfort and cost-effectiveness.

DOE-2.1E has one subprogram for translation of input (BDL Processor), and four simulation subprograms (LOADS, SYSTEMS, PLANT and ECON). LOADS, SYSTEMS and PLANT are executed in sequence, with the output of LOADS becoming the input of SYSTEMS, etc. The output then becomes the input to ECONOMICS. Each of the simulation subprograms also produces printed reports of the results of its calculations. The Building Description Language (BDL) processor reads input data and calculates response factors for the transient heat flow in walls and weighting factors for the thermal response of building spaces.

The LOADS simulation subprogram calculates the sensible and latent components of the hourly heating or cooling load for each constant temperature space taking into account weather and building use patterns.

The SYSTEMS subprogram handles secondary systems; PLANT handles primary systems. SYSTEMS calculates the performance of air-side equipment (fans, coils, and ducts); it corrects the constant-temperature loads calculated by the LOADS subprogram by taking into account outside air requirements, hours of equipment operation, equipment control strategies, and thermostat set points. The output of SYSTEMS is air flow and coil loads.

PLANT calculates the behavior of boilers, chillers, cooling towers, storage tanks, etc., in satisfying the secondary systems heating and cooling coil loads. It takes into account the part-load characteristics of the primary equipment in order to calculate the fuel and electrical demands of the building.

The ECONOMICS subprogram calculates the cost of energy. It can also be used to compare the costbenefits of different building designs or to calculate savings for retrofits to an existing building.

DOE-2.1E has been used extensively for more than 25 years for both building design studies, analysis of retrofit opportunities, and for developing and testing building energy standards in the U.S. and around the world. DOE-2.1E has been used in the design or retrofit of thousands of well-known buildings throughout the world.

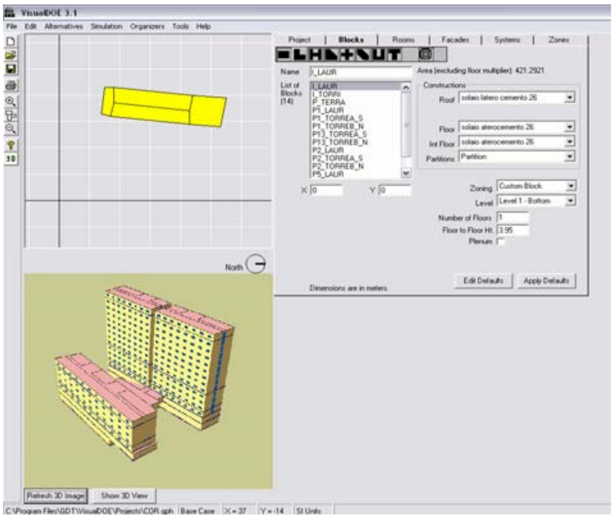

Figure 31: Screenshot of Visual DOE

The private sector has adapted DOE-2.1E by creating more than 20 interfaces that make the program easier to use.

32 ECOTECT

ECOTECT (Marsh 1996) is a highly visual and interactive complete building design and analysis tool that links a comprehensive 3D modeller with a wide range of performance analysis functions covering thermal, energy, lighting, shading, acoustics, resource use and cost aspects. Whilst its modelling and analysis capabilities can handle geometry of any size and complexity, its main advantage is a focus on feedback at the conceptual building design stages. The intent is to allow designers to take a holistic approach to the building design process making it easier to create a truly low energy building, rather than simply size a HVAC system to cope with a less than optimal design.

ECOTECT aims to provide designers with useful performance feedback both interactively and visually. Thus, in addition to standard graph and table-based reports, analysis results can be mapped over building surfaces or displayed directly within the spaces that generated them, giving the designer the best chance of understanding exactly how their building is performing and from that basis make real design improvements.

As well as the broad range of internal calculations that ECOTECT can execute, it also imports/exports to a range of more technical and focussed analysis engines, such as Radiance, EnergyPlus, ESP-r, NIST FDS and others -- and for general data import/export facilities, it includes an array of formats suitable for use alongside most leading CAD programs.

The recent addition of a comprehensive scripting engine provides direct access to model geometry and calculation results. This has made performance based generative design and optimisation a very real option for the environmental engineer/designer who uses ECOTECT. Scripting allows models to be completely interactive and self-generative, automatically controlling and changing any number of parameters, materials, zone stettings or even geometry during calculations or as the user specifies. At a more day-to-day level the scripting functions are excellent for automating the more mundane tasks involved in calculation runs, results comparison and report creation.

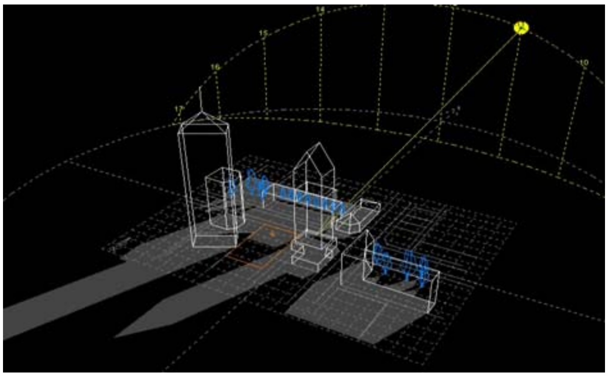

Figure 32: Shadows projection with ECOTECT

ECOTECT is unique within the field of building analysis in that it is entirely designed and written by architects and intended mainly for use by architects. The software is also quickly gaining popularity through the wider environmental building design community.

33 EnergyPlus

EnergyPlus (Crawley et al. 2004) is a modular, structured software tool based on the most popular features and capabilities of BLAST and DOE-2.1E. It is primarily a simulation engine; input and output are simple text files.

EnergyPlus grew out of a perceived need to provide an integrated (simultaneous loads and systems) simulation for accurate temperature and comfort prediction. Loads are calculated by a heat balance engine)at a userspecified time step, with 15-minute default. The loads are passed to the building systems simulation module at the same time step. The EnergyPlus building systems simulation module, with a variable time step (down to 1 minute as needed), calculates heating and cooling system and plant and electrical system response. This integrated solution provides more accurate space temperature prediction—crucial for system and plant sizing, occupant comfort and occupant health calculations. Integrated simulation also allows users to evaluate realistic system controls, moisture adsorption and desorption in building elements, radiant heating and cooling systems, and interzone air flow.

EnergyPlus has two basic components—a heat and mass balance simulation module and a building systems simulation module. The building systems simulation manager handles communication between the heat balance engine and various HVAC modules and loops, such as coils, boilers, chillers, pumps, fans, and other equipment/components. User-configurable heating and cooling equipment components give users flexibility in matching their simulation to actual system configuration. HVAC air and water loops are the core of the building systems simulation manager—mimicking the network of pipes and ducts found in real buildings. The air loop simulates air transport, conditioning and mixing. It includes supply and return fans, central heating and cooling coils, heat recovery, as well as controls for supply air temperature and outside air economizer.

The air loop connects to the zone through the zone equipment. Users can specify more than one equipment type for a zone.

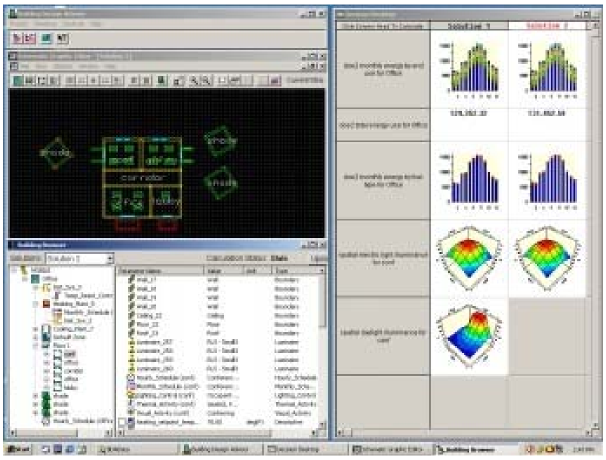

Figure 33: Screenshot of Energy Plus

The heat and mass balance calculations are based on IBLAST—a research version of BLAST with integrated HVAC systems and building loads simulation. The heat balance module manages the surface and air heat balance modules and acts as an interface between the heat balance and the building systems simulation manager. The surface heat balance module simulates inside and outside surface heat balances; interconnections between heat balances and boundary conditions; and conduction, convection, radiation, and mass transfer (water vapor) effects. The air mass balance module deals with various mass streams—ventilation and exhaust air, and infiltration—accounting for zone air thermal mass and direct convective heat gains.

EnergyPlus inherits three popular windows and daylighting models from DOE–2.1E—fenestration performance based on WINDOW 5 calculations, daylighting using the split-flux interreflection model, and anisotropic sky models. EnergyPlus' detailed daylighting module calculates interior daylight illuminance, glare from windows, glare control, and electric lighting controls (on/off, stepped, continuous dimming). It also calculates electric lighting reduction for the heat balance module. In addition, a new daylighting analysis module named DElight has been integrated with EnergyPlus. This module uses a radiosity interreflection method, and includes newly developed methods for analyzing complex fenestration systems characterized by bi-directional transmittance data.

34 ESP

ESP (ESRU 2005, Clarke 2001) is a general purpose, multi-domain—building thermal, interzone air flow, intra-zone air movement, HVAC systems and electrical power flow—simulation environment which has been under development for more than 25 years. It follows the pattern of `simulation follows description` where additional technical domain solvers are invoked as the building and system description evolves. Users have options to increase the geometric, environmental control and operational complexity of models to match the requirements of particular projects. It supports an explicit energy balance in each zone and at each surface and uses message passing between the solvers to support interdomain interactions (Clarke 2001). It works with third party tools such as Radiance to support higher resolution assessments as well as interacting with supply and demand matching tools.

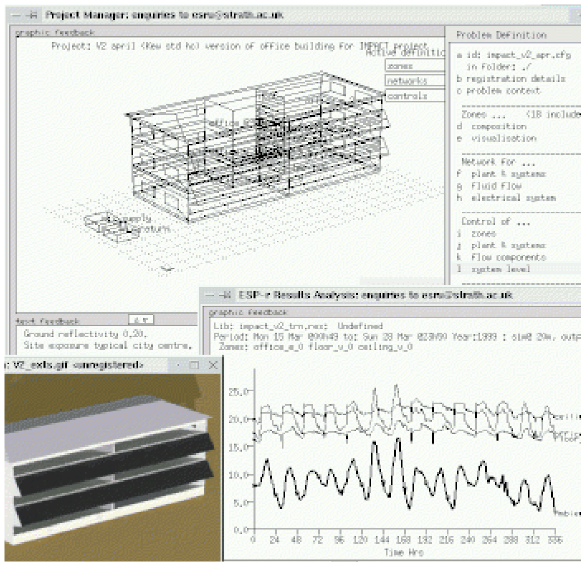

Figure 34 Screenshot of ESP-r

ESP-r is distributed as a suite of tools. A project manager controls the development of models and requests computational services from other modules in the suite as well as 3rd party tools. Support modules include: climate display and analysis, an integrated (all domain) simulation engine, environmental impacts assessment, 2D-3D conduction grid definitions, shading/insolation calculations, viewfactor calculations, short-timestep data definitions, mycotoxin analysis, model conversion (e.g. between CAD and ESP-r) and an interface to the visual simulation suite Radiance.

ESP-r is distributed under a GPL license through a web site which also includes an extensive publications list, example models, cross-referenced source code, tutorials and resources for developers. It runs on almost all computing platforms and under most operating systems. Although ESP-r has a strong research heritage (e.g. it supports simultaneous building fabric/network mass flow and CFD domains), it is being used as a consulting tool by architects, engineers, and multidiscipline practices and as the engine for other simulation environments.

35 TRNSYS

TRNSYS (Klein et al. 2004) is a transient system simulation program with a modular structure that was designed to solve complex energy system problems by breaking the problem down into a series of smaller components. TRNSYS components (referred to as "Types") may be as simple as a pump or pipe, or as complicated as a multi-zone building model.
The components are configured and assembled by using a fully integrated visual interface known as the TRNSYS Simulation Studio. Building input data are entered through a dedicated visual interface, TRNBuild. The simulation engine then solves the system of algebraic and differential equations that represent the whole sys-

tem. In building simulations, all HVAC-system components are solved simultaneously with the building envelope thermal balance and the air network at each time step. The program typically uses 1-hour or 15-min time steps but can achieve 0.1-sec time steps. User-selectable (e.g. hourly and monthly) summaries can be calculated and printed.

In addition to a detailed multizone building model, the TRNSYS library includes many of the components commonly found in thermal and electrical energy systems: solar thermal and photovoltaic systems, low energy buildings and HVAC systems, renewable energy systems, cogeneration, and hydrogen systems (e.g. fuel cells). It also provides component routines to handle input of weather data or other timedependent forcing functions and output of simulation results.

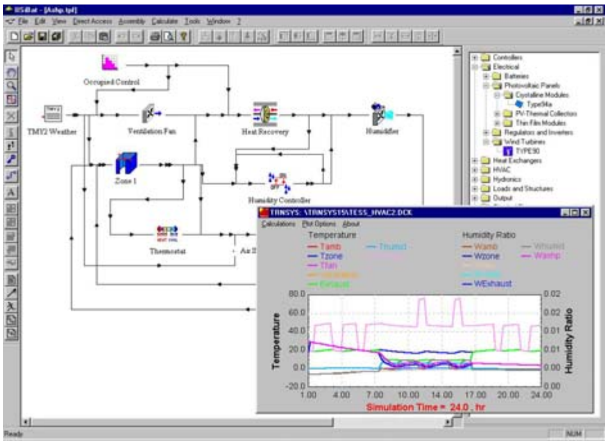

Figure 35: Screenshot of TRNSYS

The modular nature of TRNSYS facilitates the addition of new mathematical models to the program. Components can be easily shared between users without recompiling the program thanks to the drop-in DLL technology. Simple components, control strategies or pre- and post-processing operations can also be implemented directly in the input file using simple equations supporting the usual mathematical and logical operators and can use the (optionally delayed) outputs of other components. In addition to the ability to develop new components in any programming language, the program allows to directly embed components implemented using other software (e.g. Matlab/Simulink, Excel/VBA, and EES). An interpreter program called TRNSED allows non-TRNSYS users to view and modify a simplified, webpage like representation of the input file and perform parametric studies.

4 Advantages/disadvantages

As building design is a creative process based on iteration, the architectural and engineering designs will move back and forth to synthesize the design solution within given constraints. This will make simulation data and process difficult to define and conduct. For instance, during early design stages, architectural ideas and concepts are ill-structured and not well-defined. The data and information required for building simulation are either not available or only approximated. This will create an obstacle to the use of detailed simulation tools that require full building description.

In actual situation, the building design is a teamwork and the team of people with the right skills and experience must be assembled at the start to meet the project design priorities. At present, many smaller firms would not find it practical to have on staff an energy specialist who can maintain current knowledge of building energy simulation. If a building energy analysis is needed, such as to meet the performance-based requirement or upon the client's request, then another energy consultant will be hired to carry out the task.

Human judgement and experience is a critical factor in building energy simulation and analysis because the program user is the one who determines how the information are put together to define the problem and analyse the building. Given the same problem, the end results are a function of both the program and the user. As the software knows no context, a critical mind is needed to design the analysis, interpret the results and determine the consequences. The design and modelling skills of the program user play an important role in the quality and adequacy of the results produced from the simulation models.

To achieve timely design feedback and effective decision making, good communication and collaboration between different design professionals and consultants is necessary.

5 Costs

51 Investment costs

Simulation tools do not represent a cost itself. Generally, licences are available for free or al least for few hundreds of euro.

The main investment is represented by labour cost related to their use. An energy study could be performed by external consultants or by the design team itself. In this case further labor investment is required in order to aquire the know-how and skill. It can be assumed that the cost of a energy study would range from 5% to 10% of the overall design costs. This cost could be in part addressed to compulsory building code verification when it occurs.

52 Energy saving potential

It is difficult to assess the energy saving potential of simulation itself. Great savings are infact related to the measures that are designed and biased through the use of such tools. It can be said that a good simulation can give a substantial support into the design stage of building retrofit. By means of sensitivity analisys of the design, technical and economic parameters can be optimised giving additional value to the project.

6 Maintenance and service

The “maintenance” cost can be summarised in two simple requirements:

- the periodic upgrade of licences and software releases
- the personel training and skill upgrade

They do not represent a significant effort.

7 References

7.1 Compilation

This guideline is written as a part of the project BRITA in PuBs – Bringing retrofit innovation to application in public buildings, EU 6th framework program Eco-building (TREN/04/FP6EN/S.07.31038/503135).
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The professional editing was closed in May 2007.

7.2 Further reeding

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7.3 Literature

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8 Disclaimer