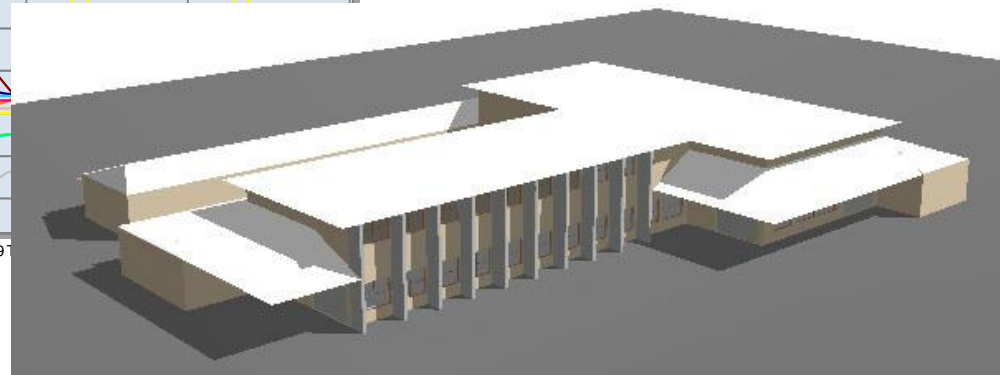
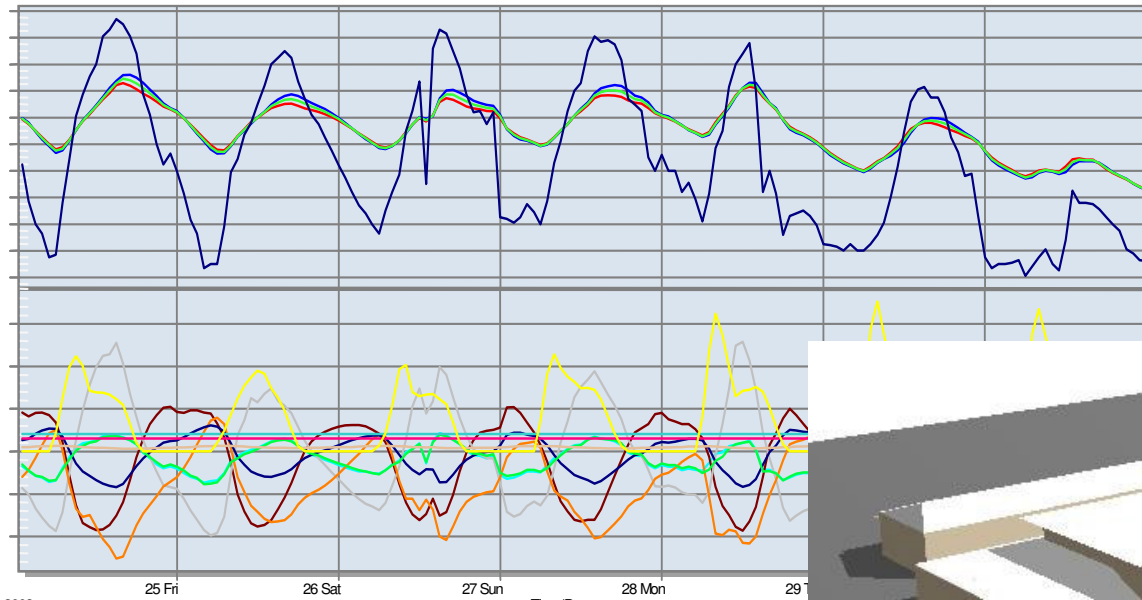


SECTION 11

SIMULATION



ENERGY EFFICIENCY BUILDING DESIGN GUIDELINES FOR BOTSWANA

Revision 1

September 2007

ENERGY EFFICIENCY BUILDING DESIGN GUIDELINES FOR BOTSWANA

Sections:

1. Introduction.
2. Design Brief.
3. Climate.
4. Indoor Environment.
5. Design and construction process.
6. Planning.
7. Building envelope.
8. Mechanical Systems.
9. Lighting - artificial and day lighting.
10. Operation & Maintenance and Building Management Systems.
11. Simulation.
12. Life-Cycle Cost Analysis.
13. Appendices.

CONTENTS

11. SIMULATION	5
11.1. Summary	5
11.2. Overview	5
11.2.1. Definition.	5
11.2.2. History.	5
11.2.3. Opportunities	5
11.2.4. Limitations	6
11.3. Simulation Tools	7
11.4. Elements of Simulation	12
11.4.1. Weather and location data.	12
11.4.2. Building construction data.	14
11.4.3. Occupancy and equipment.	15
11.5. Simulations.	16
11.5.1. Output reports.	17
11.5.2. Analysis.	17
11.6. Design Stages	17
11.6.1. Scheme Design	18
11.6.2. Detailed Design	19
11.7. Building Performance Simulation	20
11.7.1. Compliance with Codes and Standards.	20
11.8. Resource Material	21
11.8.1. Books and papers	21

11.8.2. Codes and Standards	21
11.8.3. Websites	21

11. SIMULATION

11.1. Summary

This Section gives an overview of the role of simulation in the building design process. The opportunities that simulation offers and its limitations are considered.

A number of available software packages are compared in a table that provides basic information on the features, capabilities and cost of each, as well as the links to further information.

The elements of simulation are described, indicating the information that is needed regarding climate, location and the building itself.

The role of modelling in different stages of the building design process is then considered in more detail.

11.2. Overview

11.2.1. Definition.

Simulation is defined in this context as the use of computer software tools to predict the performance of buildings, particularly with respect to indoor environment, energy transfer and lighting.

11.2.2. History.

Software tools for building simulation have been available for about the last 30 years, but much development has taken place in the past 10 years making such tools more easily available and user friendly. The main constraints in the use of simulation have been the availability and cost of the software, availability of detailed weather data, and even more so, the skills and time required to use these.

11.2.3. Opportunities

There is a wealth of information available on how to design energy efficient buildings for different climates. This includes suggestions for orientation of buildings, use of shading devices, placement of insulation and thermal mass, and appropriate use of ventilation. Many architects and engineers are aware of these concepts and apply them to the buildings that they design. It is however only with the use of computer simulation tools that the actual quantitative impact of different approaches can be determined with useful accuracy. Especially interactions between different building systems and the feed-backs involved can be analysed, which is generally not possible without an

advanced simulation software except in a very simplified form.

It ‘makes sense’ that a building should be orientated to present the smallest elevations to the rising and setting sun, but what is the actual effect on internal temperature or energy consumption of a different orientation? How sensitive is the relationship? What is the effect on performance of a shift in orientation of say 10, 20 or 30 degrees from the optimum?

It ‘makes sense’ to control heat transfer through the roof by fitting insulation and having a light coloured roof surface, but how much insulation is economically efficient? How much difference does the roof colour make?

For buildings at the design stage, questions such as these can only be reliably answered by carrying out simulations that provide actual quantitative information on the dynamic behaviour of the proposed design.

The use of simulation in the building design process allows the design team to quantify the actual impact of such design decisions, so that rational decisions leading to the most cost effective approach can be made based on actual quantitative information. A key advantage is that through the use of advanced simulation software such information becomes available *much earlier* in the design process than would otherwise be possible thereby providing many opportunities for improving thermal performance in as cost effective a manner as possible.

The usefulness of energy simulation is greatly enhanced when it is combined with lifecycle cost analysis (See **Section 12, Life-Cycle Cost Analysis**). The combination of these two modelling tools enables rational choices to be made regarding measures that impact on energy performance in the context of the total cost of a building over long periods of time, even over its entire expected life to demolition.

11.2.4. Limitations

Naturally the benefits of simulation come at a cost. The software itself can be quite expensive, depending on the package that is selected. The greater cost however is the time and skill required to set up the simulation and run the various scenarios to provide the required information.

The more accurate and detailed the model, the more time is needed to prepare it, so it is important to determine the minimum amount of detail required to provide the information that is relevant at each stage of the design process.

In practice the economics of building simulation need to be considered in determining the extent to which it is appropriate to apply it in the design methodology. There are substantial economies of scale, such that a large building is not proportionally more time consuming to model than a small building, and there is therefore more opportunity to use simulation for large projects. Large projects in general also have more to gain from simulations since the increased size brings with it increased complexity as well. Therefore accuracy of simplified methods quickly

deteriorates with increasing size and complexity of buildings.

Much information may be obtained from simulation of typical 'generic' building types in a particular climate. This information can then be applied to a large number of individual buildings that are essentially similar to the generic building. An exercise to model a number of 'generic' building types in the Botswana climate has been carried out under the Energy Efficiency and Energy Conservation in the Building Sector project. The results of this are available in the report: 'Parametric simulation of the energy performance of three generic building types in Gaborone, Botswana'. Department of Energy, Government of Botswana, January 2007.

11.3. Simulation Tools

A large number of software packages are available for simulating buildings. They differ widely in complexity and ease of user interface.

A report prepared in July 2005 (Crawley et. al.) provides a comparison of 20 building energy simulation programs including an assessment of their capabilities. The authors recommend that it may be most efficient to use a suite of different programs for different stages of the design process. The report contains 14 tables detailing the specific features and capabilities of the programs. The comparison of 17 programs in Table 11.1 is largely based on information from this report.

It can be seen from the table that there is considerable variety in the available software, in terms of their features, performance and price.

Price is not necessarily an indicator of capability or quality, and some of the most comprehensive and powerful software is available free (e.g. EnergyPlus, which however has a very cumbersome user interface.)

Software package	URL	Features	HVAC modelling	Interface	Price (P)
BSim	www.bsim.dk	Advanced dynamic Thermal simulation. Includes moisture analysis, Daylight analysis, natural ventilation, contribution from building integrated PV systems, advanced simulation of shades and solar illumination in and around the building etc.	Various / Complex	Accepts DXF input. Produces output files compatible with Excel. Can export data to various specialized programs like Radiance and CFD software. User friendly graphic interface. Can generate the necessary climate input files from user-provided data (e.g. measured hourly data) using very flexible input criteria	EUR2,680 P20,500 Plus annual support subscription fee of approx. P 4500
DesignBuilder	www.designbuilder.co.uk	Provides a graphic input and output interface for EnergyPlus	Various	Graphical input for building model. Graph / table output formats.	US\$1,449 P8,830
ECOTECH	www.ecotect.com	Highly visual and interactive. Comprehensive scripting engine.	Simple	Can export to specialised programs e.g. Radiance, EnergyPlus, etc.	US\$690 P4,200
Ener-Win	members.cox.net/enerwin/	Energy consumption analysis. Peak loads. Daylighting analysis. Life-cycle costing.	Simple		US\$49.00 P300

Software package	URL	Features	HVAC modelling	Interface	Price (P)
Energy Express	www.ee.hearne.com.au	Design tool for evaluating energy efficiency of commercial buildings. Separate packages for architects and engineers.	Simple / Complex	Fast and accurate input.	AUD\$945 P4,223
Energy-10	www.nrel.gov/buildings/energy10	Intended for early stages of design of residential and small commercial buildings. Full life-cycle costing.	Simple	Fast, user-friendly input. Built-in graphs illustrate different strategies.	US\$325.00 P1,980
EnergyPlus	www.energyplus.gov	Primarily a simulation engine. Integrated simulation for temperature, comfort and loads. Moisture analysis. Complex modelling of HVAC systems and controls.	Complex	Text file input and output files. Suitable for use with purpose made interface programs, e.g. DesignBuilder.	free
eQUEST	www.doe2.com/equest	Easy to use. Energy cost estimating. Daylighting and lighting system control. Energy efficient measures.	Simple	Interactive input interface. Output graphs to compare alternatives. 3D view of building geometry. HVAC system diagrams.	free
ESP-r	www.esru.strath.ac.uk/Programs/ESP-r.htm	Models thermal performance, air flow, HVAC systems and electrical power flow.	Complex	Can increase model complexity as a project develops. Works with third party tools such as Radiance.	free

Software package	URL	Features	HVAC modelling	Interface	Price (P)
HAP	www.commercial.carrier.com	Simulates building energy performance to derive annual energy use. Used for sizing and design of HVAC system.	Complex	GUI input. Graphical and tabular reports. Comparative reports for alternative schemes.	?
HEED	www.aud.ucla.edu/heed	Single zone simulation program for use at the beginning of the design process. Energy cost analysis.	Simple	User friendly GUI input interface. Graphical output reports comparing alternative schemes.	Free
IDA ICE	www.equa.se/ice	Based on a general simulation platform. Can model displacement ventilation, active chilled beams, radiative devices, air and water based slab systems.	Complex	Four levels of interface, from simple, wizard to programmer.	SEK18,000 P15,000
IES<VE>	www.iesve.com	Dynamic thermal simulation tool. Can link to MacroFlo for ventilation and infiltration analysis. Links to SunCast for shading and solar penetration analysis. Part of a suite of programs covering many aspects of building design.	Complex	Results viewed in Vista, a graphics tool for presentation and analysis.	?

Software package	URL	Features	HVAC modelling	Interface	Price (P)
SUNREL	www.nrel.gov/buildings/sunrel	Models small buildings dominated by envelope loads, including natural ventilation and infiltration.	Simple	Graphical interface may be used to create input files.	US\$50 P305
Tas	www.edsl.net	A suite of programs that simulate thermal performance of buildings and their systems. Models natural and forced airflow.	Complex	Wizards for creating models. Graphical results reporting with multi-run comparisons.	?
TRACE 700	www.tranecds.com	Models building and HVAC systems in four phases: design, system, equipment, economics. Specifically intended for optimisation of the HVAC system.	Complex	Wizards for creating models. Graphical results reporting with multi-run comparisons.	?
TRNSYS	sel.me.wisc.edu/trnsys	A modular transient system simulation program adapted to model building thermal performance, HVAC system performance. Easily adapted to develop special purpose applications.	Complex	Visual interface for data input. Full source code provided for components and simulation engine.	US\$4200 P25,600

Table 11.1. Comparison of energy simulation software

11.4. Elements of Simulation

11.4.1. Weather and location data.

A key requirement for accurate simulation of energy performance or lighting in buildings is comprehensive and relevant data for the weather conditions.

Weather data is often compiled into a database that includes hourly data for various parameters for a typical meteorological year. A standard format and methodology for the preparation of such a database has been adopted by most developers and is called TMY2 (Typical Meteorological Year 2). To prepare a TMY2 file for a particular location, hourly data for as many years as possible must be collated, and analysed to determine the averages for each month. The most representative full month's data for each month of the year is then selected, and used to build up a 'year' of hourly data. The first and last days of each month are then modified to smooth the transitions from one month to the next. In this way the different data parameters are kept together for each hour, and realistic variation within each month is maintained.

TMY2 files are readily available for many locations around the world, but unfortunately not many in Southern Africa, and none in Botswana. The EECOB project has developed a weather files for Gaborone and Maun for use with EnergyPlus and DesignBuilder. Weather files for other locations in Botswana will also need to be developed due to the variation in climate across the country (see **Section 3, Climate**).

Different software packages use different weather file formats, but most include a translation package to enable a TMY2 file to be translated into the required format.

The weather data required by a particular package depends on the approach taken in modelling different heat flow and lighting processes. Typically they will include the following:

- Dry bulb air temperature.
- Wet bulb air temperature.
- Relative humidity.
- Atmospheric pressure.
- Wind speed.
- Wind direction.
- Direct normal radiation.
- Diffuse horizontal radiation.
- Horizontal infrared radiation.

The location is defined by the longitude and latitude as well as the elevation above sea level.

Other information that may be required includes ground temperatures at various depths.

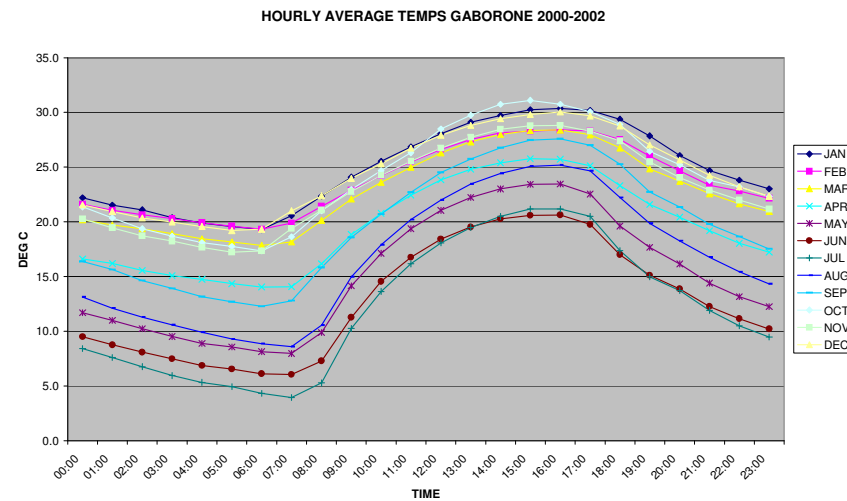
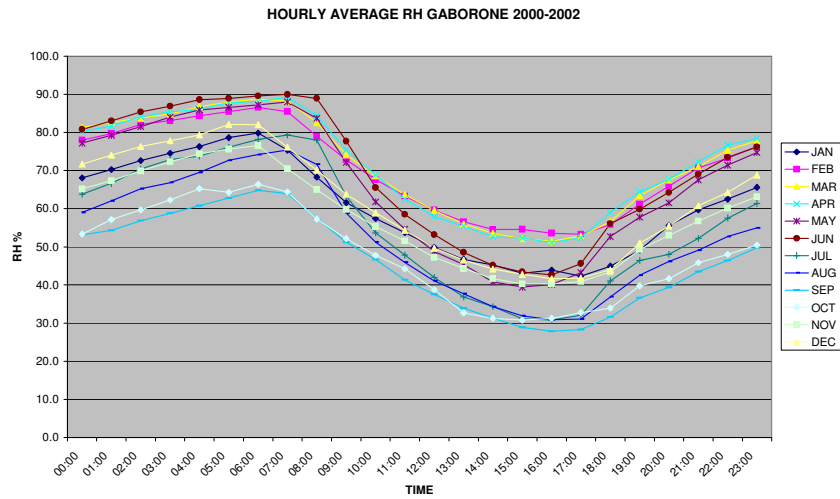


Fig. 11.1. Hourly average temperature and Relative Humidity for Gaborone

11.4.2. Building construction data.

The building needs to be defined, both in terms of the envelope geometry and the types of materials.

The input interface for this information is an important consideration in selecting a simulation programme.

At one extreme is a programme like EnergyPlus, which is entirely based on text input. Each vertex of each surface of the building needs to be defined by its Cartesian coordinates, which is a time consuming and tedious process.

Other programmes provide graphical tools to input the geometry, similar to simple CAD tools, while some allow the basic geometry to be imported as a DXF file from a CAD programme such as AutoCad.

The definition of the materials is generally supported by libraries of standard components and combinations of components, which may be edited by the user.

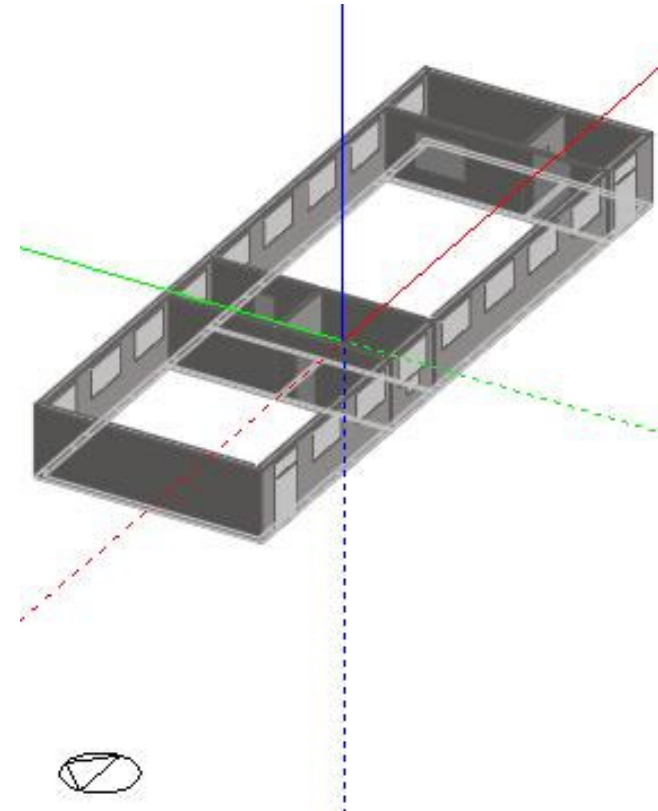


Fig 11.2 *Building construction (DesignBuilder)*

11.4.3. Occupancy and equipment.

The occupancy of the building and the equipment to be operated need to be specified, including the times of occupation and use of equipment. These are typically specified with schedules to define the times of occupancy and starting and stopping times for equipment use. The power consumption and efficiency of equipment needs to be defined to determine the heat output. (See Fig. 11.2.)

The equipment definition may also include specification of HVAC equipment, depending on the purpose for which the simulation is being carried out. Initial simulations to test out different envelope options may be carried out without any HVAC equipment specification, and report either on the ‘floating’ room temperatures, or define the heating and cooling energy needed to achieve defined indoor environment conditions.

Lighting equipment must also be defined. Again there is often the choice to define actual lighting layouts, and allow the programme to calculate the loads, or to define target light levels and have the programme determine the lighting loads to achieve these. In this case the contribution of daylighting through windows and other openings may also be determined by the programme if this facility is provided.

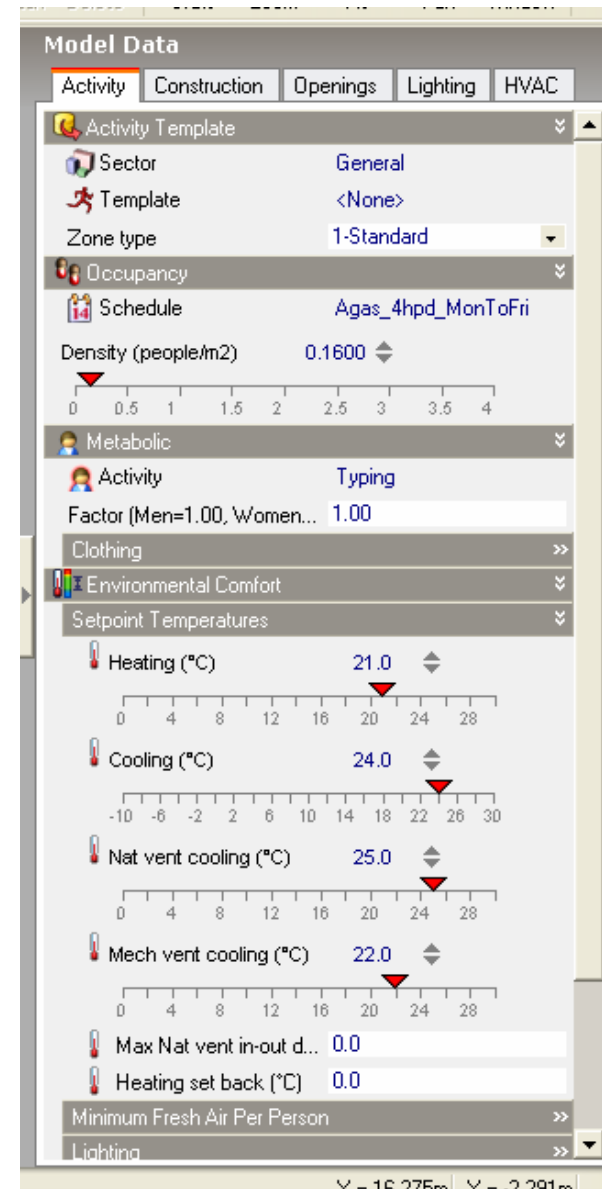


Fig. 11.3 Typical input data (DesignBuilder)

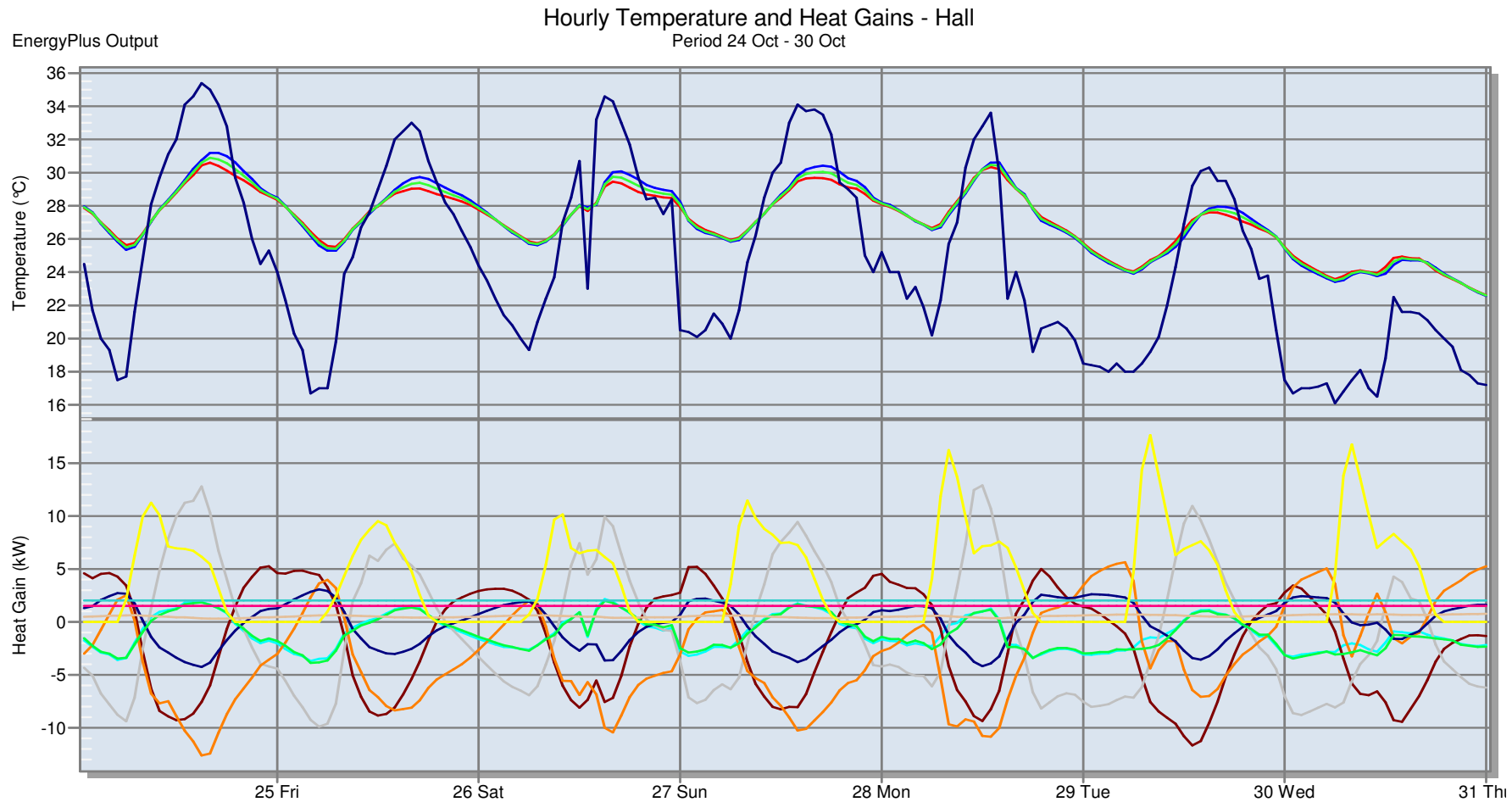


Fig. 11.4. Typical output from simulation (DesignBuilder).

11.5. Simulations.

Having input all the required information relating to the climate, location, building, occupation and equipment, the simulation runs may be performed. Typically a number of simulations will be run for each of several scenarios to try out the effect of changing one or more parameters.

The different simulations in each case may include different climatic conditions, e.g. typical summer and winter weeks, and a full year, depending on the purpose of the simulation. The sizing of HVAC equipment requires a simulation of the most extreme conditions under which the required indoor climate conditions are to be fulfilled.

11.5.1. Output reports.

Output reports may be in the form of text files that can then be imported into a spreadsheet programme for further processing (as with EnergyPlus), or the programme itself may generate both tabular and graphic output reports.

It is critical to consider what information is relevant at any particular stage of the design process, and how to use it to best advantage. This will be considered in further detail in subsequent sections of this paper.

11.5.2. Analysis.

The results of the simulations may be analysed in a number of ways, depending on the purpose of the simulation.

Typically the selected indicators may be plotted on a graph for various simulations to illustrate the effect of changing various parameters.

In other cases it may be more appropriate to present the results in a table format, e.g. where further calculations are to be performed using the results.

11.6. Design Stages

Simulation may be used as a tool at various stages of the design process. At each stage, the objectives, methods and analysis will be different. The design stages are discussed in more detail in **Section 5. Design and Construction Process**.

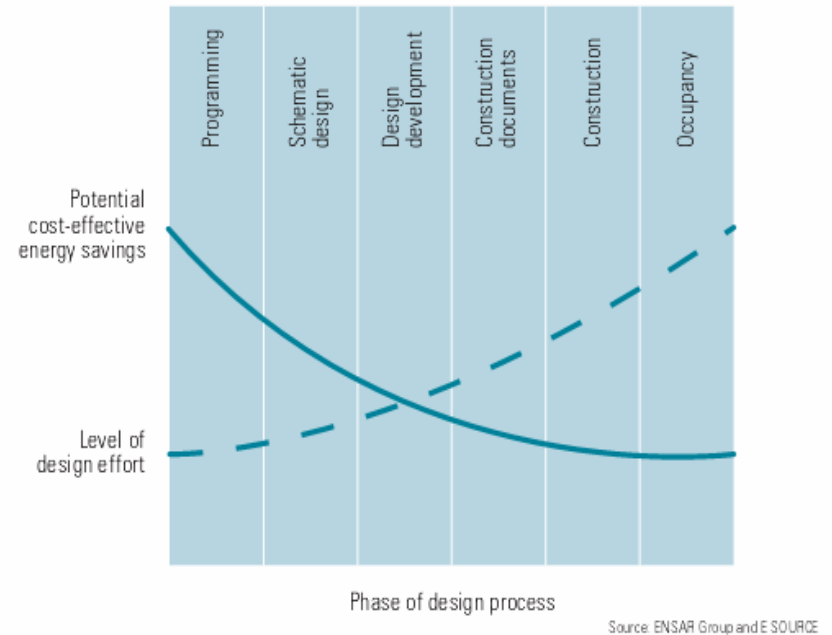


Fig. 11.5. Cost / benefit of design change with regard to energy savings. (Source: ENSAR Group)

11.6.1. Scheme Design

The scheme design stage is the stage at which there are the greatest opportunities coordinate and integrate the design of the different building systems to achieve the energy efficiency targets and criteria that were defined in the Design Brief. At this stage it is relatively easy and cheap to make substantial changes in the design approach, before the detailed design has been carried out.

Building Simulation can be an effective tool in achieving this, since it allows the design team to try out a number of initial concepts and evaluate their performance under the climatic conditions of the proposed site.

11.6.1.1. Model preparation.

For this purpose the model should not require a lot of detail, since it is the general concepts that are being evaluated. Suitable software packages for this purpose should provide a fast and easy input interface, so that various approaches can be modelled without taking too much time.

Typically the software may automatically generate windows to a specified ratio of wall area for each elevation. Lighting may be specified in terms of the required lux levels, and air conditioning systems by indicating the set points and the times when these are required to be achieved.

11.6.1.2. Simulations and results.

The objectives of simulation at this stage are to compare the effectiveness of different design approaches, and in particular the interaction of different building systems.

A decision therefore needs to be made as to what the most appropriate indicators for success will be. This may vary for different building types.

For buildings that are unlikely to use mechanical cooling or heating, the indicator may be ‘comfort temperature’ (weighted average between radiant temperature and dry bulb temperature). If heaters are likely to be used in winter, it may be appropriate to use heating energy as the indicator in winter.

For buildings that will be fitted with HVAC systems, annual energy use may be used as an overall indicator. However other indicators may be needed to determine the effectiveness of particular building elements. Typical summer and winter week results will indicate whether the building functions well under each of these conditions.

In all cases it is also helpful to analyse the energy flows between the building and its surroundings under different conditions. This will indicate where the major heat gains and losses are occurring. This information can be used to identify opportunities to improve performance, e.g. by increasing insulation, relocating translucent elements, etc. accordingly.

Through an interactive process involving the entire design team working with the simulation exercise it is possible to coordinate the design of the different building systems such as the envelope, lighting, mechanical systems, etc. to arrive at an integrated design that meets the specific requirements of the design brief.

11.6.2. Detailed Design

At the detailed design stage, building simulation can be used to quantify the energy and indoor environment impact of design decisions in each of the areas of speciality, and in particular regarding the interactions of different building systems.

At this stage it becomes necessary to provide more detailed information in preparing the model, such as the actual position and shape of windows and other translucent elements, placement of internal thermal mass, air flow and ventilation elements, lighting arrangements, HVAC systems, etc.

11.6.2.1. Envelope design

Aspects of envelope design that can benefit from simulation include the following:

- Placement and capacity of thermal mass / insulating elements and their impact on HVAC loads and / or thermal comfort.
- Interaction of daylighting strategies with artificial lighting systems.
- Geometry of shading devices at different times of day and year.
- Interaction of the mechanical systems with internal and envelope loads at different times of day and year.

11.6.2.2. Lighting design

Purpose made lighting design software may be used for detailed simulation of lighting systems. Some thermal modelling programmes are able to link to lighting software, e.g. ECOTECT and ESP-r are able to interface with the Radiance.

Particular aspects of lighting design that can benefit from simulation include the following:

- Interaction of day lighting and artificial lighting strategies.
- Checking for solar glare problems at different times of day / year.
- Ensuring that required light levels are achieved.
- Determining areas that require supplemental light at different times of day and year.
- Checking on control strategies to avoid excess lighting provision.

11.6.2.3. Mechanical systems design

Building simulation programmes are a particularly powerful tool for optimising the design of HVAC systems. They allow dynamic modelling of the interaction between climate, building fabric, occupants / equipment and the mechanical systems which cannot be achieved by static design methods. This can lead to significant savings in installed capacity. In a study of a large office building in Dublin, Beattie and Ward compared the actual installed capacity which had been designed using the CIBSE admittance method, with the design that would have been arrived at using dynamic modelling techniques. The results showed wide variations in peak cooling loads, with excess capacity of between 28% to 91% actually installed in

different zones of the building compared to the required capacity based on the dynamic modelling. (Beattie and Ward)

Particular aspects of mechanical design that can benefit from simulation include the following:

- Dynamic modelling of envelope and internal loads to determine system capacity requirements.
- Testing different system configurations to optimise the selection of systems for heating, cooling, and ventilation.
- Optimise control systems.

11.7. Building Performance Simulation

The final application of simulation to the building design process is in predicting the energy performance of the building after the design stages have been substantially completed.

Simulation may be used to confirm that the building will meet the criteria set out in the Design Brief before commencing construction, and making any necessary changes.

It may also be used to verify compliance with Codes and Standards, either as part of a statutory compliance procedure, or to demonstrate adherence to voluntary guidelines.

Simulation may also be used to assist in lifecycle cost analysis, to predict energy costs over the life of the building. Some software packages include cost analysis

modules for this purpose. In fact LCC may in many cases be a primary optimisation parameter when choosing between options for the design.

11.7.1. Compliance with Codes and Standards.

It may also be carried out as part of the procedure to verify compliance with energy standards, guidelines and regulations. Many codes for energy performance include two alternative procedures for compliance. One requires the applicant to demonstrate that each element of the building complies with the requirements of the code for that particular element, e.g. the aggregate ‘u’ value of a wall or a roof. An alternative procedure allows the applicant to demonstrate by a simulation using an approved software package that the overall performance of the building is within specified limits.

An example of such a code is the ASHRAE Standard 90.1-2001 “Energy Standard for Buildings Except Low-Rise Residential Buildings”.

11.8. Resource Material

11.8.1. Books and papers

Beattie, K.H., Ward, I.C., 1999: The Advantages of Building Simulation for Building Design Engineers. Dublin Institute of Technology, University of Sheffield. Proceedings, IBPSA conference, Tokyo 1999. BS 1999 - cd PB-16
http://www.ibpsa.org/%5Cproceedings%5CBS1999%5CB S99_PB-16.pdf

Crawley, D. B., Hand, J.W., Kummert, M., Griffith, B.T., July 2005: Contrasting the Capabilities of Building Energy Performance Simulation Programs. US Dept. of Energy; Energy Systems Research Unit, University of Strathclyde; Solar Energy Laboratory, University of Wisconsin-Madison; National Renewable Energy Laboratory, Golden, Colorado, USA.
(http://www.eere.energy.gov/buildings/tools_directory/pdfs/contrasting_the_capabilities_of_building_energy_performance_simulation_programs_v1.0.pdf)

Bauer, C and Groth, A. EECOB Report: Parametric simulation of the energy performance of three generic building types in Gaborone, Botswana. Department of Energy, Government of Botswana, January 2007.

11.8.2. Codes and Standards

ASHRAE Standard 90.1-2001. Energy Standard for Buildings except Low Rise Residential Buildings.

11.8.3. Websites

EDR. Energy Design Resources

<http://www.energydesignresources.com/>