THE UNIVERSITY OF QUEENSLAND

Department of

Architecture

INTEGRATION OF LOW ENERGY STRATEGIES TO THE EARLY STAGES OF DESIGN PROCESS OF OFFICE BUILDINGS IN WARM CLIMATE

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ABSTRACT

The thesis aims to investigate the integration of low energy strategies into the early stages of architectural design process, to improve the energy efficiency of multi-storey buildings in warm climates. It involves the study of design process and methods, the understanding of building energy performance, low energy strategies, energy tools and the integration of all elements.

This thesis recalls fundamental thoughts and methods from different disciplines and reiterates two basic approaches. The first is the quantification of architectural design decisions. Unachievable without advanced computer simulations, a comprehensive parametric analysis is carried out and a database is developed to replace conventional qualitative approaches. The second is an ongoing appreciation of how to influence architectural practice in favour of energy efficiency.

The thesis proposal has no preconceived ideas in relation to the different design methods and practice. It attempts to support such methods as far as possible. Indeed, the approach is comprehensive and the results can be extended to different designers: architects with different levels of experience, energy consultants and architecture students.

DECLARATION

I declare that the work presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the text. It has not been submitted, either in full or in part, for a degree at any other university.

Aldomar Pedrini

June 2003

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1 Introduction

The energy consumption of buildings is a crucial design issue due to global warming, cost and availability of energy. New buildings are marked with 'green' labeling, new energy performance codes are in constant development to eliminate bad practices, and there is a growing awareness that the early stages of design involve the most influential design decisions. However, after four decades of development, software packages which calculate an energy performance are still underutilized in the majority of architectural offices. Perhaps there is a mis-match between the nature of the tool and the potential user. Efforts have been made in different disciplines to rectify this problem but it seems that there is no single solution. This thesis addresses this polemic issue through an analysis of the integration of low energy strategies with the early stages of design process. Its aims are the identification of obstacles to energy assessment plus alternatives to improve the process. In conclusion, a method is proposed to quantify, as accurately as possible the impact of architectural design on energy consumption, specifically limited by type of building and climate: office buildings in Brisbane.

Motivation

This research is motivated by previous experiences training architects and engineers to use energy tools and the assessment of building designs. Software packages such as DOE2 became a common resource in LabEEE, LMPT and LabCon[1] in the last decade. After some years researching modelling and calibration, assessment methods were developed. The first trainees came from PROCEL, a Brazilian program developed to avoid wasting of electricity in commercial buildings. Subsequently, traineeships were extended to other professionals, such as air conditioning system designers, energy consultants, postgraduate students and researchers from other universities. At the end of three years, more than one hundred professionals had been trained. It was observed that mechanical engineers, usually the designers of air conditioning, were highly receptive to the methodology and the software. In contrast, architects who lacked expertise in building energy performance had demonstrable difficulties getting used to the software environment. Furthermore, the architects were too concerned with the representation of the building geometry, making them uncomfortable with an apparently simplistic model. Meanwhile, other issues with more influence on building

[1] Laboratory of Building Energy Efficiency (LabEEE) at the department of Civil Engineer, Laboratory of Porous Media (LMPT) at the department of Mechanical Engineering and Laboratory of Comfort (LabCon) at the department of Architecture are laboratories at the Federal University of Santa Catarina, Florianópolis, Brazil.

performance were unobserved by them. This was disturbing because these tools are also intended to support design developments. Discussions then lead to an intention to develop a smart and interactive graphic interface: the software would assist a sequence of modelling based on the previous variables and their influence on energy performance. This proposition became the impetus for this thesis: the development of an interface for energy tools orientated to the design process.

Other factors influenced the focus on the architectural design process. Early collaborations with architects were unsatisfactory. On one hand, due the advanced stage of the designs our recommendations were limited to building services rather than the architectural design. On the other hand, we consultants never prepared an architecturally-oriented briefing or parametric analysis for the pre-design and schematic phases. Obviously, the synergy could be improved.

Identification of problems

Paradoxically, energy tools are under-utilized in the early stages of design, although the first sketches embody the most influential architectural design decisions. Energy tools are software packages that make it possible to calculate the building energy performance with results far more accurate than other methods of estimation. Despite apparently incomparable capability to assess architectural design decisions, these tools seem somewhat incompatible with architects. In practice, energy tools tend to be used by engineers to assess detailed designs (and real buildings) and consequently to support decisions related to the building services. Such tendency is also related to the characteristics of modelling. Models demand reasonable detail and many defined variables, which makes it easier to assess a detailed design than a rough sketch design. Indeed, it is rare to find a design process supported by energy tools and/or energy consultants during pre-design and schematic phases because peer influences and other qualitative inputs are more popular and accessible. For these phases, energy tools provide parametric analysis; the simulation of many models. This process is highly time consuming, requires more effort to execute than a detailed design assessment, and demands careful choice of characteristics not yet decided by the architect. Obviously, they are incompatible with tight time schedules for the early stages of design.

Aim

This thesis aims to create knowledge leading to the improvement of a building's energy performance based on the integration of low energy strategies with the early stages of design. Since the first thesis draft, my approach had matured due to contact and discussion with architects. The focus moved slightly from 'development of the features of energy tools' to 'architectural design decisions and their impact on energy performance'. This meant a shift to an appreciation of the architectural mindset, prerequisite to my development of a tool fitting the architects' purpose.

Thesis structure

Fig. 1-1 sets out the sequence of literature review, research method, results and conclusions. The literature review starts with an introduction of issues such as context, variables and classification related to building energy performance.

Next, the conventional design process is framed by theoretical representations and the design process in professional practice is organized by phase. Architects' usual approaches to bioclimatic and low energy strategies are reviewed. Procedures to increase the building energy efficiency are listed for the three main phases of the design process: pre-design, schematic and detailing phases. Energy tools are then reviewed. The literature review finishes with a series of comments and hypotheses, which form the base of the research proposal.

The research targets three main areas. Firstly, the architects' behaviour is surveyed through questionnaires: four groups of architects are assessed to find out how they produce the conventional and 'energy efficient' designs. Secondly, three case studies of the design process with emphasis on energy efficiency are assessed from within (the author being an 'energy consultant'). Thirdly, approximately 36 000 models are simulated for a parametric analysis, and influence of architectural design decisions on the building's energy consumption is quantified. Each approach is followed by observations and conclusions. As an outcome, a tool to support design decisions is proposed.

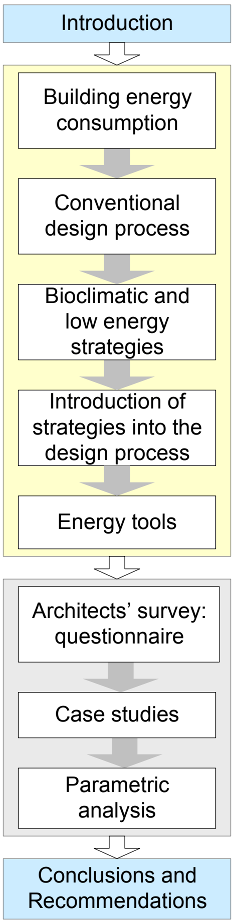

Fig. 1-1. Thesis structure.

The final chapter draws conclusions from the three areas targeted and recommends future developments.

Contribution to the knowledge

This thesis builds on disciplines developed in the last half century: bioclimatology emerged in the 50's, design process research had its apogee in the later 60's, low energy strategies arose in the 70's and parametric analyses are available since the advent of computers in the 80's. This thesis recalls fundamental thoughts and methods from these disciplines and reiterates two basic approaches. The first is the quantification of architectural design decisions. Unachievable without advanced computer simulations, a comprehensive parametric analysis is carried out and a database is developed to replace conventional qualitative approaches. The second is an ongoing appreciation of how to influence architectural practice in favour of energy efficiency.

Considerations

The study of design process assumes that the architect always manages the design process and oversees all sorts of decisions; the architect is an agent acting in the clients' interests.

There are many meanings of the term 'efficient', but here it is exclusively used to express the rational use of electrical energy. For example, productivity and occupancy are not considered.

Richard Burton[2] (Lawson 1997) stated in 1979: '*energy in building has had something of a fanfare latterly and maybe it will have to continue for some time, but soon I hope the subject will take its correct place among the twenty other major issues a designer of building has to consider*'. This thesis deals exclusively with the energy performance issue and assumes that the architect, based on his/her priorities and understanding of the subject, will define the '*correct place among the twenty other major issues*'.

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[2] Burton established the first ever energy policy for the RIBA (1979).

2 Literature review

2.1 Introduction

Todesco (1998) traces a changing of habits in the 20^{th} century, when architectural strategies used to guarantee thermal and lighting comfort were replaced by new technologies, such as the fluorescent lamp and air conditioning:

'Since HVAC (Heating, Ventilating, and Air-Conditioning) *equipment and fluorescent lighting could satisfy comfort needs, architects could pursue unrestricted designs without making comfort part of the architectural design.... With the freedom to pursue the architectural design as a pure art form, the architect created a design and then passed it on to the mechanical and electrical designers to "fit" the equipment needed to achieve comfort. The design process that at one time integrated all design disciplines evolved into a sequential process. The usual interaction between mechanical designers and architects no longer occurred, which severely handicapped each discipline's ability to contribute to the overall design. The result was buildings that were not designed to coexist with the weather and were costly to operate.'*

Oil crises, Greenhouse effect, cost of energy, ecological attitude and other factors are influencing a change of habits again. The most obvious justification must be the lowering of costs as a result of decreasing energy consumption in the operation of the buildings (Hamzah and Yeang 1994). For example, energy utilization is one of the top seven most influential factors on rental (the other six are: location, period of construction, height and density, car parking and distinctiveness), observes Lim (1994). To argue the importance of promoting more comfortable buildings, which are integrated with the environment, is fashionable. For all these reasons, efficiency improvement is an object of research in many scientific fields and, in the last decades, it is associated with the rational use of energy resources and minimization of the greenhouse effect due to CO_2 emission.

Buildings are responsible for a significant parcel of CO_2 emission due to electrical energy consumption, especially office towers. Indeed, office and public buildings have more potential to reduce the energy consumption and CO_2 emission than other type of buildings, if the architect applies low energy strategies during the design.

There are other secondary reasons to improve the energy performance. Office buildings are not so highly influenced by microclimate as residential buildings, due internal heat generation. Consequently, many regions can share similar methods for an efficient building design. Office buildings also have a 'global' language in terms of architecture; it is possible to cite examples of regional house style, but not regional skyscraper style. Another incentive for studying office buildings is the standard characteristic for occupation schedule; the effect is enormous if we consider the reduction of the number of assumptions to model and simulate buildings behaviour. The multi-storey is the chosen type of building because it has the main elements of office buildings, but the influence of the ground and the roof is minimal. Basically, this type of building aims to intensify the site use, adding more people and more activities in a restricted place; to maximize the internal area on each floor (net areas) and to maximize the gross floor area for the site.

The direct benefits of energy efficiency improvement are (WorldBuild 2001):

- first cost savings in construction through reduction of system requirements, loads and materials efficiencies;
- benefits for the developer: higher tenant rent, including rental rates, faster lease-up and increased tenant retention;
- enhanced building operating performance and annual operating cost savings (energy, water & waste);
- increased building loan potential due to higher building net operating income
- optimisation of employee health and productivity, reduction in building occupant related illness liabilities[3];
- increased building value and return on investment;
- increased public relations and community support;
- increased local job creation;
- investment tax credit possibility (specifically for States of California and New York legislation).

The indirect impact on society is *'reductions in future energy supply capacity requirements, improved awareness of energy efficiency throughout the building industry and export opportunities and increased local demand for manufacturers or suppliers of energy efficient products and services'* (Drogemuller, Delsante et al. 1999).

[3] '*Energy efficiency improvements often mean having non-operable windows, which does not necessarily increase user satisfaction or illness liability. Often the reverse*' (Carruthers 2003).

2.2 Buildings

Buildings have a significant share in the world energy consumption and associated greenhouse effects, as Balcomb (1998) reports: '*buildings account for 30% to 40% of world energy use, 25% to 35% of greenhouse gas emissions, and 50% to 70% or world electricity use'*. Gartner and Haves (1999) affirm that 4.6 million commercial buildings in the USA account for approximately one sixth of total material energy consumption and 32% of total material electricity consumption. In terms of evolution, the electricity consumption has doubled in the last 18 years and can be expected to increase by another 25% by 2030 if current growth rates continue. Further, the authors state that *30% improvement in energy efficiency can be realistically achieved in the coming decades by applying existing technologies. Even more dramatic improvements – ranging from 50 to 80%- could be achieved with aggressive implementation*.

In Australia, the operational energy in buildings of the residential and commercial sectors is approximately 16.5 % of total end-use energy[4]; 51.8% of electricity generated is directed to buildings and associated uses and a significant proportion of this is used for lighting, heating of water and space heating and cooling (Ballinger, Prasad et al. 1995). In 1990 the building sector was responsible for 21% of the total greenhouse emission and 28% of the energy-related emissions; the residential sector contributed 60% of the total building sector and the non-residential sector contributed the other 40% (Drogemuller, Delsante et al. 1999). Most recent Australians reports show increasing importance of buildings. Energy use in buildings accounts for almost 27% of all energy related greenhouse gas emission. (ABCB 2001i).

2.2.1 Building sectors

The residential and commercial sectors have different emission patterns, due to different energy end-use (compared in Fig. 2-1 and Fig. 2-2). In residential buildings, the electrical appliances are the dominant cause of CO_2 emission (51%) and climate control has a lesser share (13%). Commercial buildings have the opposite characteristic: plug-in equipment causes only 12% of total CO_2 emission, lighting causes 21% and climate control causes 63%.

[4] As most of this is electricity, in primary energy terms this ratio would be over 25%.

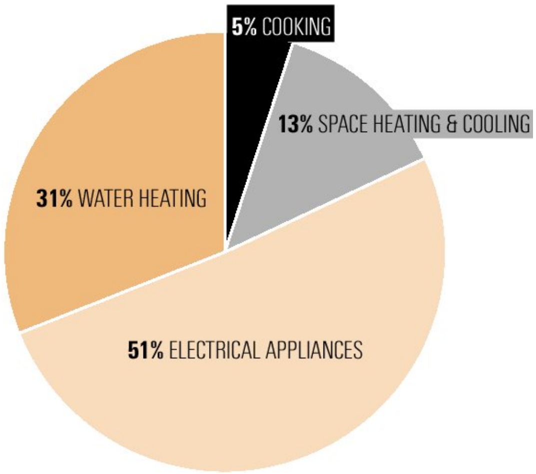

Fig. 2-1. Residential building greenhouse gas emission share by end use 1990 (Drogemuller, Delsante et al. 1999)

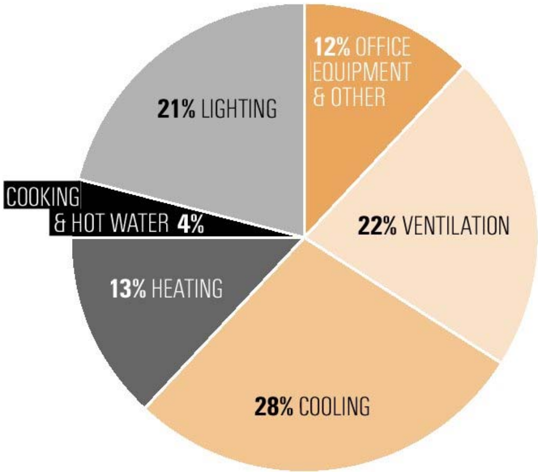

Fig. 2-2. Commercial building greenhouse gas emission share by end use 1990 (Drogemuller, Delsante et al. 1999)

The influence of the architect on building thermal performance is generally paramount. In the residential sector, the appropriate design determines thermal comfort (probably because there is a low air conditioning saturation). In the commercial sector, due an extensive use of air conditioning and artificial lighting, the effects of the envelope design are associated with the energy consumption of the systems and subsystems.

Based on the nature of causes of CO_2 emission share by end-use (Fig. 2-1 and Fig. 2-2), it is reasonable to conclude that the architect has more impact in the commercial than in the residential sector.

The analysis of multi-storey office building can also be extended to another type of building that shares similar architectural style and type of use: public buildings. The ‘Australian Commercial Building Sector Greenhouse Gas Emissions 1990 – 2010’ (EMET Consultants Pty Ltd and Solarch Group 1999) indicates that finance & business, plus public administration are responsible for 53% of the total emission, Fig. 2-3.

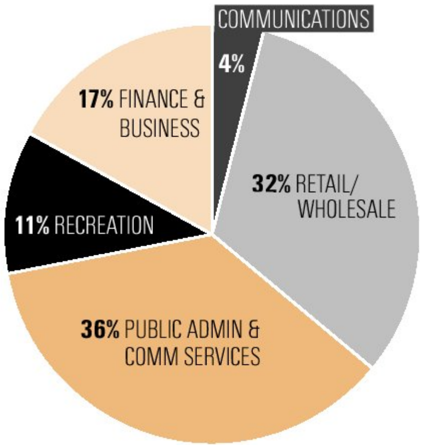

Fig. 2-3. Commercial building greenhouse gas emission share by sub-sector 1990 (EMET Consultants Pty Ltd and Solarch Group 1999).

In terms of building type, the 'office' is responsible for an estimated 27% of total sector emissions and the 'public' type is for another 12%, Fig. 2-4. Offices and a segment of public buildings have similarities that allow a common treatment under energy performance parameters, as suggested by the 'Model Technical Specifications for Commercial and Public Buildings' (Sustainable Energy Authority Victoria 2000). Consequently, it becomes the most influential type of building.

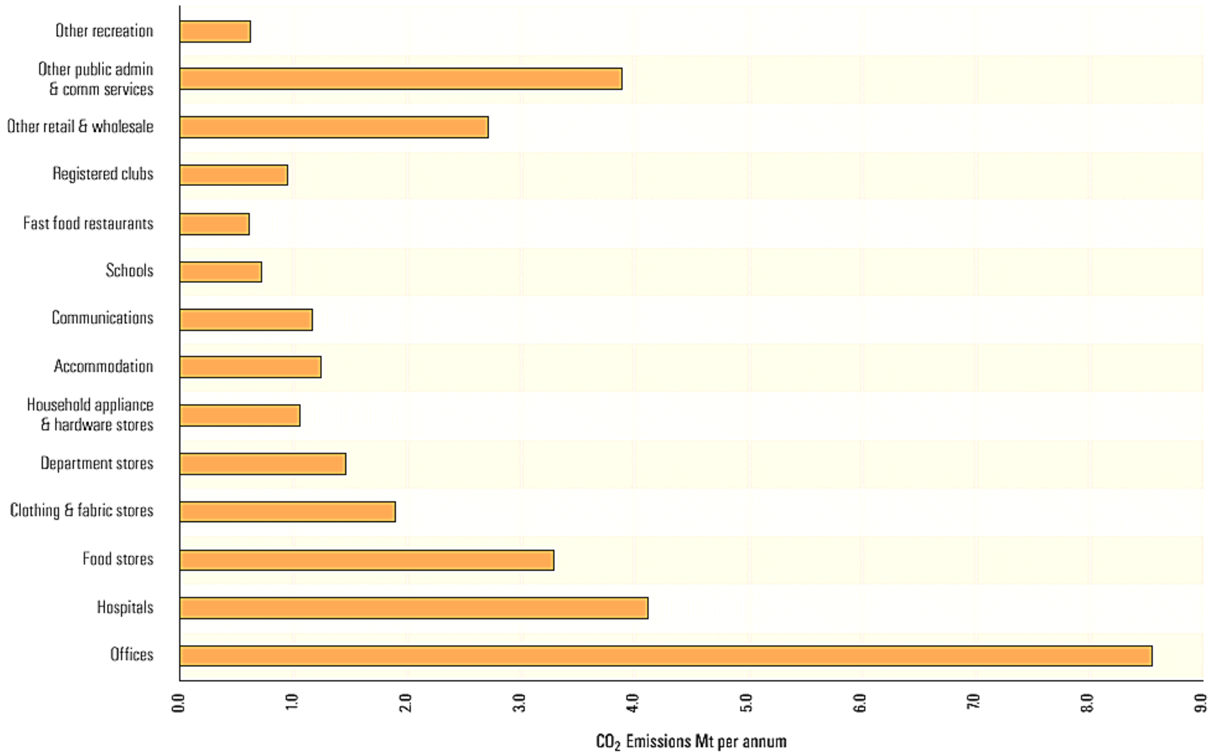

Fig. 2-4. Commercial building greenhouse gas emissions by key buildings types 1990, in Australia (EMET Consultants Pty Ltd and Solarch Group 1999)

In the view of the Sustainable Energy Building and Construction Taskforce Report (Sustainable Energy Building and Construction Taskforce Report 2001), the targets that Australia committed with the Kyoto Protocol were seen as generous, particularly, to those developed nations who made commitments to reduce emissions to 5 per cent below 1990 levels by 2010:

'*Australia's national undertaking was to limit growth in emissions by 2008-2012 to only 8 per cent above 1990 baseline levels. While estimates vary, it is now recognized that achievement of this target will require a reduction in total emissions of some 30 per cent on 'business as usual' projections of growth for the period 1990 to 2010, or some 100 million tones of carbon dioxide equivalent gases….At present, Australia's commercial buildings sector is not even sufficiently geared up to contribute equitably to the national target. A possible goal that has* *been discussed for the non-residential building sector is a 30 per cent reduction on a level of growth which itself represents a doubling of 1990 levels by 2010. Achieving this apparently small step calls for substantive action and investment, which requires the commercial sector to move beyond a 'no regrets' mindset and scenario.*' Based on international best practice, the Taskforce believes that very significant reductions in energy consumption can be achieved now, without reducing amenity or increasing whole of life costs.

As an example, the California State Automobile Association (CSAA) Headquarters Building Project, California, demonstrates overall energy savings of 70 per cent below the current California Title 24 Code by combining efficiencies from both active and passive systems (equivalent approximately to a SEDA 2 Star Rating), Fig. 2-5.

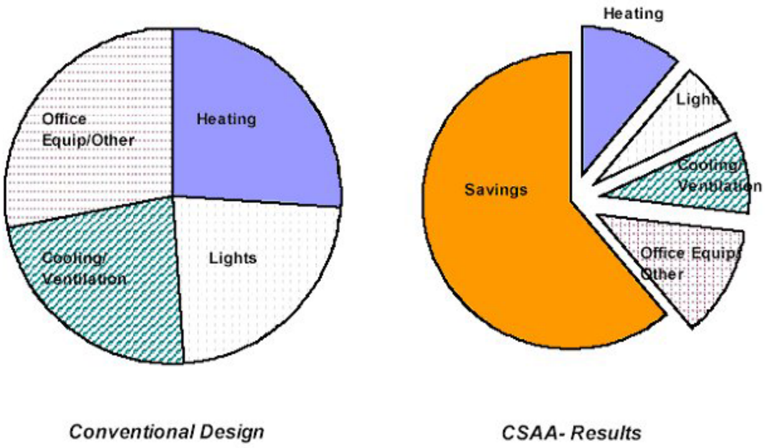

Fig. 2-5. Example of 70% energy saving (Sustainable Energy Building and Construction Taskforce Report 2001)

Considering the nature of lighting and thermal loads, the influence of envelope design on the commercial building performance is evident. This is a result of a balance between daylighting and heat transfer. The Energy Smart Building Design, subchapter Architectural Issues (Sustainable Energy Authority. 2001), recognizes the potential: '*a well-designed envelope can reduce energy costs by up to 50%*'. Kearney (2002) affirms that building can achieve at least a 20% reduction in energy consumption by fairly simple changes. Specifically, Rivard et al. (1995) recognize the obstacles: over 50% of building deficiencies are due to the envelope. Rivard et al. argue that the main reason is the lack of communication and coordination throughout the envelope design process between the involved professionals.

2.2.2 Building behaviour

Baird (1984) observes that the concept of building performance can be approached from several directions and buildings can be examined from a variety of viewpoints. In terms of energy, there are three basic factors that interact and determine the overall performance: building fabric, building services and building occupants. Although energy can only be measured in systems and subsystems, and they are responsible for the energy consumption in a building (Balcomb 1998), the building fabric is also partly responsible for the energy consumption. Due to the high complexity of the interactions, it is practically impossible to quantify the influence of each factor and any estimate must be taken as guesswork based on experience and applicable only for a very specific condition.

In the Building Energy Brief for Commercial & Public Buildings (Taylor Oppenheim Architects et al. 2000) there is a suggestion for Australian office and public buildings (Fig. 2-6), which attributes 25% to the building fabric.

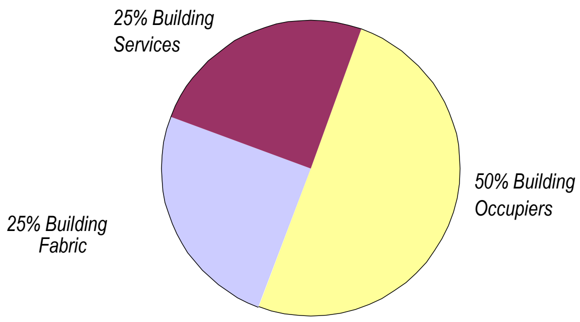

Fig. 2-6. Influencing factors (Taylor Oppenheim Architects, Lincolne Scott Australia et al. 2000)

Field studies have shown that energy consumption can vary by a factor of up to 10 between the best and worst performing buildings of a similar type. Within this range, construction related factors (e.g. orientation, form, fabric etc.) can have a variance of 2.5, system related factors (e.g. lighting, A/C systems and equipment etc.) 2.0 and people related factors (e.g. use, misuse, operating and maintenance etc.) also 2.0 (Sustainable Energy Authority Victoria 2000).

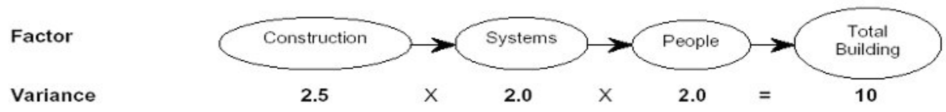

Fig. 2-7. Influencing factors energy efficiency (Sustainable Energy Authority Victoria 2000).

Baird (1984) argues the human factor has less effect in office buildings due to the high level of automatic control and sealed envelope, but still has a key role in setting the controls. On the other hand, in buildings with personal AC and heaters, opening windows and task lighting the human factor can become the major influence on energy consumption.

In a more detailed attempt to trace energy consumption in buildings, Baird (1984) describes a model proposed by Brander[5] (Fig.2-8), in which the energy systems are equivalent to building services, non-energy systems are equivalent to building fabric and human systems are equivalent to building occupants. Baird (1984) suggests that the behaviour of occupants determines the effect of non-energy systems on energy systems, such as the drawing of curtains or the lighting switch: *'maintenance procedures determine the degree to which plant and controls operate efficiently and as intended, and how nonenergy systems will affect energy use'*.

The energy relation among the three systems is represented as intersections in the Fig.2-8:

1. energy flows between the building fabric and the building services (4), such as solar gains, thermal conduction and air infiltration;
2. direct controls (5) such as thermostats, valves and time switches to tune how much energy is desirable to extract or provide in the building services to satisfy the occupants necessities;
3. indirect controls (6) such as window opening and curtains to control the quantity of energy gain by the building fabric.

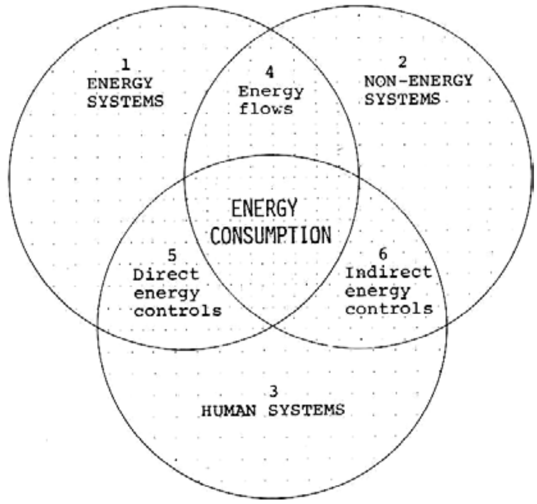

Fig.2-8. Brander's model of the interaction of energy, nonenergy and human systems (Baird 1984).

Although Brander's model is discussed only in broad terms, some comments can be added. The recommended strategies for the item 4 are chiller plant design to suit the profile of thermal loads and not exclusively the peak thermal loads; use of enthalpic control to modulate the rate of air renewal and use of nocturnal ventilation to cool the building. Additional strategies to item 5 are controlled air movement to raise the cooling set point and use of variable air volume as secondary part of the system.

[5] Brander, W. D. S., Energy Conservation Strategies for University of Canterbury, M.Sc. Research Project Report, University of Canterbury, Christchurch, 1980.

As an illustrative example for the Lecture to RAIA in Brisbane (Hyde and Pedrini 2001), eight hypothetical models were simulated combining efficient and not efficient envelope with efficient and inefficient building services with efficient and inefficient occupant behaviour. Using a classification based on CO_2 emission and represented by star rating (Exergy Group. 1999), the eight combination results are presented in Table I.

The results show that an efficient building can only reach the highest performance (5 stars) if the architect designs an efficient envelope. On the other hand, buildings with mediocre designs can also be very efficient (4 stars) due efficient building services and conscious use by occupants; obviously, the performance will be limited by the design. Although this exercise is not a rigorous representation of the reality, it does help to highlight a potential mistake among architects: to follow as an example the design of a building which performs reasonably well, although this is due to good services and well-behaved occupants and not to the building itself. In terms of efficient building, the architect's intervention is the major influence to reach efficient buildings because it increases the potential to save energy through the efficient envelope design. Furthermore, it is smarter than other interventions because it can be cheaper. It is highly desirable for the architect to be conscious of the building services and future occupants' behaviour, but the envelope design comes first in an order of priorities. Indeed inefficient building services may be replaced and occupants can be trained, but it is difficult to change the envelope.

Table I: Building energy behaviour.

Envelope	Building services	Occupants	CO_2*	Star
Good	Good	Good	50	☆☆☆☆☆
Good	Good	Bad	92	☆☆☆
Good	Bad	Good	91	☆☆☆
Good	Bad	Bad	120	☆☆
Bad	Good	Good	83	☆☆☆☆
Bad	Good	Bad	117	☆☆
Bad	Bad	Good	232	0
Bad	Bad	Bad	418	0

*annual CO_2 emission ($kgCO_2/m^2$), based on Queensland/ Australia energy-greenhouse factor Index of performance:

one star: poor energy management or outdated systems; two stars: average building performance; three stars: current market best practice; four stars: strong performance; five stars: best building performance.

2.2.3 Energy design guidelines for new buildings and refurbishments[6]

Energy efficiency is often assumed when constructing new facilities or refurbishments, but it is seldom delivered. Motherhood energy efficiency briefs may be given to the Project Manager, but unless such a requirement is enforced, it is rarely provided.

Energy efficiency is essentially a question of quality. A well designed, well constructed, well commissioned and well operated and maintained facility will be energy efficient. Conversely, the energy performance of a completed facility is a good performance indicator for the quality of service the facility provides. An inefficient plant and equipment is often ineffective.

The key to energy efficiency is accountability for energy consumption through all phases of project delivery - from design through to operation. The BOMA (Property Council of Australia) "Energy Guidelines" indicates a commercial building designed for low energy consumption can use 50% less energy than a typical commercial building.

Sustainable Energy Authority has produced "Guidelines for the Energy Efficient Design and Construction of New Buildings and Refurbishments". The guidelines deal with the planning aspects of new projects, and contain consultant-briefing clauses in a form readily incorporated in documentation. Sustainable Energy Authority also has "Guidelines for the Energy Efficient Maintenance of existing Facilities" which is an energy management scope of work to be incorporated in a maintenance specification. Both guidelines contain separate specifications for both a prescriptive and performance based scope of work. The prescriptive scope of work would normally be applied.

The prescriptive scope of works, for the construction of new buildings and refurbishments, includes:

- enlist the services of an energy engineer;
- establish energy design targets, and design criteria;
- assess energy consumption and cost implication of various design options;
- provide detailed life cycle costing of various design options;
- submit an energy impact statement;
- test and commission completed project;

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[6] http://www.energyvic.vic.gov.au/govt/esgisgud.htm, 21/06/00

- provide maintenance strategy.

The key requirements of the guidelines are:

1. Integrated whole of life approach
2. Design
3. Construction
4. Operation and Maintenance
5. Energy accountability
6. Design Targets
7. Energy Impact Statement
8. Reporting actual consumption

Inclusion of an "energy engineer" in the project team, either engaged by the construction manager, the project manager or directly by the principal, helps ensure an energy efficient outcome. The brief for the "energy engineer" may be merely a watching brief or may involve more detailed design input and building energy computer simulation. The "energy engineer" makes energy consumption more accountable throughout the project life cycle, and at the same time assists optimizing the amenity of the completed project by ensuring a high quality outcome.

The current tendencies to improve energy efficiency define a sort of strategies, which relate to different areas. Some of them are beyond the aims of this study, while others are explored with different level of details. This variety is observed in the Gartner and Haves (1999), who suggest that technology changes are important but not enough to make buildings significantly more efficient. The authors state the other three key elements: '

- *clear performance metric that makes a compelling economic case for and help define high-performance commercial buildings;*
- *changing the process by with building planning, design construction, and operation and maintenance are conducted – enabling a collaborative whole-building approach;*
- *market transformation, to overcome the current lack of demand for high-performance commercial buildings.* '

2.2.4 Performance criteria and energy codes

Energy performance criteria are elements by which codes specify or measure energy efficiency in buildings. Codes differ as they are associated with characteristics of each city, region and country, such as climate, culture, technological level and others. The International Survey of Building Energy Codes – Executive Summary (Office of the Australian Building Codes Board, CSIRO Building Construction and Engineering et al. 2000) reports different regulatory approaches:

- performance approach;
- prescriptive approach that usually uses a multi-tabular format (probably similar to a check-list);
- trade-off approach that compares a notional building complying with the prescriptive tables with a proposed building and it usually trades between envelope thermal insulation elements and may allow trading to take into account heating and cooling systems;
- energy rating approach that compares a notional building to the proposed building on an energy consumption or cost basis.

The survey recognizes that the Canadian and USA codes for public and commercial buildings have multiple methods, procedures and option paths, and appear complex. Most overseas provisions for envelopes in large buildings are complex but are considerably simpler for smaller commercial and public buildings. The more complex approach gives a range of options for the performance of all envelope elements as the window area increases. All performance and prescriptive codes require specialist energy expertise for use and assessment of compliance. The comparative survey is summarized in Table II.

As emphasized, building performance depends on the interaction of three components and each must be considered. Some designs of engineering services are already regulated in mandatory laws and codes, such as AS 1668.2 (Australian Standard. 1991) for ventilation and the DR 00178 (Standards Association of Australia 2000) for minimum energy performance requirements for ballast in fluorescent lamps. The Energy Committee of BOMA Victorian Division (1978) suggests that it is possible to deal similarly with building fabric design, legislating for building design by specifying the use of particular materials, ratios of glass area to solid wall. A similar proposition is already available in the standard proposed by ASHRAE (1999). It is often referenced in many codes in the USA and Canada. It intends to provide minimum requirements for the energy-efficient design, except low-rise building. The standard provides minimum energy-efficiency requirements for the design and construction of buildings and their systems, and criteria for determining compliance with the requirements. The provision applies to the envelope of buildings, to HVAC (heating, ventilation and air conditioning), service water heating, electric heating, electric motors and lighting.

Table II. Summary of commercial and public building provisions (Office of the Australian Building Codes Board, CSIRO Building Construction and Engineering et al. 2000).

Country	Performance v Prescriptive	Building Envelope	Space Heating or Cooling	Lighting	Exemptions
United Kingdom	Performance	Minimum R rating	Yes	Yes	Small extensions <10m², buildings with no heating or cooling
United States	Prescriptive	Calculation of U values or compare to reference building	Yes	Yes	Buildings with no heating or cooling
New Zealand	Performance	Minimum R rating or compare to reference building	No	No	Buildings with no heating or cooling and <300m²
Canada	Prescriptive	Minimum R rating or compare to reference building	Yes	Yes	Farm buildings, small buildings <10m²
ACT	Performance	Minimum R rating for Class 2 and 3 only	No	No	N/A
South Australia	Performance	No	No	No	N/A
Victoria	Performance	Minimum R rating for Class 2 and 3 only	No	No	N/A

The ‘Scoping study of minimum energy performance requirements for incorporation into the building code of Australia’ (Drogemuller, Delsante et al. 1999) proposes four methods for demonstrating compliance with energy efficiency provisions for buildings. The recognized easiest to apply is the ‘elemental requirements’, which matches the previous ASHRAE standard. The second is the system performance measures for the building envelope, the lighting system, and the HVAC system, which is usually a single index, calculated using a relatively simple formula. Whole-building simulation is the third one and consists of modelling a building and simulating its performance. The designers change the model until it reaches satisfactory performance or until ‘minimum performance level’ is reached. The last proposition is the expert panel opinion and it is used when the other methods cannot handle the problem.

2.3 The design method

Many authors recognize that the best opportunities for improving a building's energy performance occur early in the design process (Goulding and Lewis 1992). The same way the design process offers a structure to ordinary commercial commitments, the process analysis also provides a structure that can address the most important questions for an energy conscious design, identified early by Burberry (1978):

1. What design decisions involving energy must be made?
2. What is the importance of each decision?
3. Who should make these decisions?
4. At what stage of design must the decisions be made?
5. What data are available to guide thermal decisions?

The answers can only be produced after an understanding of the building and climate interaction, but the answers start with the design process investigation, as follows.

2.3.1 Design theory

The sixties and seventies decades provided the main contribution in design process research when the available methods were analysed and others were created using scientific theories. Nowadays, in comparison with that period, such methods have little impact. The break in design theory leads Heath (1984) to the statement *'the total history of design methods, as a recognised subject with an impact on architecture, covers only about fifteen years'*. It starts with the Oxford Conference on Design Methods in 1963 and ends in the late seventies with the second-generation methods. Heath (1984) analyses the subsequent history and confirms the hypothesis that their application to architecture is in some ways limited.

The literature review confirms Heath's opinion and shows other ones. Firstly, there is a 'considerable' break in publication after the seventies. Secondly, there is no clear evidence that any theory reached success or was well accepted in practice. Thirdly, the subject is complex and demands more than this thesis proposes to explore. In view of these facts, this chapter aims to expose the most discussed ideas and tendencies, in a chronological order of publications.

Broadbent (1966) introduced the design method classification in his lecture notes:

1. Classic. The designer starts with an 'image' or icon of what the building is going to look like. The design begins with a generalized brief, a schedule of accommodation and a site plan.
2. Canonic. The designer starts with the same steps as the previous, and proceeds to organise the building formally by one or more of the following devices: topological, juxtapositional and geometrical (a grid may be used to represent the chosen CANON of proportion).
3. Cartesian Method. The design problem is broken down into its smallest elements and each element is designed separately.
4. Functional. It attempts to improve the previous methods by stressing technical aspects of design, such as structure, services, assembly and geometry.
5. Analogue. "*Imhotep (c 2860 BC) and others translated the iconic forms of temporary mud and reed structures into stone, for ritual purposes. This was designed by ANALOGY and there are strong indications that the actual process of translation was achieved by the use of drawings as intermediaries or design ANALOGUES."* However, Broadbent believes *"the drawn analogues tend to 'take-over' from the designer, he is seduced by the excellence of his own sketches*". For this reason, the author suggests the use of diagrams and charts for the analysis of design problems and a route for a typical 'analogue' process:

   - determine functions of building;
   - list activities to be performed therein;
   - prepare data sheet for the activity;
   - prepare flow charts showing sequential relationships between activities;
   - prepare interaction charts showing functional and/ or environmental relationship between activities;
   - prepare connections diagrams from interaction charts;
   - prepare analysis of site;
   - manipulate connections diagrams topologically in accordance with the nature of the site.

6. Environment[7] process. It resembles the ‘analogue’ process, but the investigation is more fundamental: ‘the building is seen as an envelope, which modifies the indigenous climate offered by the site so that certain human activities are housed in comfort’. The author suggests an ‘environmental’ structure:

   - determine the functions of building and relationship to community as a whole;
   - list activities to be performed therein;
   - prepare data sheet for each activity;
   - prepare flow charts showing relationships between activities;
   - prepare ecological analysis of site;
   - prepare environmental matrix of site;
   - determine critical activities;
   - locate less critical activities around these, with reference to flow charts;
   - plot spatial divisions around activities;
   - analyse the distribution of loads from activities;
   - consider the need for external cladding, internal space division etc according to environmental standards required;
   - evaluate building ‘shell’ by ‘analogue’ testing and check environmental performance against specifications needs;
   - determine quantity of internal finishes with reference to environmental needs;
   - re-cycle as necessary.

7. Symbolic: ‘Alexander’. It avoids the seduction by sketches and it tries to translate design problems into abstract and mathematical terms.
8. Symbolic ‘Linguistic’. It is concerned with the fine shades of meaning which individuals or groups attach to particular concepts, such as:

   - the meaning of the building itself for the client, users, architect and others;
   - provide relationships between activities within the building and the surrounding environment.

[7] At this time, ‘environment’ refers to interior building conditions.

Broadbent (1966) also proposed a classification according to attitude to design: rational design, empirical and indeterminate or cybernetic. Heath (1984) suggested classification by the method of searching:

- Recognition (‘knowing the answer’): basic procedure of unselfconscious design and the most common penultimate stage of more complex design procedures.
- Generate-and-test: involves procuring candidates for the role of ‘solution’ and then seeing whether they in fact comply with whatever tests or rules are available for determining whether or not something is a solution. This also can be interpreted as “iconic” design: a situation in which the available building types are all standardized and the designer simply selects the building type appropriate to the task in hand. The method is advantageous when the generation and the testing of solution are both easy and cheap, and the size of the solution space is not very great.
- Heuristic[8]: it searches to make use of information already obtained to guide the remaining steps of the problem-solving process; the search process is redefined as a search for information which will limit the area of search, ultimately to the point at which generate-and-test or recognition methods become practicable.

The search for morphology lead Broadbent (1966) to consider two components, which are explained by Broadbent and Ward (1969):

- the design process is the entire sequence of events, which leads from the first inception of a project to its final completion;
- the decision sequence corresponds to individual loops within this, of briefing, 'analysis, synthesis’ and so on.

As Broadbent (1966)observes, ‘*the complete design process itself may follow a sequence of events similar to the decision sequence…in other cases, the complete process may be represented by a re-cycling or looping through several such stages’*. Therefore, the author presents five main graphic representations of the sequences, as illustrated in Fig.2-9: linear

[8] Heuristic also may referred as ‘*thinking relying on the use of intuition, human feel, experience, rules-of-thumb, examples by analogy for judgement and decision making in real life condition, without normative analysis based on mathematical representation’* Bay, J.-H. (2001). Cognitive biases in design: the case of tropical architecture. Technische Universiteit Delft. Delft, The Design Knowledge System**:** 248.

(a), linear with feedback (b), looping (c) and adaptive (d). Furthermore, The Energy Research Group (1993) represents it by a spiral (e).

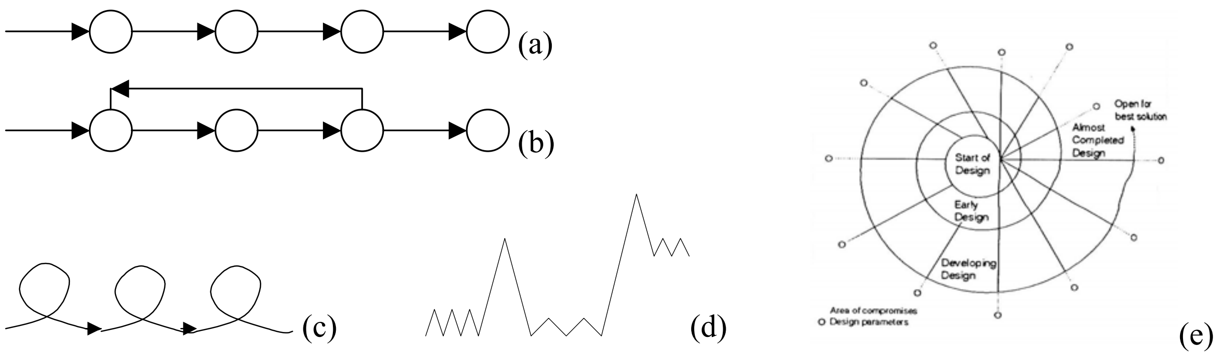

Fig.2-9. Design sequence representations.

Broadbent (1968) observed that ‘design method’ developed during the WWII when some designers felt that methods used to improve war method efficiency (such as to sink submarines) could be used to design buildings. The proposed method is basically a scientific research approach, which Bruce Archer denominated as ‘the design process’ in 1965 and proposed the graphical representation as shown in Fig.2-10 (Broadbent 1968).

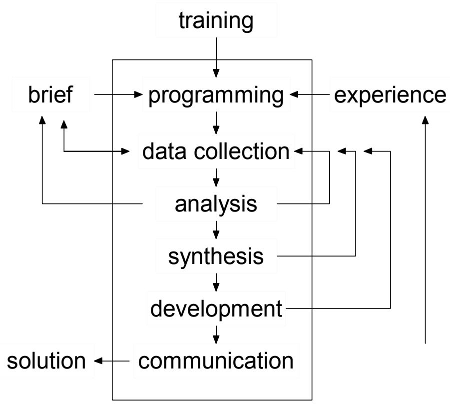

Fig.2-10. Bruce Archer’s original Design Process (Broadbent 1968).

It consists of five steps, described by Broadbent (1968):

1. briefing: in which the designer finds out what the problem is, and collects information about it (includes client’s instruction); analysis: in which the information is sorted out, classified and put into usable form;
2. synthesis: in which a variety of solutions to the problem is generated;
3. evaluation: in which the various solutions are tested, and one of them selected for development;
4. implementation: in which drawings and other material are prepared, so that the design can be put into production.

The RIBA Architectural Practice and Management Handbook had in the same year (1965), as described by Lawson (1997), a similar map, but with four steps:

- phase 1/ assimilation: the accumulation and ordering of general information and information specifically related to the problem in hand;
- phase 2/ general study: the investigation of the nature of the problem. The investigation of possible solutions or means of solution;
- phase 3/ development: the development and refinement of one or more of the tentative solutions isolated during phase 2;
- phase 4/ communication: the communication of one or more solutions to people inside or outside the design team.

Levin, in Markus (1967), breaks down the design process into eleven stages:

1. Identification of design parameters: measures of controllable causes.
2. Identification of independent variables: uncontrollable causes and effects, e.g. climate, economic state of the community.
3. Identification of dependent variables: the designer's goals; effects the designer wishes to achieve, e.g. a given environment, a level of activity.
4. Identification of relationships among parameters and variables: cause and effect.
5. Prediction of value of independent variables.
6. Identification of constraints governing dependent variables: upper and lower limits.
7. Identification of constraints governing design parameters: limits of the means by which design may be achieved; cost limits; standards; regulations.
8. Identification of value of design parameters: in any design each parameter will have a unique value.
9. Identification of expected value of dependent variables: prediction of effect of the setting design parameters at chosen values.
10. Investigation of consistency of values, relationships and constraints: sub-solutions; consistency of these with each other; optimisation.
11. Comparison of and selection from alternative sets of design parameters: using dependent variables as criteria, selecting best solution.

In a similar way, John Luckman (Broadbent and Ward 1969) represented the design process using the same decision structure:

1. Analysis: the collection and classification of all relevant information relating to the design problem at hand;
2. Synthesis: the formulation of potential solutions to parts of the problem, which are feasible when judged against the information contained in the analysis stage;
3. Evaluation: the attempt to judge by use of some criterion or criteria which of the feasible solutions is the one most satisfactorily answering the problem.

The RIBA handbook is more detailed and includes inception, feasibility, outline proposals, scheme design, detailing design, production information, bills of quantities, tender action, project planning, operation on site, completion and feedback (Broadbent and Ward 1969); (Royal Institute of British Architects. 1973), Table III.

Table III. Outline plan of work for design development (Royal Institute of British Architects. 1973)

Stage	Purpose of work and decisions to be reached	Tasks to be done	Usual terminology
A. Inception	To prepare general outline of requirements and plan future actions	Set up client organization for briefing	BRIEFING
B. Feasibility	To provide the client with an appraisal and recommendation in order that he may determine the form in which the project is to proceed	Carry out studies of user requirements, site conditions, planning, design, and cost, etc., as necessary to reach decisions	
C. Outline Proposals	To determine general approach to layout, design and construction in order to obtain authoritative approval of the client on the outline proposals and accompanying report	Develop the brief further. Carry out studies on user requirements, technical problems, planning, design and costs, as necessary to reach decisions	SKETCH PLANS
D. Scheme Design	To complete the brief and decide on particular proposals, including planning arrangement appearance, constructional method, outline specification, and cost, and to obtain all approvals	Final development of the brief, full design of the project by architect, preliminary design by engineers, preparation of cost plan and full explanatory report	
E. Detailing Design	To obtain final decision on every matter related to design, specification, construction and cost	Full design of every part and component of the building by collaboration of all concerned	WORKING DRAWINGS

As observed by Markus[9], (Broadbent and Ward 1969), the RIBA Handbook's design process has a linear structure; the process is sequential and not iterative. Any retracing of steps from a

[9] "The role of building performance measurement and appraisal in design method".

later phase to an earlier is seen as a design failure. The importance of completing each phase before starting the next is generally emphasized. Thus each phase has an input, which is the output of the previous one. The main criticism of the linear design process is the high influence of the client and the architect to determine the main design parameters. Consequently, strategies that must be decided in the early stages of design might be underrated. Lawson (1990) also criticizes the linear structure and the logic sequence: *'It is quite difficult to know what information to gather in phase 1 (assimilation) until you have done some investigation of the problem in phase 2 (general study)'*. Furthermore, as observed by Broadbent (1968) designers could not cope with the vast mass of data they had collected and usually lapse into old unsystematic ways of designing, such as relying on their experience. Regarding the analysis step, architects prefer to concentrate on one correct solution achieved by a flash of inspiration rather than to play with many ideas in a range of solutions. The evaluation step also suffers from excessive information and can become a confusing task.

Lawson (1990) understands the RIBA Plan of Work (Royal Institute of British Architects. 1973) as a map, which can help the design understanding. The author recognizes the map just to tell the designers that they have to gather information about a problem, study it, devise a solution and draw it, though not necessary in this order. Furthermore, the RIBA handbook declares that there are likely to be unpredictable jumps between the phases. The RIBA Plan of Work is not a process description but the description of the products of the process (Lawson 1990). In this way, it may also be seen as part of a business transaction. Austin, Baldwin et al. (1999), who have an engineering background, defend the RIBA Plan of Work as the most widely used model of design process, although it just sets out the details of work to be carried out by each profession during each stage of the design process and it does not bring information between activities to indicate how particular tasks are related.

Well-known architectural associations did derivations of the linear structure presented in the RIBA Plan of Work and The American Institute of Architects (AIA 1999) proposed the design process in seven discrete phases:

1. Programming phase, setting of size, use, and budget;
2. Schematic design phase, when preliminary schemes are presented to the client for review;
3. Design development phase, when a preferred scheme is refined;

4. Construction documents phase, when the preferred scheme is comprehensively documented;
5. Bid (tender) phase, when the drawings and specifications for the project are put out for bid;
6. Construction supervision phase, when the project is inspected for conformance to contract documents;
7. Commissioning phase, when the building is tested for performance compliance; and,
8. Post-occupancy analysis phase, when building performance is verified over time.

Markus[10] (Broadbent and Ward 1969) was not satisfied with the rigid structure of design representation and he proposed integration with decision sequence. As described by Lawson (1997), Markus and Maver elaborated maps of the architectural design process (Fig.2-11) detailed in decision sequence in the stages 2, 3, 4 and 5 of the RIBA Handbook:

1. Analysis: clarification of goals; identification of problems; nature of difficulties; exploring relationships; producing order from random data.
2. Synthesis: creation of part-solutions; combination of part-solutions into consistent and feasible overall solutions; generation of ideas.
3. Development: expansion of synthesis in more detail.

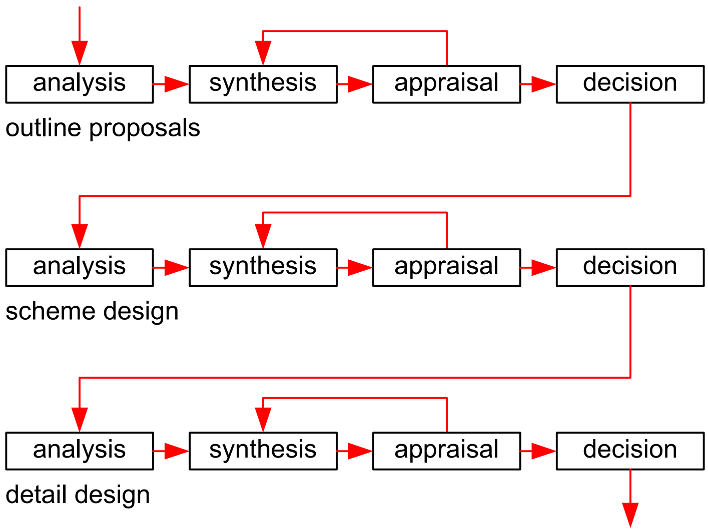

Fig.2-11. The Markus/ Maver map of the design process.

4. Appraisal or evaluation: application of checks and tests; application of criteria, constraints and limits; selection of 'best' solution from set; consistency testing.

[10] "The role of building performance measurement and appraisal in design method".

Markus (Broadbent 1966) characterizes the decision sequence by its iterative and cyclic character, which has vital feedbacks loops and demands that the task is repeated as often as necessary within the limits of design resources available at any phase.

Lawson (1997) argues how functional is the return loop in the diagram: in some cases, when the development of a solution suggests the previous step was incomplete and that further analysis is necessary. While the diagram has the tendency to begin with outline proposals to reach detail design, the same not necessary happens in reality, when designers already decided some specific questions in the early process.

Szokolay (Szokolay and Pedrini 2000) recognizes the '*analysis – synthesis – evaluation*' sequence as the kernel that leads to three different mental processes:

1. briefing, delineation of the design task, identification of constraints and factors which have an influence on the design, the 'pre-design analysis'
2. the creative leap, the birth of a design concept and
3. development and refinement of the design, with the repeated use of evaluative tools, from cost control to environmental performance, to support design decisions.

Szokolay understands the first and third processes are based on rational thinking, where scientific methods are employed and computer programs can be useful. The second process, is hard to define; it can be irrational, subconscious, intuitive and artistic: it is the '*black box'* or the '*act of creation'*.

Bamford (2001), from Department of Architecture/ University of Queensland, has a critical opinion about analysis/ synthesis (A/S) as a scientific method extended to the design process. Initially, Bamford cites the opinions of others to support his arguments:

- Broadbent: "the rational thought dominates the 'briefing' and the 'analysis' stages; creative thinking is confined to 'the 'synthesis' stage, and value judgment concerns 'evaluation' stage";
- economist A. B. Wolfe: 'creativity is banished from the early stages in science and implies it is unnecessary elsewhere';
- Francis Bacon and Rene Descartes reject the custom as a source of knowledge and reject creativity.

Referring to the statement 'analysis presupposes or depend upon a prior synthesis', Bamford refutes the illusion of universal data collection and suggests the searching for a solution starts together with the analysis. Bamford also refutes the extension of Cartesian legacy in A/S for problems solving '*problems can be dismantled and solution assembled from individually designed pieces'*, because he judges it an implausible ontology for architecture: *'in design, the whole or aspects of the whole govern the parts'*. Further, Bamford introduces Popper' theory of Conjecture/ Analysis, which inverts the views of A/S:

- the idea that scientific inquiry begins with observations or facts is false because scientific theories are putative explanations;
- there is no logic or method of discovery that will conduct anybody from observation to theory: *'scientific theories are imaginative constructions which typically go well beyond whatever they were designed to explain*';
- *'hypotheses or conjectures, contrary to the long standing Baconian and Newtonian prohibition, are indispensable to inquiry'*;
- *'science is replete with bold conjectures, and a bold conjecture is logically more likely to be false that a conservative one'*;
- Popper's statement is: *'there is no more rational procedure than the method of trial an error – of conjectures and refutations'.*

Bamford (2001) identifies derivations of Popper's theory. The first is the publication 'Knowledge and Design' (Bill **H**illier, John **M**usgrave and Pat **O**'Sullivan, or HMO), which introduced the C/A model of problem-solving as the core of design: *'design is essentially a matter pre-structuring problems either by a knowledge of solution types of by a knowledge of the latencies of the instrumental set in relation to the solution types'*. The second one is the book 'The Reflective Practioner' (Donald Schön), which located conjecture/ test at the heart of problem solving in the profession generally.

In the Department of Architecture/ University of Queensland, some teachers have an implicit tendency to prefer the Alexander of model design process. Christopher Alexander introduced the Graph Theory in 1963 (Broadbent 1968), which consists of breaking the problem down into its tiniest parts, so as to find the individual forces, the 'misfit variables' that act on each part, and to break the problem down. The graphic representation in Fig.2-12 seems to be a tree and each misfit variable is an individual twiglet in the decomposition of the problem. The first limitation of the method is the complex interactivity among variables. Even after several modifications, Alexander concluded the theory is too simple to express the complex ways in which most real design problems have to be broken down (Broadbent 1968). Furthermore, as observed by Broadbent, the method has grave deficiencies of logic and he emphasizes the following points: *'…there is no guarantee whatever that by breaking the problem down into little bits, solving each one separately, and assembling a design from these separate solutions, that the result will be any better that one conceived as a whole'.*

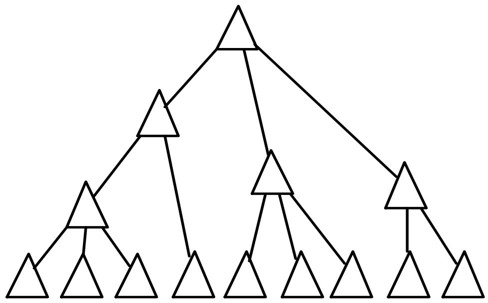

Fig.2-12. Alexander's Graph Theory (Broadbent 1968).

Sometimes simple diagrams cannot be found and the solution may be incomplete and it can distort the design in other ways. The theory supposes that the reactions are impersonal and the designs are not ambiguous.

The last referenced method for problem solving is Heath (1984) that suggests a simple method to deal with the 'black box' process. It consists of defining a solution space: '*eliminate the impossible, and what remains, however improbable must be the solution*'. Design begins with the construction of the problem space, and proceeds initially by the reduction of the boundaries of that space to the narrowest limits possible, without the space becoming negative. Heath sets up the information network and identifies the main subsystems of the organization:

- Task 1. Identification of the most constrained subsystems, since these subsystems will be less capable of adaptation and adjustment.
- Task2. Identification of the subsystems of the total system, to classify them according to their degree of constraint, or, if one prefers to look at it in that way, in order of their adaptability; this last operation may require the detailed investigation of some subsystems.
- Task 3. Generation of hypotheses. It is much more a productive than a creative process. After generating some hypotheses, they would be tested for any conflicts.

As a complementary information to the design process, Laseau (2000) refers to Horst Rittel that identified three variables of the typical design problem:

- performance variables which express desired characteristic of the object under design, and in terms of which the object will be evaluated;
- design variables, which describe the possibilities of the designer, this ranges of choice, his design variables;
- context variables, which are those factors affecting the object to be designed but not controlled by the designer

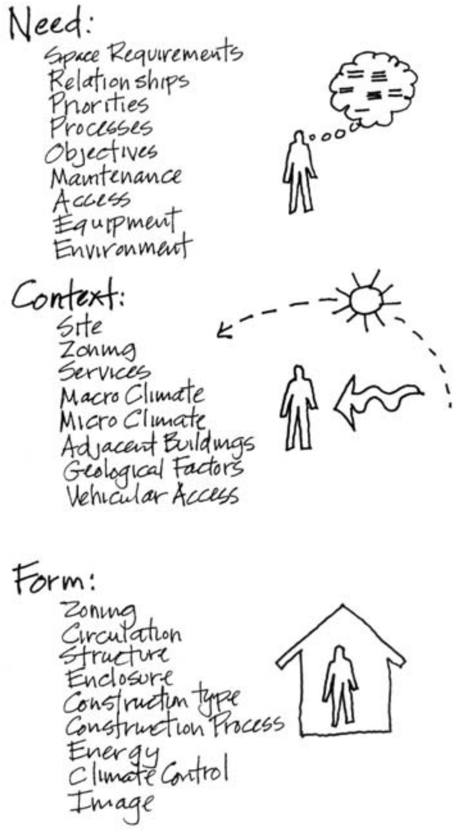

Fig. 2-13. Design project information organized by major design variables (Laseau 2000).

The last topic of design method is the design maps, which are helpful to represent some further proposals. Lawson (1997) is the first one to agree that design maps have a considerable degree of agreement (in theory), although there is no evidence that designers actually follow their maps. These are more a result of thinking than a result of experimental observation. Even the most used map, the RIBA Plan of Work, is not complete because it does not bring information about the links between activities. However, Austin, Baldwin et al. (1999) have combined the level of detail in the RIBA Plan of Work with information 'links' to achieve in-depth models of the different stages of the building design process using data flow diagrams. Data flow diagrams enable a model to be devised at the overview level, and then decomposed to reveal finer detail. Among many modelling methodologies, the authors opted for IDEF0, which is a derivation of IDEF (Integrated DEFinition Language) that was created in the 1970s for use in the US aerospace industry, to improve communication and analyze manufacturing in an attempt to improve productivity. First, the authors did little changes to the IDEF0 notation, which they called the IDEF0v, as represented in Fig.2-14.

The method consists of an identification of the design process hierarchy, determination of the information requirements of the tasks, production of design process model diagrams and their verification.

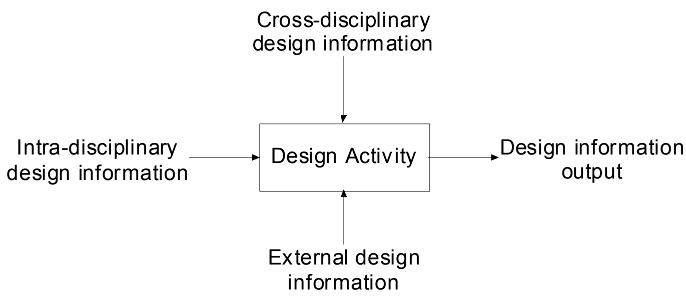

Fig.2-14. Modified IDEF0 notation (IDEF0v).

The design process model has been tested on a pharmaceutical laboratory, a railway terminal, an office development and a hospital. However, it is important to highlight that the technique was created for and is used by civil engineers and not by architects.

2.3.2 Design method: academic

The current model of design education, as Lawson (1997) argues, is based on the studio where students learn by tackling problems rather than acquiring theory and then applying it; emphasis is on the final product rather than the process. In this model, Lawson (1997) highlights another obstacle to creativity, based on a study by Laxton[11], which shows that children cannot expect to be truly creative without a reservoir of experience. In architectural terms, Laxton argues the ability to initiate or express ideas is dependent on having a reservoir or knowledge from which to draw these ideas. Lawson (1997) concludes that *'design education is a delicate balance between directing the student to acquire this knowledge and experience, and yet not mechanizing his or her thought processes to the point of preventing the emergence of original ideas'*.

While knowledge supports the creative process in theory, in practice scientific knowledge is relegated to secondary importance in architecture schools. As Szokolay (1994) observes, a typical course has 50% of studio and 50% of supportive subjects. Of the latter 50% is given to 'soft' subjects such as psychology, history and theory, and the other 50% to 'hard-edged' subjects shared between 'fabric studies' (materials/ construction/ structures) and 'environmental studies'. Basically, science isn't a predominant issue among architects and usually the art issue comes first in theirs minds. The dichotomy of science & creativity has produced discussions and it has protagonists in both fronts. Szokolay (1980c) debates the

[11] Laxton, M. (1969). Design education in practice. Attitudes in Design Education. London, Lund Humphries.

question and criticizes radicalism. While creativity is identified with enthusiasm and emotional involvement, science is a painful method that can inhibit creativity. Of the Vitruvian principles of commodity, firmness and delight, ‘delight’ is important, but how can one deny attributes of the building, which are based on science, such as firmness and commodity? Both are predictable by scientific tools.

Historically, architecture was an empirical discipline same as medicine. But later the development of the two professions diverged. Szokolay (1994) is straight in his criticism: ‘*the two (medicine and architecture) were practically at par only 150 years ago. Many bemoan the fact that whilst medicine is thriving and expanding, we are shrinking both in activity area and in earning capacity’*. The same author goes on to compare the two: ‘*while medicine embraced specialization and research*, *architecture did the exact opposite . As the science and technology of building developed, specialization was bound to occur, but any specialist spawned was immediately excluded. The ‘master-builder architect’ shed his building role, structural design was passed on to the engineer, quantity surveying developed as a separate profession … A whole range of engineering specializations developed to look after various aspects of the building design, such as lighting, electrical, mechanical, acoustic, HVAC engineers’*.

Now, educators such as Corner and Corbella (2000) try alternative methods to teach concepts of psychrometry and bioclimatology to architecture students. They use analogies and concepts close to the student reality and fundamental concepts are explained through the minimum and representative set of concepts. Enthalpy is still a complex concept for theirs students!

For teaching purposes, Szokolay (1994) acknowledges that creativity must be used, but it must be supported by scientific bases, which can be combined during the course: *‘the studio projects should be constructed to serve as vehicles for learning the science subject’*. He argues that it is necessary to stimulate the desire for knowledge, which must be presented in a related format to be understood and recorded in the students’ minds. Szokolay (1980c) comes with a conciliatory thesis: enhance the knowledge without sacrificing the creativity. For the design process, Szokolay (1980c) theorizes: ‘*the real skill in using scientific tools is to proceed with the analysis at one level only to a point, beyond which it would prejudice the process at some other level*’. Furthermore, the creative jump comes about at the point when a formal solution is born.

Duffy[12] (1998) also describes how architects can be uncomfortable when knowledge is used as a way of describing the essence of their discipline. The author recognizes that knowledge and research are rarely revered by architects as in other professions, and he goes further: *"For an architect to be relegated to 'research' is sometimes a code for failure as a designer, detailer or project manager"*. Ironically, Duffy cites the RIBA charter 1937:

'… forming an Institution for the general advancement of Civil Architecture, and for promoting and facilitating the acquirement of the knowledge of the various arts and sciences connected therewith; it being an art esteemed and encouraged in all enlightened nations, as tending greatly to promote the domestic convenience of citizens, and the public improvement and embellishment of towns and cities'.

2.3.3 Design method: in practice

The design process is, as constantly argued, an abstract and intimate practice. Everybody has his/her own. Many design practitioners and researchers have attempted to define explicit procedures or methods, but none of these proposals have received anything approaching unanimous acceptance. The AIA (1999) affirms: *'the range of these methods does suggest something important about architectural design- it is rarely a deterministic process'*.

In a general review, Lawson (1997) describes a sequence to represent the popular creative process, based on personal account and observations, from mathematicians to designers and architects.

Although the process does not occur in separate steps, the author represents it as follows in Fig.2-15: a recognition of the problem, conscious effort in the search for a solution and intense work, a relaxation period for reorganizing and re-examination, a 'spark' and finally the period of test, elaboration and development.

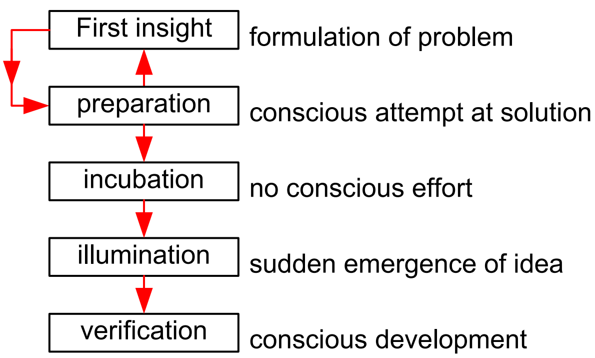

Fig.2-15. The popular five-stage of the creative process.

[12] Past-president of the Royal Institute of British Architecture (RIBA) and actual chairman of DEGW, which is an international architecture and consultancy firm that plans and designs environments for working and learning.

There is little evidence in the literature for design methodology as practiced by designers. The process is so intimate and complex to rationalize that few designers are willing to talk about it. And when it happens, these few professionals are questioned to explain the formula of success rather than to explain their frustration or obstacles to the process. Although these testimonies are welcome, they might not be representative for what commonly happens in design offices. Furthermore, the subject is so extensive that a serious study demands long period of observation and large number of case studies. In this context, Lawson (1997) has analyzed the process in detail and split it into many other issues. Some observations and conclusions are pertinent:

1. None of the design maps are totally representative and practitioners follow more routes than the theory predicts.
2. It is common for designers to carry some set of guiding principles, usually gathered during their career.
3. Architects have declared preference to be involved with the project in the very beginning, underlining the importance of briefing.
4. Using protocol studies, design sessions reveal that most designers adopt strategies that are heuristic in nature because relying more on experience and rules of thumb than theoretical first principles.
5. There is a behaviour identified as 'primary generator', which restricts design solutions due the influence of an early focus of attention, or using the Lawson (1997) observation from the studies of Darke[13]: *'... the architects tended to latch on to a relatively simple idea very early in the design process…Thus a very simple idea is used to narrow down the range of possible solutions, and the designer is then able rapidly to construct and analyse a scheme'*. Although it is highly desirable to focus on the central problem, the primary idea can lead to a dead end, the whole primary generator may have to be scrapped in favour of a new focus.
6. *'….there is no natural end to the design process. There is no way of deciding beyond doubt when a design problem has been solved. Designers simply stop designing either when they run out of time or when, in their judgement, it is not worth pursuing the matter*

[13] Darke, J. (1978). The primary generator and the design process. New Direction in Environmental Design Research: proceedings of EDRA 9. Washington, EDRA. 325-337.

further….Unfortunately, there seems to be no real substitute for experience in developing this judgement' (Lawson 1997).

Many authors stress the importance of experience and knowledge in the ordinary design process. If experience is gained with activities and time, knowledge can be a shortcut for young architects and architects from different areas to improve their qualities as designers. Indeed, some protagonists of the 'design studio' in education argue that the sequence of the design projects is 'accelerated experience'

2.4 Bioclimatic architecture and low energy strategy design

In 1993, Susan Maxman has suggested that 'sustainable architecture isn't a prescription. It's an approach, an attitude. It shouldn't really even have a label. It should just be architecture (Guy and Farmer 2001). The use of natural resources to create better comfort conditions in buildings is mentioned in the last century in many cultures and is an ancient practice as old as architecture itself. Nowadays, bioclimatology emerges as a scientific approach: *'bioclimatic design is a disciplined approach to architecture that fosters the act of envisaging, defining, construction and appraising whole functioning buildings containing and including all environmental control systems in various combinations'* (Lima 1995). In warm climates, bioclimatic architecture involving architectural design and choice of materials aiming at providing comfort while minimizing the demand for energy used to cool a building (Givoni 1994). In recent times, Szokolay (Auliciems, DeDear et al. 1997) highlights the beginning of bioclimatic architecture:

In the post-war years, architects started to work with unusual tropical climates and climatic design of buildings became an issue, which resulted in an analytical examination;

1. Olgyay, in 1953, in his paper 'Bioclimatic approach to architecture', managed to synthesise relevant products of many different sciences;
2. Olgyay coined the term 'bioclimatic design', which expresses an attitude to design:
    - the purpose of architecture is the human being
    - (s)he is exposed to a climate, which is not always favourable
    - the task is to create a 'filter' between the human and the climate

Since then, the issue has grown up and was impelled by historical influences such as the oil crises, the conservationist movement (both in the seventies), the 'Earth Summit' in Rio de Janeiro and the Agenda 21, in 1992, and recently the Kyoto Protocol.

2.4.1 Concepts

In bioclimatic design, 'passive' and 'active' are terms used as boundaries for strategies with climate integration (passive) or no relying on energy input (active). Passive cooling systems are strategies to be incorporated into bioclimatic architecture, and it may also require specialized details in design: the two approaches supplement and reinforce one another (Givoni 1994). The design of passive controls (passive control is a function of the building and active are energy based installations) is usually associated with climatic design (Szokolay 1980a). Baker and Steemers (1996) adopted the terms to structure their energy tool (LT Method), where passive zones are areas, where it is possible to satisfy the user necessities with natural resources, such as natural air ventilation and daylighting. The same way, non-passive zones are away from the envelope and thus require mechanical ventilation and artificial lighting, but do not suffer from unwanted solar gains or fabric heat loss.

2.4.2 Bioclimatic design plus active strategies

In practice, the experience has shown that office buildings usually can't be 'free running' in a warm climate. Well known buildings such as Menara UMNO and Menara Messiniaga (both designed by Dr. Ken Yeang) didn't prove it possible to use only natural air ventilation successfully to keep the cooling set point. The reasons for this failure might be high internal loads, occupancy schedule beyond daylight availability (high use at night), influence of user's behaviour, difficulties to control the wind speed, changes in the original project and others. Hyde (2000) suggested that the integration leads to a hybrid model, which is the more representative example for passively low energy architecture. Yeang (Tzonis, Lefaivre et al. 1999) also recognizes the potential of it: '

Simply stated, bioclimatic design is the design of buildings that optimises all passive modes …. All these passive means need to be optimised in relation to the ambient climate of that latitude to achieve improvements in comfort levels better than the ambient conditions of the place. This must first be achieved through the use of non-active and hence non electro-mechanical means.'

The subject is not easily accessible to architects because the domain and use of the strategies to reach a successful design are structured in science. Some educators believe this obstacle can be solved if science understanding is changed by exposition of <u>principles and guidelines</u>, combined with <u>case studies</u> and <u>design assessment</u> (Hyde 2000). The hypothesis is laudable if one assumes no changes in the curriculum of architecture courses, but even in this condition it might not be enough. The three approaches are analyzed as follows.

2.4.3 Design principles and guidelines

The term 'principle' is used in an architectural sense, with a meaning different from the original one, which means '*a comprehensive and fundamental law, doctrine, or assumption*' (Encyclopædia Britannica 1994-1998). Commonly used in architectural books and essays, principle's meaning gets mixed up with style, but it is also associated with recommendation, suggestion and guidelines. While style is more a consequence of critics observations than a set of rules, Lawson (1997) believes style is associated with fashion and consequently, with something temporary and passing. Architects feel the need to describe their work as supported by more lasting ideas and perhaps it is comforting to have some *'principles'* which suggest fairly unequivocally that some ideas are more right than others. The issue is polemic as it became dominated by a doctrinaire approach. Meanwhile, Yeang (Hamzah and Yeang 1994) prescribe bioclimatic '*principles'* for warm and humidity regions:

- core position: it can act as a buffer zone on west and east facades;
- windows position: windows orientated to north and south façade;
- deep recesses: provide shade;
- transitional spaces: use the veranda to provide shade;
- permeable external walls (probably for natural ventilation);
- passively conditioned ground floor: it acts an interface between outside and inside;
- building plan: stimulate the interior air movement;
- planting and landscaping: cooling effect;
- solar shading: use of passive devices;
- cross-ventilation;
- thermal insulation;
- structural thermal mass.

Although these recommendations probably have a strong scientific base, the language is accessible enough for an ordinary designer. As these propositions are assumed '*principles'*, they are less questionable and consequently they rapidly diffuse in the architectural society and can gain more sympathizes. If well integrated in a design process, these principles can act as an introduction for a more detailed approach. On the other hand, the exclusive reliance on '*principle'* is probably unlikely to generate efficient buildings.

2.4.4 Case studies

Architects and architecture teachers largely use case studies to explain building characteristics, style analysis and technological innovations, to exemplify use of principles and to comment on building performance. While the quantification of building performance is still absent from their agenda, some buildings are claimed to be a model of energy efficiency without any convincing proof. Sometimes, the existence of a solar collector or a PV system is enough to classify a building as an efficient model, just because the building uses less energy from the grid. Another symptomatic characteristic of a poor case study is the lack of observance of the real contribution of each component in a building system. A building can become a model of energy consumption even if its envelope is mediocre, but its building services are highly efficient and it is appropriately managed. If there is no explanation of this, then there is a risk of inexperienced architects using the mediocre envelope characteristics as a reference for future designs.

Using the prestigious periodical The Architects' Journal as a reference source, it is possible to identify some points in energy analysis. While the magazine brings one case study in each issue, between 2001-2002 only one case highlighted concerns for energy performance.

The case detailed in Clegg, Baily et al. (1998), Fig.2-16, describes some characteristics and intentions, such as the proposition that encourages changes in the organization, it is a low-energy building, its area is 5 000m² and it is mainly for office use. While the costs are very clearly described, there are no numbers to characterize the energy performance; the

Fig.2-16. Feilden Clegg's Berril Building for the Open University in Milton Keynes.

comments are restricted to notes about principles that help to reach a better performance, such as thermal insulation use and integration with daylighting.

In another case study, Lim (1994) describes the client's briefing for the construction of Commonwealth Bank (Fig.2-17) 35-storey and A$67 M in Brisbane, designed by Conrad & Gargett Pty Ltd. Following the author's opinion (Lim 1994), the building is seen as a desirable architectural product, which achieves architectural merit and client satisfaction. The author relates the client's briefing with an appropriate design strategy (Table I) and again there is no quantification to prove how good is the building performance.

Table IV. Case study for briefing and design strategy.

Clients' briefing	design strategy
symbol of strength, stability and image	architectural form
response to the local climate and 'Queensland' character	building façade, precast sunhoods over large windows
low energy	polished finish concrete panels to give a light surface colour, increase the thermal mass, awning to reduce the sky glare, BMS
maximum exposure of banking chamber	'tower-on-podium' concept; translucent awnings, fully glazed facades, luminous ceiling
good quality	materials
minimum maintenance	low maintenance materials, BMS
optimisation of utilization of site	'tower-on-podium' concept

Fig.2-17. Commonwealth Bank, Brisbane.

Many other examples of publications for architects, which discuss energy performance, show a superficial approach. For example, Tzonis, Lefaivre et al. (1999) and Powell (1999) basically reproduce intentions of Dr.Yeang's designs. In the collection of 22 cases studies presented by Wigginton and Harris (2002), 'Intelligent skins', only one shows the energy consumption for end use and two show the total energy consumption from records. In another extreme, publications with engineering and physics background emphasizes only the energy performance analysis and other architectural issues are unobserved. Periodicals such as the ASHRAE Journal and Transactions, Energy and Building, and Building and Environment usually deal with a specific component of the building. For example, Gupta (1997) only describes in detail the thermal proprieties of the envelopes and Patton (2000) only reports the building energy consumption behaviour. Isolated from the architectural context, both publications offer little contribution for the architect. Furthermore, the buildings analyzed in the majority of periodicals are not architectural icons and, for a architect, they are frequently seen as insignificant.

The reliability of case studies is further questioned even when an energy assessment is done following engineering guides, such as those provided in Haberl and Komor (1990a) (1990b), Kaplan Engineering (1991a) (1991b), Kaplan (1992), Kaplan, McFerran et al. (1990) and Pedrini and Lamberts (2001). The thesis defended by Pedrini (1997) raised this question and proved the influence of different levels of building modelling (for energy assessment purposes) for an office building in a subtropical climate.

The building analyzed was the headquarters of energy supplier for South of Brazil, the Eletrosul (Fig.2-18), with 30 000 m² (20 000 m² air conditioned) and 3150 kW of capacity of refrigeration.

Fig.2-18. Eletrosul building, Florianópolis/ Brazil.

The quantification of energy end-use depends on the method. For example, Toledo[14] (1995) estimated that the cooling energy end-use was between 20% (warm and wet period[15]) and 8% (cold and dry period[16]) of the total energy consumption of the Eletrosul building. Using an accurate method, Pedrini and Lamberts (2001) found that the cooling (AC) energy end use

[14] Toledo did a very extensive analysis in eleven buildings using a simplified assessment method.

[15] wet period corresponds to the high incidence of rain in the hydroelectric catchment areas and also coincides with the warmer season: Dec-April.

[16] dry period corresponds to the low incidence of rain in the hydroelectric catchment areas: May-Nov.

was higher: 44% for whole year (Fig.2-19). The first method underestimated the energy end-use of air-conditioning by more than 50% of that determined by the accurate method.

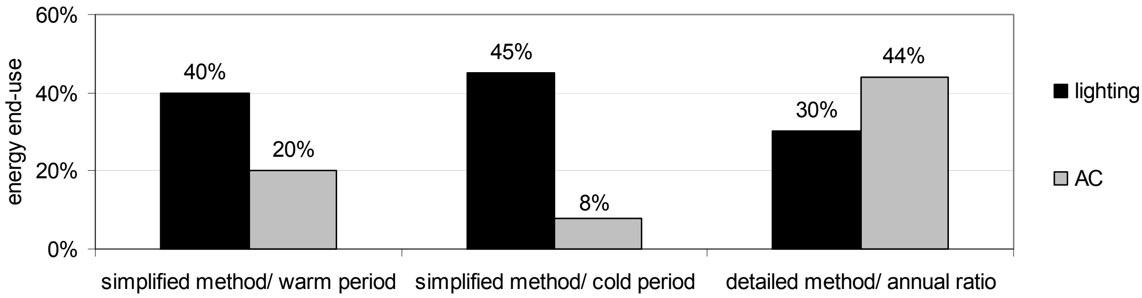

Fig.2-19. Energy end-use result for different assessments (the other end-uses concern equipment in general).

Pedrini and Lamberts (2001) created four building models in DOE-2 software from four different energy assessments: documentation analysis, walk through with spot measurements, energy end-use monitoring and coefficient of performance measurement. As shown in Fig.2-20, the fraction of energy consumed by lighting, equipment and cooling (related to the total energy consumption) is different in each of the four models; the energy use components can be underestimated or overestimated by more than 50%.

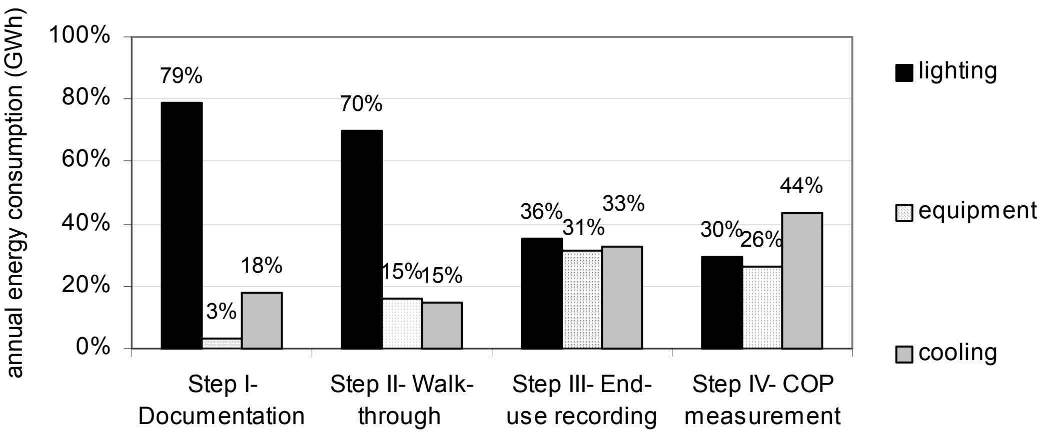

Fig.2-20. End use energy for different levels of modelling.

There is much information to guide an energy assessment. In Australia, the Australian Standard offers a comprehensive methodology in AS 2725-1984 (Standards Association of Australia 1984) and AS 3598-1990 (Standards Association of Australia 1990), which consists of three successive approaches for energy audit. It starts with a general evaluation composed by survey and measurement of energy use, reporting of energy use and analysis of the reported data. The second step is an extension and includes the selection of a plan of action, implementation of selected measures and monitoring of energy use. The third approach refers to specific tasks, which consists of precise description of specific tasks which the auditor will be expected to perform, such as:

- energy survey of plant, processes, equipment, buildings and services on the site;
- identification of energy usage patterns;

Although energy audit is a term used even for a fast walking through the building, the AS 3598-1990(Standards Association of Australia 1990) restricts the validity of the analysis for minimum information, such as:

- description of the site and nature of operations at the site;
- selected measures, including an estimate of costs and proposals for further monitoring energy use;
- records of energy use, which may include periodic records of energy consumption and cost and for different facets of operation, and details of tariffs applicable to the site;
- a set of available drawings, including schematic layout of the operations at the site, drawings of various items of plant using energy, and architectural drawings including location of the items of plant;
- examination of control systems status and performance.

At the end, Rogers (1998) recommends: '*An energy audit establishes where and how energy is being used, and the potential for energy savings. Generally, it includes a survey and review of energy using systems, an analysis of energy use, and the preparation of an energy budget. It should also provide a baseline from which energy consumption can be compared over time.*'

Case studies give a simple approach for the issue, if compared with the current level of available knowledge; it is advisable to be skeptical each time a '*case study*' is presented. Case studies must be treated as an interdisciplinary task and not an exclusive matter for architects or engineers.

2.4.5 Design assessment

The measurement and appraisal of general performance of a building design appears to take place whenever the designer pauses to evaluate what he/she has done, or when he/she considers design alternatives in order to reach a decision. The client can also perform an appraisal of the design at various stages of development to ensure that the buildings and its systems are designed, and able to perform as intended, for different phases (Watson, Crosbie et al. 1997). But when the task requires expertise, a consultant can be contracted to do it.

Friedmann, Zimring et al. (1978) reproduce the recommendation of the American Society of Landscape Architects of 1974: '*The systematic analysis and evaluation of completed works (i.e. design evaluation) provides the greatest potential for obtaining the kinds of data and knowledge essential to improving professional performance. Systematic approaches should provide the basis for comparative as well as case studies. The findings would be of value for the continual iterative up-dating of educational programs as well as for the prediction of impact of design-planning decisions by providing a more substantive information base on which to make such decisions*'.

The design assessment can also be a part of the Building Performance Evaluation (BPE). Preiser and Schramm (Watson, Crosbie et al. 1997) proposed a model that encompasses design and technical performance of buildings alongside human performance criteria.

The authors use a framework (Fig.2-21) that shows a cyclic evolution and refinement toward a moving target, achieving better building performance overall and better quality as perceived by the building occupants. The whole process is composed of five phases[17], of which the fist three relate to the design assessment:

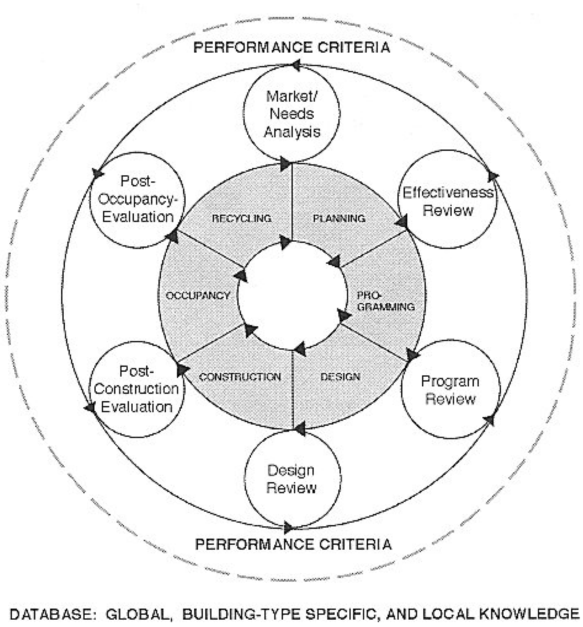

Fig.2-21. An integrative framework for building performance evaluation (Watson, Crosbie et al. 1997).

[17] The fourth and fifth phases are concerned with construction and post occupancy evaluation. These two issues don't belong to the scope of the thesis and they are not discussed.

- reviewing of the process to organize a program that establishes needs;
- start of the programming and, in the end, a new review involving client, programmer and occupants groups;
- assessment of the designs and analysis of the effects from various perspectives, while it is still not too late to make modifications in the design.

Well represented in the previous model, the usual approach is to assess the design when it is already defined or only some small questions are undefined. Unfortunately, this approach is very inefficient when it aims to improve the building energy performance. As mentioned in the introduction of the subchapter 2.3, many authors recognize that the best opportunities for improving a building's energy performance occur early in the design process (Goulding and Lewis 1992).

2.4.6 Strategies

There are many available strategies aiming at comfort and efficient energy use in building. They can be classified by climate, type of building, energy input (passive or active) and building system (building fabric, building services and building use). Indeed, the classification is not rigid and many strategies concern more than one class. Another interesting point is the method used to introduce a strategy: it may be explained using scientific analysis, technical vocabulary or simplified architectural recommendations.

Szokolay (Cowan 1991) introduces a set of strategies that is fundamentally based on physical principles (in the real sense of the word). Three basic conditions are differentiated: '…

- When cold discomfort (or heating necessity) conditions prevail:
  - minimize heat loss (insulation, air-tight construction);
  - utilize heat gain from the sun and incidental internal sources.
- When hot discomfort (or cooling necessity):
  - prevent or reduce heat gains (insulation);
  - maximize heat dissipation.
- When conditions vary diurnally between hot and cold discomfort:
  - even out variation (thermal capacity);
  - introduce flexibility or adjustment facility.'

This interrelation with the climate derives six basic passive or climatic design strategies presented by Szokolay (Szokolay 1986; Szokolay 1990b; Szokolay and Docherty 1999) in the *Control Potential Zone* method (CPZ),

- passive solar heating
- mass effect or thermal storage;
- mass effect with night ventilation;
- air movement effect (physiological cooling);
- evaporative cooling;
- indirect evaporative cooling.

The author advises that '*these control-potential zone boundaries are indicative only, they are not rigid or exact, they are influenced by the actual building design solutions. They are intended for the user before a design solution would be produced, but in some cases it will be shown how certain design characteristics can be included in the definitions, when they become available, in lieu of the initially assumed average values'* (Szokolay 1986).

Burberry (1983) synthesizes some of the previous strategies using straight recommendations for architects in temperate and cold climates, specifically for building fabric:

- location: minimum exposure, minimum shading, cube desirable form;
- envelope design: minimum volume and surface area, minimum heat transfer through fabric, minimum ventilation and infiltration rates, appropriate cost-effective insulation standards, avoid cold bridges;
- interior: avoid open plan;
- external windows/ doors: minimum number and area, southerly orientation (in the northern hemisphere), recess windows.

Yeang (1999) goes further and produces a set of suggestions to guide architectural practice decisions, supposedly based on scientific knowledge such as OTTV (Hui 1997) and LT (Baker 1994). The author uses sketches, plan views and diagrams as a way to communicate his thoughts, Fig.2-22 and Fig.2-23. Questionably, these suggestions are called 'principles' (already discussed in subchapter 'Design principles and guidelines', page 39).

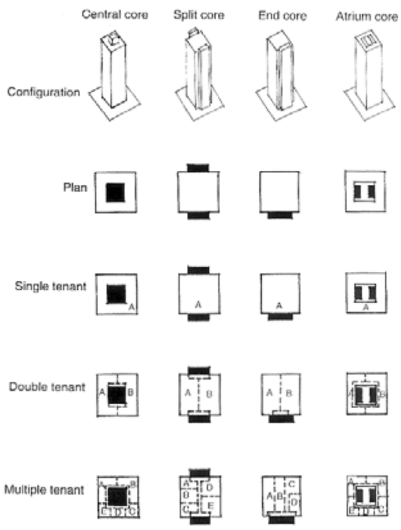

Fig.2-22. Service core configuration (Yeang 1999)

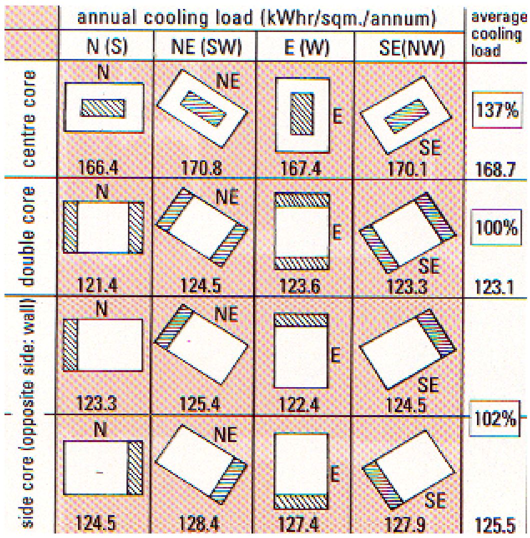

Fig.2-23. Orientation, core position and cooling load (Yeang 1996).

The next set of strategies is specific for warm climates. In contrast with the previous set that avoids the loss of heat through the envelope, Givoni (1994) presents preferred strategies to minimize cooling needs by appropriate architectural design: ‘

- *building layout*;
- *orientation of main rooms and windows,*
- *window size, location and details;*
- *shading devices for windows;*
- *colour of the building’s envelope;*
- *vegetation near the building.*’

Givoni (1994) has a intermediate approach: he uses a mathematical model, experimental results represented in charts and suggestions to deal with ventilation cooling, radiant cooling, evaporative cooling systems, 'earth ‘cooling source’[18] and cooling effect of outdoor spaces (such as patios).

Low energy strategies commonly deal with the interaction of building fabric and building services. For example, Boyer and Grondzik (1987) suggest strategies concerning the economizer concept: fan and damper act in an existing HVAC network to bring cool outdoor

[18] ‘cooling source’ is the term he uses for heat sink.

air for the temperature relief inside the building (when $T_o<T_i$). Balcomb (1998) proposes a comprehensive list of strategies:

- daylighting;
- energy efficient HVAC;
- economizer cycle or enthalpic control;
- insulation;
- energy efficient lights
- improved windows;
- air leakage control;
- HVAC controls.

Using a different approach, Walsh and Verwer (1986) report the use of case studies to assess the impact of a variety of energy management techniques, particularly in office buildings. They observe that the most influential strategies are:

- efficient lighting systems;
- hight efficiency heating and cooling plant; capacity divided into several units helps to avoid use at partial capacity with reduced efficiency;
- economy cycle (using outside air) when possible;
- variable air volume systems can reduce considerably the energy requirements for heating, cooling and fans;
- good shading and insulation of glazing;
- economical time-switching of plant.

Todesco (1998) uses energy simulation to identify (and quantify) the most important strategies in building: ‘

Building Form (minimize surface to floor area ratio): The most efficient building encloses the largest volume for the least surface area because heating and cooling energy use is affected by the amount of exposed wall area.

1. Building Orientation: Energy use is minimized by limiting a building's exposure to the east and west. When possible, buildings should be oriented north/ south, with the long axis running in an east-west direction.

2. Optimise Use of Glazing: Optimising the use of glazing maximizes daylighting while minimizing glare, solar heat gain and building heat loss. Limiting window area in the east and west facades *(no location specified!)* and using shading techniques such as a deep window recess or window overhangs, which can also control glare.
3. Maximize Use of Daylighting: Introducing daylighting into the building's interior can be maximized using techniques such as high window designs paired with a high ceiling near the window (sloped ceiling), lightshelves and clerestories. In addition, daylighting should be included in the overall lighting design by considering luminaire layout, lighting circuit layout and lighting control strategy.
4. Optimum Equipment Sizing: HVAC equipment should be sized as closely as possible to the design loads by taking into account any load reductions from an improved building envelope, use of daylighting strategies and any other efficiency measures. It is also important to use appropriate values for lighting loads, office equipment/ plug loads and occupant densities that reflect actual conditions or are based on measured data rather than suggested guidelines, accepted practice or nameplate *(label)*.'

The literature offers much more strategies that covers many areas of research and are very specific in their approach: effect of vegetation on the roof (Takakura, Kitade et al. 2000), optimisation of overhang dimensions (Raeissi and Taheri 1998), thermal analysis of the ground floor (Labs 1979; Mingfang and Qigao 1998), optimisation of the building shape (Stathopoulos and Wu 1994) (Marks 1997), cooling effect of trees (Akbari, Kurn et al. 1997; Akbari, Pomerantz et al. 2001), roof influence (Akbari, Konopacki et al. 1999), thermal storage systems (Akbari and Sezgen 1995), influence of shading on the condenser or air conditioning (Parker, S.F. Barkaszi et al. 1994), chiller water efficiency (Avery 2001), etc. .

There are so many strategies available and the designer has to choose some of them. But before they would do it, Burberry (1983) advises: '*….strategic design depends upon knowledge and understanding of building performance and upon the making of overall decisions with understanding of the their thermal implications*'. In a further article, Burberry (1998) argues '*to achieve energy conservation, small and simple is beautiful'*.

2.5 Integration of low energy strategies with the design process

The usual building design process is an interaction of many professionals, including building owners, architects, engineers, financiers, managers and operators, building trades representatives, contractors, and other key players. The development of a high performance building brings in even more specialized professionals to consider the questions related to energy flows, use of daylighting and artificial light and efficient building services.

Burberry (1983) endorses the theory that '*the interdependence of design factors has the consequence that, if satisfactory thermal performance is to be achieved, thermal considerations must be taken into account from the earliest stages of design'*. This can be reached in two ways: *'the strategic stage when general concepts are being developed and the detailed design stage when, within the strategic framework previously established, the final details of sizing, construction and operation are determined'*. He proposes a design procedure for the whole process:

- obtain data on typical energy consumption pattern and systems used in other buildings of the same type;
- establish the preference of the client or occupant for comfort levels, types of emitters, etc;
- establish constraints imposed by site;
- identify factors pre-determined by the nature of the building;
- determine the environmental strategy;
- order the design decisions[19];
- At the sketch design stage, include the standards and methods to be employed and the anticipated patterns of energy usage in the presentation;
- other recommendations regarding workmanship, supervision, commissioning and manual for users.

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[19] proceed with the normal stages of design and for each aspect which is the subject of drawing, report on analysis record of the drawings or documents the relevant items for the rank ordered list

Burberry (1983) suggests a summary of energy conserving features, most of them only appropriate for cold climates, such as building with minimum volume and surface area, minimum shading. The author uses the RIBA plan of work to relate it to the timing of many of the design factors, Fig.2-24. Although the diagram is very clear, some aspects such daylight and natural ventilation should probably come into earlier stages than the proposed.

Burberry (1983) believes that building design does not follow a set pattern, consequently it is necessary to conceive possible answers to the problem which are then checked in many ways to see whether they offer acceptable performance: '*the initial concept cannot be supplied by analytical procedures nor can they be balanced into a unified architecture whole….it is possible to conceive several different possible solutions and then test them for performance in particular areas such as the thermal one'*.

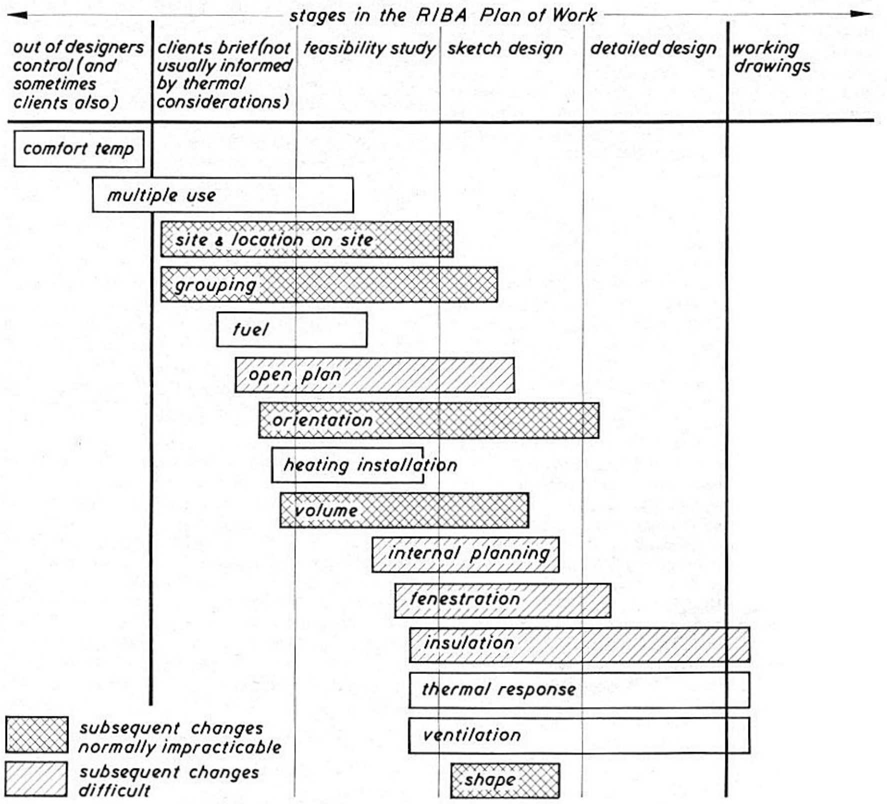


Fig.2-24. Progress of building design showing stages at which thermal decisions are usually taken (Burberry 1983).

Szokolay (1984) argues that the consideration of passive and low energy techniques must permeate all stages of the design process. The author divides the design process into four main stages, defines the tasks and input information, suggests tools and characterizes the output product, Table V. The integration of the previous table with the design processes reviewed generates the Table VI.

Table V. Energetics in design (Szokolay 1984)

stage	task	information	tools	product
PRE-DESIGN ANALYSIS	digest brief identify constraints study climatic conditions define 'solution space'	climatic data energy standards precedents images of appropriate forms	bioclimatic analysis Mahoney tables rules of thumb CLIMATE program	performance specification energy target 'if...then...' type guidelines
if energy matters are ignored at this stage, this may prejudice the later work, the design product – if brought in later, they may modify the design, it may become contorted, as it is forcibly 'made to work'				
SKETCH DESIGN STAGE	generate ideas formulate and test design hypotheses	knowledge of thermal effect of shape and form, of thermal behaviour of materials evaluation criteria	test alternatives, refine the selected one by a simple method, eg. the HARMON program, using the THI index as measure	design proposal
the very first hypothesis should satisfy energy criteria, alongside all others, such as accommodation, circulation, structural and 'buildability' aspects, as well as aesthetics				
DETAIL DESIGN STAGE	make all detail design-decisions: fenestration, shading, dimensions, envelope materials, thicknesses, surfaces	awareness of energy consequences of detail decisions	special purpose tools: diagrams, protractors, nomograms, or simple programs, eg. DAYLIGHT, SOLPAK, optimisations	contract documentation: working drawings, and details, specifications
many of these decisions will have energy consequences, interconnected two ways: the same element may have influence on several factors (heat, light, sound), or the same factor may be affected by several elements				
FINAL EVALUATION	analyse thermal performance in detail, estimate energy use for all purposes	precise data on materials, hourly climatic data, occupancy data	sophisticated thermal response and energy analysis programs: ZSTEP, TEMPER or incl. mech. systems: BUNYIP	final energy budget
compare results with energy budget targets set at the pre-design stage, modify design if necessary: use load breakdown outputs to indicate 'weak spots'				

Table VI. Integrated design process.

RIBA terminology	John Luckman*	RIBA's stages	AIA's phases	'Energetic' phases
Briefing	analysis	inception feasibility	programming	Pre-design analysis (programming, strategic planning, pre-project, investigation of base)
Sketch plans	synthesis	outline proposals scheme design	schematic design	Sketch design (preliminary design, schematic design, preliminary studies, project)
Working drawings	evaluation	detail design production information bills of quantities tender action project planning operation on site completion	design development construction documents Bid construction supervision commissioning	Detail design (design development, preparation of realization, definitive proposal) Final evaluation (construction documents, building documents, realization)

* article "An approach to management of design" (Broadbent and Ward 1969)

Hiller and Schuler (1999) go further suggesting that the usual design process is not suitable for an economical and ecological building and they suggest a so-called integrated design process (Fig.2-25). In their proposal, cooperation between the architect and engineers is mandatory and a ‘new’ professional emerges: ‘*the climate engineer –a new branch of engineering - supports the architect by developing and integrating the energy concept*’. Actually, the Poly of South Bank (London) had already a course of ‘environmental engineering’ in 1970!

The authors recommend the use of parallel computer simulations to verify the expected thermal behaviour of the building design. After approving the draft building concept all members of the design team have to draw consequences for their own work area. The authors illustrate the approach with two cases: the DATAPEC's new office building (Fig.2-26) and the Bangkok International airport (Fig.2-27). In both cases the process started with basic concepts, probably defined from an exploratory study, such as the importance of atrium for air and light, use of floor as air duct and thermal storage, façade with passive shading devices. The next steps are the energy evaluation in an outline model and detailed analysis.

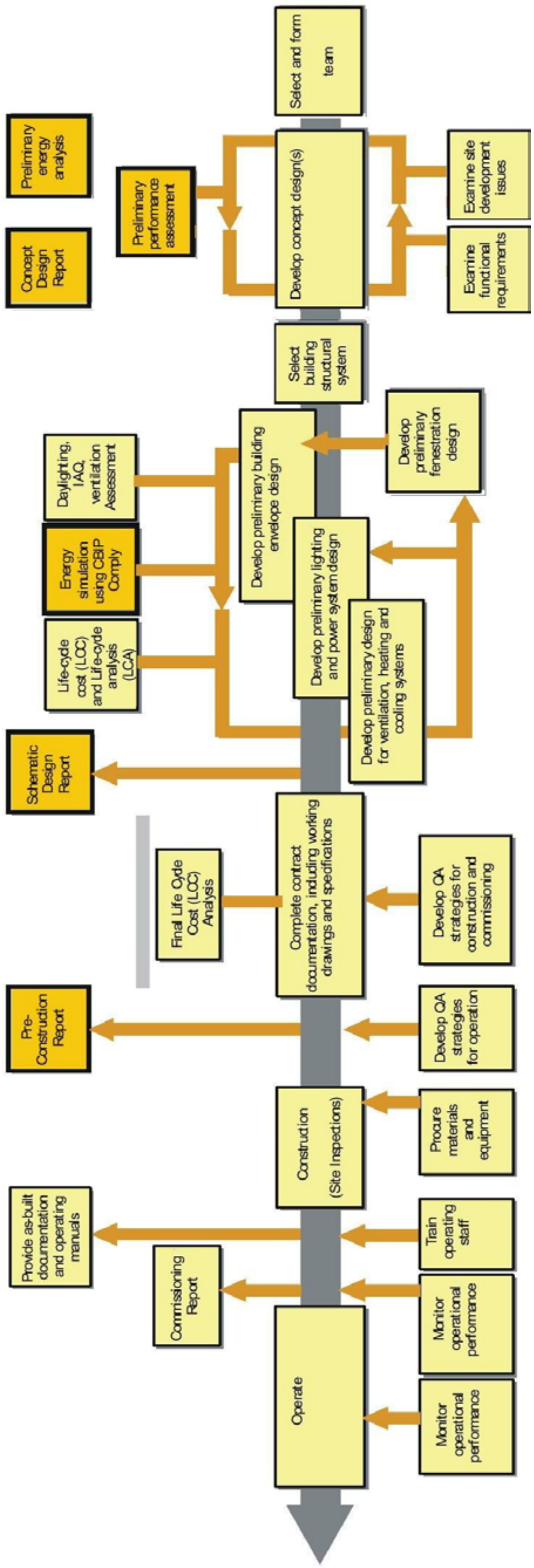


Fig.2-25. Integrated design process (Hiller and Schuler 1999).

Fig.2-26. DATAPEC Headquaters Gniebel.

Fig.2-27. New Bangkok International airport.

In a deeper study Wilde, Augenbroe et al. (1999) aim to develop a strategy for the use of simulation tools as an indispensable support instrumental in building design. They use two cases, Rijnland office and ECN building (Fig.2-28 and Fig.2-29), to analyze the role and point of invocation of tools in the design process and to investigate the role of the design team in the decision to request expert analysis interventions. The first observation is the difference of intentions between simulation tool developer and the design team.

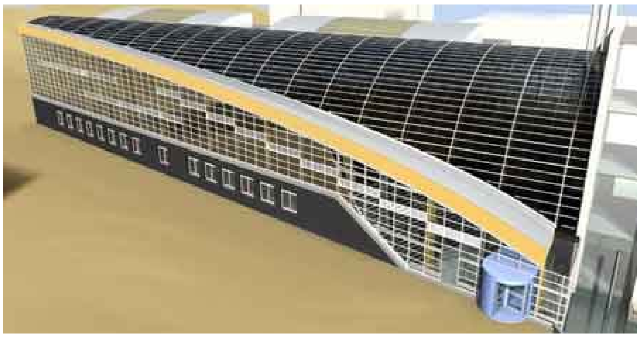


Fig.2-28. Rijnland office[20].

Fig.2-29. ECN building 42[21] (note the curved roof covered by PV panels).

The Rijnland office process distinguishes five main phases: feasibility study (1), conceptual design (2), preliminary design (3), final design (4) and preparation for building construction (5). The article highlights the importance of integrating a building physics consultant in the early stages and the successful introduction of energy saving components also in the early

[20] Designed by Jan Brouwer Associates, the project has been granted the status of 'exemplary project' in the field of energy-conscious and sustainable building by the Dutch government.

[21] Designed by BEAR Architects, Netherlands.

stages that were retained in the final design. Regarding the relationship, *'…there is very little evidence of a consultant 'informing' the choice between different design options by offering analysis based on calculation or simulation*' because computers were mostly used to confirm assumptions and not to make decisions. The negative aspect is a lack of tools in the diagram in Fig.2-30.

The ECN building case differs from the previous case because the architect is the only member of the design team. In this case the design process evidenced six phases (and not five as the previous one): preparation of the brief (1), feasibility study (2), conceptual design (3), preliminary design (4), final design (5) and preparation of building specification (6). The diagram representing the process in Fig.2-31 shows as main characteristic: the position of the architect, who develops the building design and determines the areas for input from the consultants. Energy tools are used to check whether the performance meets with expectations and not to decide between different building design options.

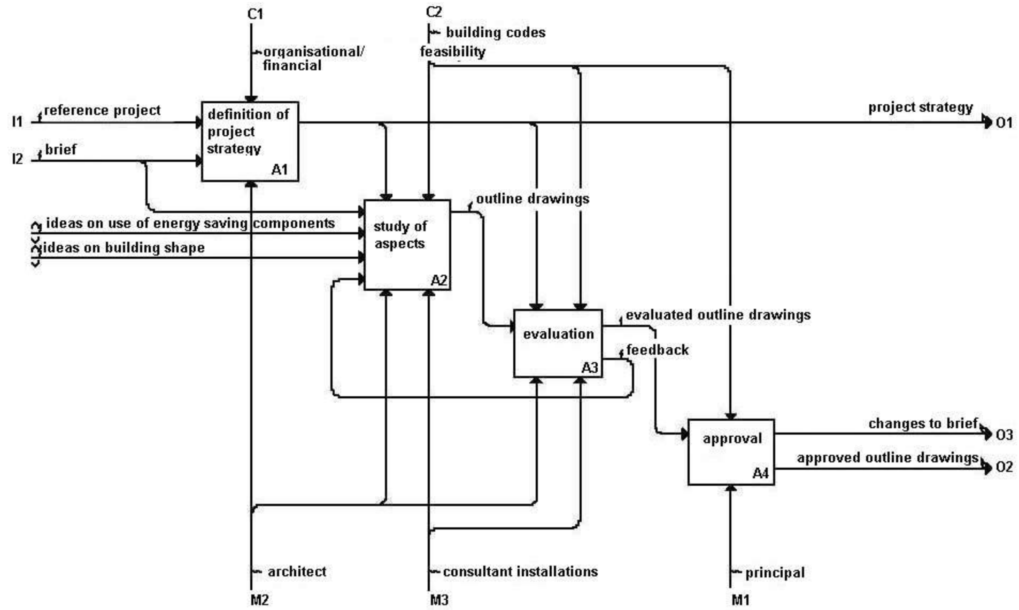


Fig.2-30. IDEF-0 diagram describing the phase of conceptual design for Rijnland office.

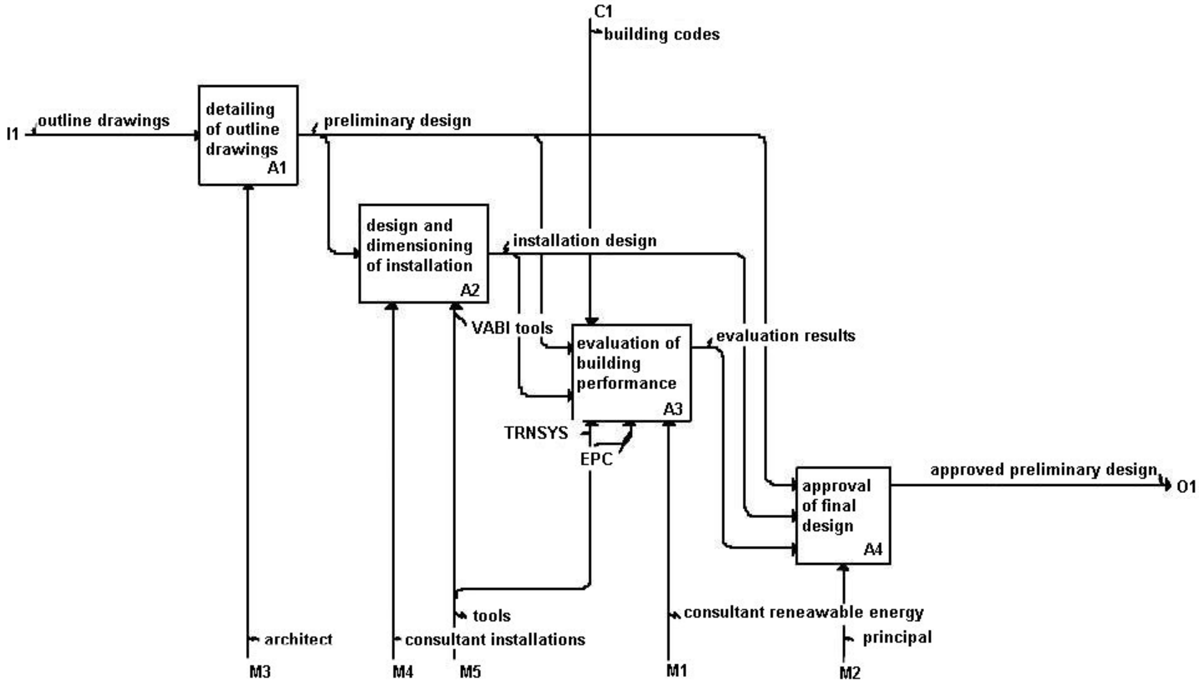
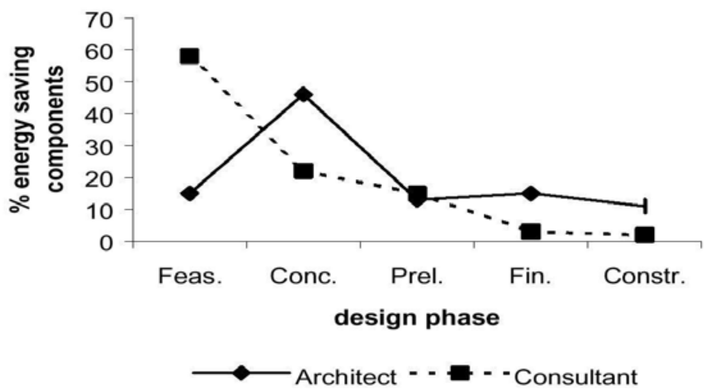


Fig.2-31. IDEF-0 diagram describing the phase of preliminary design of ECN building.

Wilde, Augenbroe et al. (1999) conclude that any analysis using energy tools plays a very limited role in the average application of advanced energy saving technology and there is a lack of control over when and how a particular analysis should be commissioned in order to take maximum benefit for the immediate design decision.

In an investigation of the need for computational support for a specific stage of the building design process, Wilde, Voorden et al. (2001) evidence distinct perception by architects and consultants concerning the phases in which energy saving features or components are selected.

In ten building projects questionnaires, architects state that most energy saving measures are selected during conceptual design, whereas consultants state that most energy saving measures are selected during the feasibility



study in Fig.2-32.

Fig.2-32. Energy saving measures selected per building design phase[22].

When questioned about the phases that tools were used, the graphical representation of the answers in Fig.2-33 shows that the computational efforts start early in the design process and takes some time to be completed. For consultants the question was divided into an indication of the phase in which computations started and an indication of the phase in which they ended.

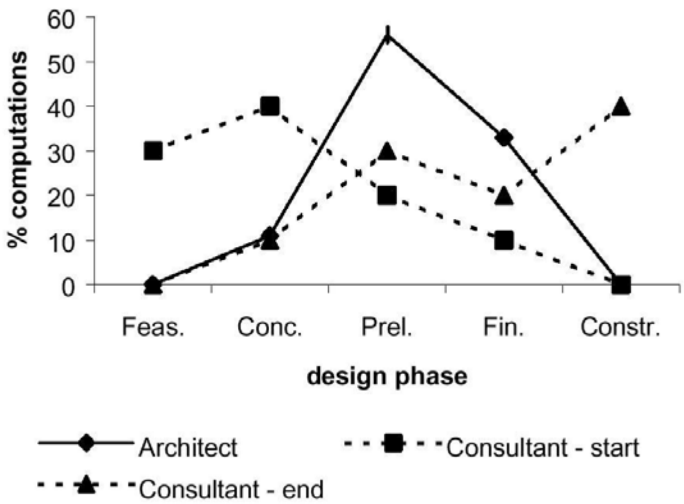


Fig.2-33. Phases in which computational tools are used for assessment of energy consumption of whole buildings.

Furthermore, at the beginning of the preliminary design, seven computational analyses have been started and only one was completed.

2.5.1 Pre-design analysis (Briefing)

Using the RIBA classification, the pre-design analysis involves the stages A-inception and B-feasibility, which consist of setting up client organization for briefing, consider requirements, carrying out studies of user requirements, site conditions, planning, design, cost, etc, as necessary to reach decisions. Both stages are classified in usual terminology as '*briefing*' (Royal Institute of British Architects. 1973). Whatever type of design process is finally chosen, the earliest phases will be concerned with briefing and search for a solution space definition, which may contain the optimum solution Szokolay (1984).

The origin of the briefing, as noted by Heath (1984), comes from British legal practice: '*A solicitor receives instruction from his client. He learns what matter is in dispute, and what, at least in his client view, are the facts of the case. He writes all this out in a suitable form for*

[22] The design phases are feasibility study, conceptual design, preliminary design, final design and construction drawing and building specification.

study by a barrister, who uses this brief as the basis for his pleading in court, together of course with his knowledge of legal precedent'.

The usual briefing starts with information on the given building type, available in R.I.B.A. bibliographies, briefing guides, journals, and visit to similar buildings. It must include office standards studies, such as statutory requirements (town planning, building regulations, loading, fire, etc), environment standards (lighting, heating, ventilation, sound control), anthropometric and ergonomic standards. By the end, it is necessary to be aware of equating resources available with client requirements and distributing expenditure in terms of cost/ benefit (Broadbent 1966).

The owner/ client is not always aware of the briefing or even of the implications of his requirements. Lawson (1997) noticed that many clients are not ready to prepare a brief in accordance with architects' preference: architects preferred few lines or a simple mission statement rather than a two inches thick document. Using the experience of a practicing architect, Heath (1984) presents four considerations:

1. Clarification of goals for the project and the background of the organization and the participants;
2. A definition of the area requirements in terms of physical space, tools, participants, and activities, including anticipated flexibility;
3. Development of adjacency matrices based on the adjacency of social activities, environmental criteria, and servicing proximities;
4. Establishing alternatives in terms of activities, personnel, size of units, and relationship to site and community.

In smart building briefing, Lima (1997) recommends that the first step establishes the organization's and project's goals, such as level of control, energy efficiency, maintenance and operating costs, effective use of space and effective business operation. The second step establishes the organization's and user's requirements in order to achieve the goals, such as business organization. The third step utilizes information from previous steps to identify the requirements of each building attribute. The fourth and final steps consist of physical building requirements to achieve the established set of goals.

The integration of low energy strategies follows similar approach. Szokolay (Szokolay and Pedrini 2000) defines the pre-design analysis as the crucial phase: "*it is this stage that rational analysis must delineate the boundaries of the designer's freedom: … define the* *'solution space*'". The process starts with a collection of ingredients: client's brief, environmental constraints, given site, climate conditions, cultural factors, images from 'glossies', fashion magazines of architecture and so on. At this point, Szokolay understands that these elements are filtered down in the subconscious (what the RIBA calls assimilation of the design problems): '*put them into the cocktail shaker, shake it well, prod and thrust the non-rational mental processes to come up with a basic design idea, a concept suitable for further development'*.

The 'High-performance commercial buildings: a technology roadmap' (Representatives of the Commercial Building Industry 2000) defines the targets to be set for the building as the first element. The Energy Research Group (1993) proposes the same action because the designer must have a clear idea of objectives. Using information contained in the briefing such as type of activity, acceptable thermal conditions are defined and the designer has a clear target. At a later stage, the designer should identify the key energy-using processes that can help to achieve the performance goals.

Many authors agree that the first clue for a solution is the site considerations. Broadbent, in his article 'Notes on design method' (Broadbent and Ward 1969) starts his commentary about environment design process with the follow sentence. '*There is one simple fact about any building. It has a site, which is 'real' and physically measurable'*. Climate, microclimate, access to sunlight and views are components of this analysis. Visits to the site, discussion with local residents, analysis of the general climate of the district and review of bioclimatic design strategy are essential tasks, but they are also amazingly simple to be done. There is much information associated with the site, such as weather, shading, type of energy available, culture and others. Szokolay (1984) recommends initially the thorough study of the weather and suggests some tools to support it: the use of bioclimatic analysis based on Olgyay and Olgyay (1963); simple software based on the Mahoney-table method (Szokolay and Docherty 1999); review of designs and consulting codes and recommendations prepared by trusted bodies. In his opinion, this step is characterized by 'rules-of-thumb', as opposed to rigorous calculations and long reporting with quantifications. Any advice produced should be in the form of '*if…. then….*'.

The other clue is the interaction between the environment and the type of activity: ' *is it possible to use daylight for the task inside the building(?) …. the thermal comfort can be reached using natural air ventilation and the users accept it?* 'Broadbent and Ward (1969).

Burberry (1983) also points to similar topics, as previously shown in subchapter Strategies (page 46).

Combining the briefing method proposed by Lima (1997) for 'smart building' with bioclimatic design and energy performance requirements, discussed by Burberry, a sequence is synthesized as presented in Table VII.

Table VII. Pre-design sequence.

step	definition	evaluation
1. Organization and project goals	time-dates for building construction finances-resources available energy performance (based on patterns and guidelines)	energy guidelines client preference and constraints site potential for bioclimatic principles cost savings and pay-back
2. Organization requirements	user's necessities	comfort levels nature of work strategies for energy saving
3. Analytical framework	interrelations that would be affected by decisions and set their priorities	rank order energy inputs flexibility for future changes, such as exterior shading of envelope and even exterior obstructions
4. physical building requirements	synthesis of all information into a physical environment	evaluation of the synthesis

Some of the previous issues (as site potential, pay-back, rank order of energy inputs and evaluation of synthesis) are orientated to analysis based on calculation. They match the statement of Szokolay (Szokolay and Pedrini 2000) '*we need a numerical sense, a feel for numbers and a repertoire of numbers indicating everyday magnitudes'*. Although it is possible to use case studies that match the initial design intentions, the use of computer tools to assess energy performance is still the most accurate measure.

2.5.2 Schematic design phase

The Royal Institute of British Architects(1973) uses the terminology '*sketch plans'* to characterize the outline proposals and scheme design stages. The first one determines general approach to layout, design and construction in order to obtain approval of the client. The brief is developed further and whole building design team is involved, as well as the client. The second one aims to complete the brief and decide on particular proposals to obtain all approvals. The briefing is finalized and the design is fully developed. In theory, the ideas are generated and developed into a hypothesis, which is achieved, discarded or modified until a final sketch and design proposal is agreed (Szokolay 1984).

Balcomb et al. (2000) warn that the first critical juncture in the process is the transition from pre-design to preliminary design: '*the most efficient use of the designer's talents will be made if they can proceed with the design with many decisions that affect energy efficiency and sustainability having already been made'*. The statement considers that low energy strategies are already decided in the pre-design phase and the next step is the development of them. For example, the first phase decides the use of exterior shading for windows and the second phase details it. But the skill of the architect will determine its aesthetics and efficiency.

The Taskforce (Sustainable Energy Building and Construction Taskforce Report 2001) ratifies the common sense: '*… the main design parameters are determined in the Schematic Design phase, often by the client and architect, and inputs on environmental initiatives are often only sought in the Design Development phase − by which time the client may be locked into a sub-optimal solution…Engineers and specialty areas such as environmental design are often locked out of initial design decisions and the team is poorly placed to acquire detailed knowledge about new technologies and processes. Advanced systems and features are often added to basic design in later phases with consequent reduced performance levels, higher cost and disruption of the team'*. The engineers suggest that the usual design must be reformulated to emphasize integration of a wide range of technical skills in the design team and representation of all stakeholders including the client, property consultants, values, etc. Apparently, the keys elements suggested in the report, Table VIII, group the pre-design with the schematic phases (based on previous reference). However, the most important aspect is the recognition of a preliminary energy analysis during the schematic phase, followed by detailed energy simulations during the design development phase.

Table VIII. Key Elements of an Integrated Team Process.

Schematic Design Phase	Design Development Phase
Definition of performance goals Preliminary energy analysis Establish performance assessment criteria Site and climate aspects of buildings Project Quality Plan for design Preliminary Environmental Management Plan for design, construction and operation.	Design Environmental Management Plan to ensure following occurs: Day-lighting, indoor air quality and ventilation assessment Detailed energy simulations Preliminary building fenestration design Structural system selection Preliminary building envelope design Preliminary lighting/power system design Preliminary heating, ventilation and cooling systems design Preliminary life cycle cost and life cycle analysis (materials embodied energy). Preliminary building commissioning requirements to meet Sustainable Design initiatives

For the evaluative programs, Szokolay (1984) suggests the use of some simple software as opposed to more refined ones such as DOE-2 and ESP-r, due the long time to input the parameters and time of machine run: '*If the procedure takes more than 10 or 15 minutes then* *it simply won't be used* '(Mazria 1980). For the generative programs, Szokolay (Szokolay and Pedrini 2000) believes in the interoperability of CAD packages and energy tools to support the process. The process is predominantly rational and many simulation programs can offer a contribution:

- a solution is postulated and the software is used to evaluate (evaluative programs);
- a solution is provided by software, typified as constructive or generative.

2.5.3 Detail design phase and final evolution

The detail design process and final evolution are well known processes for users of energy tools because they naturally fit to the usual method of model and evaluation. Basically, the tools work with a base case, which could not be produced in the earlier stages. Hayter, Torcellini et al. (1999) synthesize the process in a nine-step process for low-energy building design: '

Detail design:

Create a base case building model to quantify base case energy use and cost, which meets the '<u>ASHRAE STANDARD 90.1-1999. Energy Standard for Buildings Except Low-Rise Residential Buildings'</u> (American Society of Heating Refrigerating and Air-Conditioning Engineers and Illuminating Engineering Society of North America. 1999).

Complete a parametric analysis to determine sensitivities of specific load components.

1. Develop preliminary design solutions.
2. Incorporate a preliminary design solution into a computer model of the proposed building design.
3. Prepare preliminary set of construction drawings (based on step 4).
4. Identify an HVAC system that will meet the predicted loads.
5. Finalize plans and specifications.

Final evaluation

6. Rerun simulations before design changes are made during construction.
7. Commission all equipment that would affect the building's energy performance.'

In terms of decisions during the detail design stage, the parametric simulations executed in specific software (for thermal performance, solar position angle determination, lighting levels, CFD, etc) are used to decide the most appropriate materials, dimensions, thicknesses and other details (Szokolay 1984).

For final evaluation, Szokolay (1984) recommends that *'when the design process is nearing completion (but before everything is cut and dried) it may be advisable to employ one of the more sophisticated energy budgeting tools available'*. Using the same procedure as described in Hayter, Torcellini et al. (1999), that all elements are analyzed as parts of the whole system. The performance results are compared with performance-based codes and with budget target numbers. The approach allows identification of dramatic mistakes and, if there is a still time available, correction can be made.

2.6 Energy Tools

Energy tools are software and methods to assess building design and real building. The aim of using such tools is to improve performance of the building. The software reproduces the complex and dynamic interactions the building has with its environment and its installations. It produces predictions or performance based on the building model. *"The design analysis involves the 'creation' of a behavioral model of a building design, … and analyzing the outputs of the simulation runs. Models are developed for a problem domain by reducing the physical entities and phenomena in that domain to idealized form on a desired level of abstraction, and formulating a mathematical model through the application of conservation laws"* (Augenbroe 2000).

The origin of computer simulation for building energy assessment is obviously associated with the advent of computers because the process consists of repeating a large number of manual calculations. Probably it started simultaneously in many laboratories in many parts of the world as soon as a computer became available. Particularly in the USA, Kusuda (1999) recalls that the full scale computer applications for HVAC related problems started in the early sixties, to evaluate the thermal environment in fallout shelters by an hour by hour simulation of heat and moisture transfer process between human occupants and shelter walls under limited ventilation conditions. And general building thermal simulations based on hour-by-hour calculations were started at that time by gas and electric industries. Since then, the oil crisis in the seventies and the world environment concerns in the nineties influenced the continuous development. Nowadays, computational developments that bring faster processors and friendlier graphical interfaces, stimulate the extension of many energy tool applications, extended from the research in laboratories to commercial use in offices. As Hiller and Schuler (1999) recognize, the tools are useful to check the feasibility of low energy strategies. The impacts of design decisions made can be assessed and their cost consequences evaluated. Hong, Chou et al. (2000) define seven main uses of energy tools that fit in well with the M&E engineer's task:

- building heating/ cooling loads calculation to quantify and optimise HVAC equipment;
- energy performance analysis for design and retrofitting;
- building Energy Management and Control System (EMCS) design;
- complying with building regulations, codes, and standards;
- cost analysis;
- studying passive energy saving options;
- Computational Fluid Dynamics (CFD).

Hong, Chou et al. (2000) also classify energy tools in two categories: design tools (DTs) and detailed simulation programs (DSPs). DTs are more purpose-specific and are often used at the early design phases because they require less and simpler input data. DSPs are more complex and often incorporate computational techniques such as response factors, finite differences, finite elements, and transfer function for building load and energy calculations. Energy tools can also be classified based on other attributes. The most comprehensive website devoted to energy tools has more than 200 software packages in its database, more than 80 specifically for whole-building analysis (Office of Building Technology 2001)[23]. It provides information for each one and the link to contact the produce. The classification uses the following parameters:

[23] http://www.eren.doe.gov/buildings/tools_directory/

Whole-Building Analysis

1. Energy Simulation
2. Load Calculation
3. Renewable Energy
4. Retrofit Analysis
5. Sustainability/Green Buildings

Codes and Standards

1. Materials, Components, Equipment, and Systems
2. Envelope Systems
3. HVAC Equipment and Systems
4. Lighting Systems

Other Applications

1. Atmospheric Pollution
2. Energy Economics
3. Indoor Air Quality
4. Multibuilding Facilities
5. Solar/Climate Analysis
6. Training
7. Utility Evaluation
8. Validation Tools
9. Ventilation/Airflow
10. Water Conservation
11. Misc. Applications

2.6.1 Limitations

The use of simulation in practice requires a warranty that the results conform to reality, and this is only possible by a comprehensive evaluation and a generalized sensitivity analysis. The current main energy tools are acceptable in terms of accuracy of their algorithms, because they were subjected to exhaustive validation studies, such as DOE-2 (Sullivan and Winkelman 1998) and ESP-r (Strachan 2000). The validation can be done comparing energy tool outputs with analytical calculations, with a validated tool or through experimentation, measured response of real buildings.

Furbringer and Roulet (1999) propose a comprehensive approach (Fig.2-34) to validate the tool through experimental validation: '*...squares represent operators acting on the reality or on the output of other operators.*

The reality is first questioned to obtain data used to model the phenomenon. Interpretation, modelling and translation into computer algorithms are the main operations for obtaining a simulation model. When validating this model, new measurement on a distinct subset is necessary'.

However there are other factors that affect the accuracy of energy simulation results, besides the algorithm, such as the subjectivity (Corson 1992) of the modeler. First, it is necessary to consider a model as an abstraction of the reality, in which the modeler uses codes to represent physical variables. Second, the user effects in algorithms are a permanent problem unfortunately, especially when the user does not understand the assumptions made (Carruthers 2003).

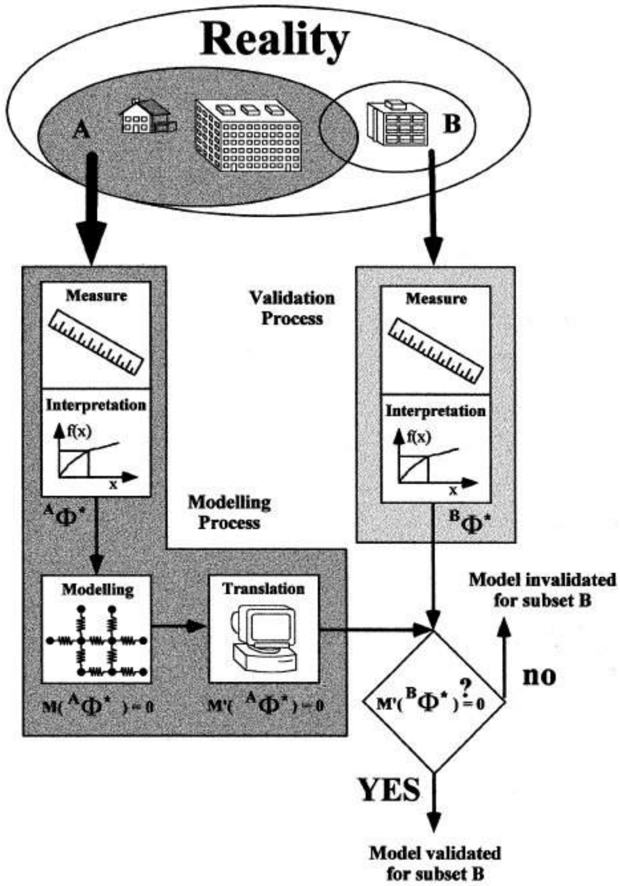


Fig.2-34. Knowledge model used to elaborate the validation process.

The consequences are:

1. Each physical variable has its own accuracy and frequently the modeller must adapt the real case to the software (simplifications).
2. Algorithms demand hundreds of inputs to run a simulation. The majority of the energy tools have defaults to simplify the input process, which are variables with high chance to be appropriate. Usually, the adoption of defaults is not obvious for the user, mainly for beginners.
3. Sometimes the modeller may not be aware of all possible sources of information. A consultant working with an architect or a modeller executing an analysis at a distance may also lack complete information.

Lawson (1997) describes a series of limitations regarding the use of computers in design. Energy tools are a specialized type of software and their solutions are limited to their point of view (energy performance). They can be ignored in another part of whole design process, such as circulation arrangement. In addition, there is no evidence of designers generally using a sub-optimizing approach to the process. Another problem is that these tools demand their own input: a thermal analysis tool demands an input different from a lighting analysis tool. Szokolay (1984) confirms it as an obstacle to widespread use of the tools: *'the building must be described in a form suited to the various programs, which have all been developed independently of each other. And this is not only a rather time-consuming exercise but also requires the learning of each program's particular idiosyncrasies'*.

Brown and Novitski (1987) introduce the Energy Scheming (a new software) with a straight critique of the common practice: '*The vast majority of software for designers, whether analytical or presentational in purpose, requires as input a building which has already been designed, or at least developed to the point that it can be reduced to a set of clearly understood number of lines. This exacerbates the schism between technical considerations and the creative process because it requires users to pick up lock, stock, and media and move to a new work environment in order to change from a designing mode to an evaluation mode'*.

Brown and Novitski (1987) remedy the problem offering '*a computer environment that allows users to sketch ideas in ways that encourage experimentation and imagination and that also lead, without cognitive interruption or a sharp break in work habits, to technical evolution'*. In a later article, Brown (1995) affirms '*during the early stages of design, precision is not the goal… The idea is to allow designers to consider energy at the same time* *as basic architectural issues, such as site orientation, elevation composition and functional relationships between spaces.*' Apparently, the software concerns energy assessment in residential buildings.

Szokolay (Szokolay and Pedrini 2000) recognizes a lack of energy tools for pre-design analysis beyond an initial climate analysis: '*the designer's thinking on approaching the first concept may be dominated by images, by structural possibilities or by plan considerations, just to mention a few*'.

The overview of energy-based tools in usage in Singapore (Hien, Poh et al. 2000) identifies obstacles to their dissemination in architecture offices. The main one is the inherent system limitations. The other factors are: emphasis on the initial or capital cost by the clients and the fragmented building delivery process. The authors suggest that a solution is the development of an integrative computational design support environment where there is effective integration of a CAD system with various performance based simulation tools.

In a building simulation overview, Hong, Chou et al.(2000) recognize limitations already mentioned, such as the general impossibility of assessing the sketch during the early stages of design and absence of integrated systems. They also recognize that the current systems are knowledge-based: '*they can only solve closed problems (what-if type), i.e., they can provide results corresponding to what the user inputs, but they cannot provide suggestions to improve design*'.

2.6.2 Tendencies

Hensen and Nakahara (2001) believe that most practitioners are aware of the emerging building simulation technologies, but few are able to claim expertise in their application. In their opinion, the imminent introduction of performance-based building standards, supported by training in simulation, will diffuse the energy tools into practice. Hien, Poh et al. (2000) share a similar opinion '*the shift from the prescriptive nature of the building legislation to a performance-based approach will further enhance the use of energy tools*'; the authors believe the solution is an integrative computational design support.

Software developers are working to create energy tools interoperable and there are many packages in development as software and protocols. One of the early attempts is referenced in Szokolay (1984), which describes a project to link energy tools to the PALETTE CAD package. Probably more researchers identified the potential of this strategy, but the massive effort came later, in the nineties. The COMBINE project (Kenny 2001), started in 1991, was created to merge all functional elements of a building project into a totally integrated design (Fig.2-35). In 1994, the International Alliance for Interoperability (IAI)–with help from LBL – began developing a universal object data model, in which each tool is able to access a common building data model (Bazjanac 1999). The last version, released in 1999, is the IFC 2.0 (Industry Foundation Class). The IFC-compatible software products are being released and the EnergyPlus (Crawley, Lawrie et al. 2001) is the LBL's first IFC-compatible simulation tool.

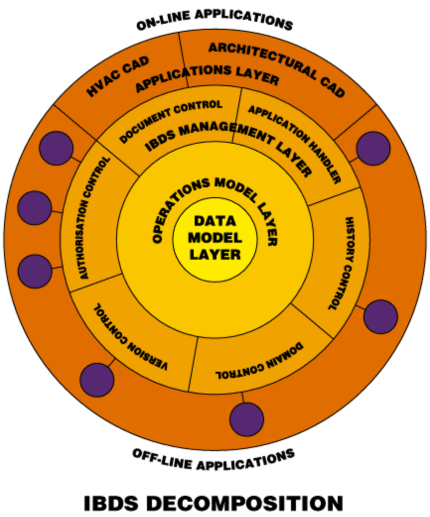


Fig.2-35. Combine 2 project (Kenny 2001)

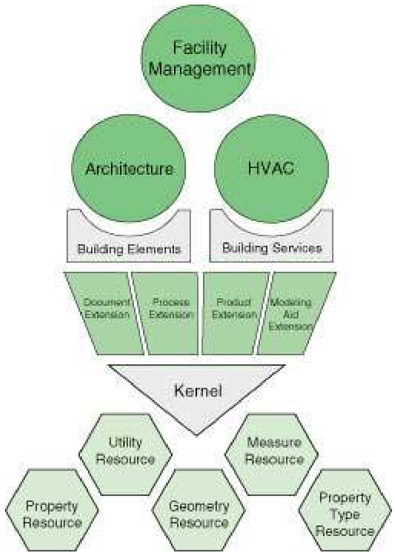


Fig.2-36. IFC interoperability diagram (Bazjanac 1999).

Gartner and Haves (1999) introduce another interoperability project that aims at the development of a series of new technologies, integrating a set of software tools to address all aspects of the life-cycle of commercial buildings (Fig.2-37). These include tools such as lighting, thermal, diagnostic techniques, cost effectiveness, sustained energy savings, enhancing health, comfort and performance of building occupants.

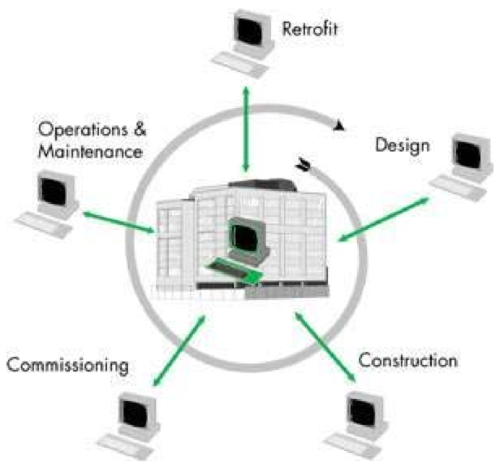


Fig.2-37. Integrated tasks (Gartner and Haves 1999).

Conlon (2000) recognizes the lack of truly usable building energy simulation tools and suggests that software developers need to understand the design process through the eyes of non-engineers. Other aspects are also mentioned, such as time demand to learn the software, the software does not recognize the architect's approach because it asks the user to think like mechanical engineers, the software does not match the tight schedule because demands so much time for modelling and evaluation. This mismatch leads to the observation that energy tool developers must appreciate the practice of architecture and the author refers to the survey conducted by Geopraxis, Inc. to show how practitioners use current computer tools. The results show the 3D CADs are used in the early stage for marketing presentation in large projects (although mid-size and smaller projects do not) and 2D models are used for drafting.

Moreover, two thirds of offices that use 3D models prefer simplified rather than detailed models. Considering that low energy strategies have more impact on building performance, GeoPraxis, Inc. announced the development of an easy-to-use energy analysis software module that will be integrated with an existing 3-D CAD software tool (Conlon 2001), Fig.2-38.

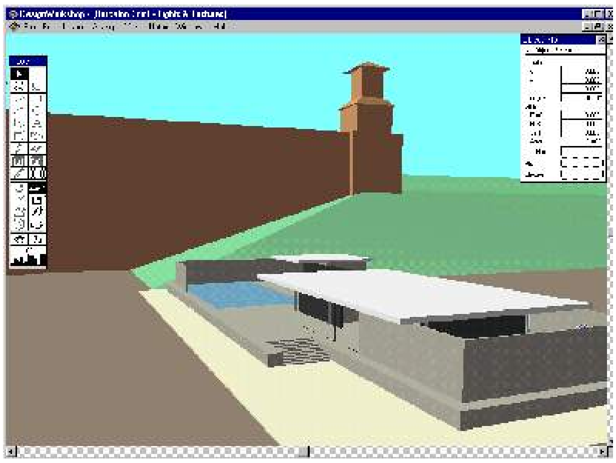


Fig.2-38. Simplified 3D model.

Other projects in development aim to support architectural design, such as the Building Design Advisor[24] (BDA) from LBL. As described by its author (Papamichael 1999), the aim is *'to create a software environment that will facilitate building design by allowing designers to quickly and easily specify the characteristics of potential designs and get information about their performance'*. The BDA centralizes the building information in a database that can be shared as input for another software, such as DOE-2 for thermal analysis, Radiance for lighting and COMIS for airflow. The philosophy is the same as of object-orientated programming. Furthermore, each time a parameter is requested, the tool addresses the task for the specific software, which automatically runs the process. The BDA developers believe the software can be used in the early stages of design, when the required details of building components and systems are not yet specified. Then, the BDA automatically assigns default values to the model if the user does not declare it.

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24 http://gaia.lbl.gov/BDA

2.7 Observations and Conclusions

At this point, there are many observations, doubts and directions for further exploration that need to be discussed.

2.7.1 Interaction of professionals

The first observation concerns the involvement of different professionals in an efficient building design development. Basically, there is no guarantee of satisfactory synergy in this field due so many aspects, such as complexity of the theme, lack of knowledge, misunderstanding regarding building behaviour, lack of communication between the architect and the engineer and so on. The few references that argue successful achievement do not detail the interactions.

The absence of a true integration of professionals is evident in many supporting areas, such as the case studies and the energy codes. The literature is selective when reports interaction of professionals to achieve an efficient building design. Only the successful cases are reproduced while the majority of the ordinary cases are unobserved. Obviously, nobody would like to confess his/her own mistakes if the result is frustrating in terms of final performance. Nobody knows what is going on in these interactions unless by self-experience or a good net of contacts. Another problem, considering a lack of critical evaluation is that architects do not want to say 'unfavorable' things about fellow professionals. Is that benevolence or a fear of litigation?

There is a consensus that it is highly desirable for architects and engineers to work together from the early stages of design (Jones and Boonyatikarn 1990; Hiller and Schuler 1999); commonly the success in energy performance is proved with early partnership. The personal experience (of the author) working with architects had produced some observations, which do not have a scientific rigor, but address the subject. The observations come from three building design processes in different periods in the last tree years, with three different groups of architects who have very different level of understanding of low energy strategies (from basic to ostensibly high understanding). The first and highly pronounced obstacle observed during the three tasks is the beginning: the dialogues were poorly productive. The architects did not have a specific question or doubt; they asked to the engineer to assess the sketches and to recommend alternatives to improve the design. The engineer (the author) had little to contribute in terms of architectural design because these parameters were already defined, with a great investment of time. The engineer's actions were restricted to identify the main sources of thermal loads and to derive alternatives with low energy strategies, with emphasis on the building services. One of the three tasks started in the early stages and it gave an opportunity to work during the pre-design steps. Unfortunately, the short time available for that and the occurrence of 'bugs' in the software frustrated the process; the sketch that emerged did not have any pre-study regarding the bioclimatic principles and low energy strategy. Anyway, the attempt showed the difficulties to provide a pre-design study when the only parameter is the site and the type of building. In this case, the engineer opted to concentrate on potential doubts of the architect, to reduce the number of analyses.

Another observation from these experiences is the difficulty of the task to 'translate' the usual technical output reports (from energy tools) to accessible and usable information for the architects. They did not assimilate graphic outputs of thermal load behaviour and other technical details. They expressed more satisfaction with results based on 'rules-of-thumb'. Simple and short answers are wanted.

The experience and informal conversations with others consultants, as Dr. Szokolay and Dr. Willrath[25] evidence architects' behaviour. Usually, architects look for support in energy assessment design during the detail design phase, when there are only a few possible changes to be made. At this point, the design is almost fully developed and the remaining doubts are usually about materials and components. Although this procedure is criticized by many energy consultants, Burberry (1983) thinks that there are two ways to reach an efficient design: *'the strategic stage when general concepts are being developed and the detailed design stage'*. This affirmation finds support when the available energy tools are assessed and the lack of resources between the two steps (briefing and detail) is evidenced. In view of these facts, the architects seem to do the right thing: principles are in the books and guidelines and energy consultants happen during the detail phase. But are the results satisfactory?

Probably nobody can properly answer it, but there is a suspicion that some of the buildings referenced as models of energy performance, are a product of building services (which consists of a strategy related to the detail phase) and energy management. Both factors combined would be enough to lead a building with mediocre envelope to an efficient performance (Table I: Building energy behaviour., page 15).

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[25]Energy consultant, author of BERS (Willrath, H. (1998). The thermal performance of houses in Australian climates. [St. Lucia, Qld.],**:** 1 v.

Another point concerns the briefing for low energy strategies. The subchapter ‘Design principles and guidelines’(page 39) suggests that the current architectural ‘principles’ are vague, general valid only under certain conditions (which are not specified) and even fashionable; insufficient to guarantee a satisfactory performance. Then, even the most useless ‘principle’ could be used to support some design idea, which could be further ‘fixed’ by engineers. If this hypothesis is true, or partially true, the design of envelopes can be significantly improved. However, it is necessary to provide tools and methods to act in the intermediate phases.

1.1.1 Strategies

Low energy strategy is a multifaceted issue and the most appropriate manner to deal with architects during the design process is still not clear. Some points concern the subject and are valid for strategies:

1. Low energy strategies can be specific (or appropriate) for different stages of design.
2. Low energy strategies can be ordered in a rank of importance, considering type of building, climate and occupancy.
3. Low energy strategies change their impact on the building performance when interact among themselves. It is desirable to assess different combinations.

1.1.2 The creative action

The ‘black box’ that produces the design is ‘technically’ localized between the briefing and the sketch. The briefing or pre-design stage carry a sort of information, piece by piece, to feed the ‘cocktail shaker’, as Szokolay theorizes (Szokolay and Pedrini 2000). The complex interaction of these data in a designer’s mind produces a ‘spark’ of creativity and the design is created. In this stage, the prediction of energy performance is just guesswork. However, the designer may need specific assessment to test hypotheses restricted to components, which is not a rule.

1.1.3 Design phases

Based on the premise that most influential decisions are taken during the early stages of design, the ‘outline proposals’ phase carries a huge potential to improve energy efficiency, which is little discussed.

The representation of the building is a *draft* that must express intentions and offer information enough to support decisions such as design and cost (Royal Institute of British Architects. 1973). Consequently, it is reasonable to believe the *draft* must also provide some sort of energy performance as against a cost assessment.

There is a current tendency to replace the usual draft by more seductive ways of presentation, using 3D models (Conlon 2000), but it happens without any increase in the level of detailing. For example, the model of the Fig.2-40 (Bank of China Tower) does not seem be more detailed than the sketch of Fig.2-39 (although it may give a better notion of volume and proportion). However this type of model is adequate for the use of energy tools such as the LTV (Pedrini and Hyde 2001).

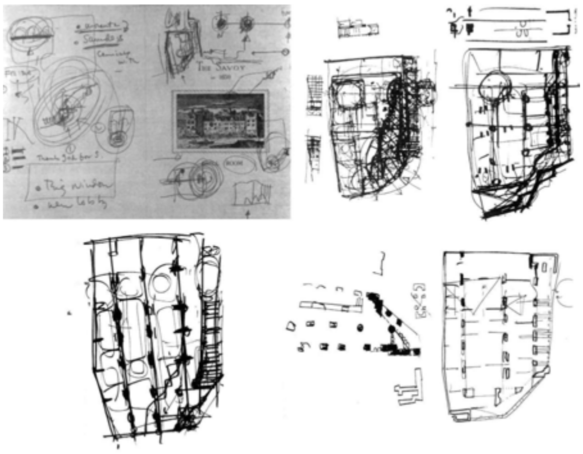


Fig.2-39. Robert Venturi developing a line of thought about the National Gallery extension as plan (Lawson 1997)

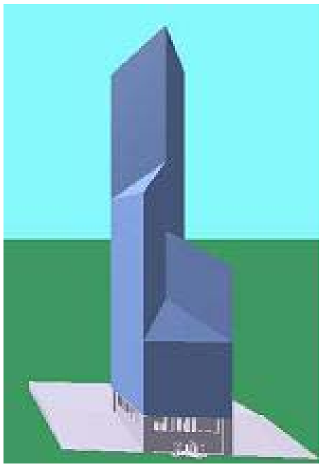


Fig.2-40. Bank of China Tower, 3D Spatial Model (Great Buildings Online. 2001)

Fig.2-41. Bank of China Tower, exterior overview (Davis 1990-2001).

1.1.4 Architect’s behaviour

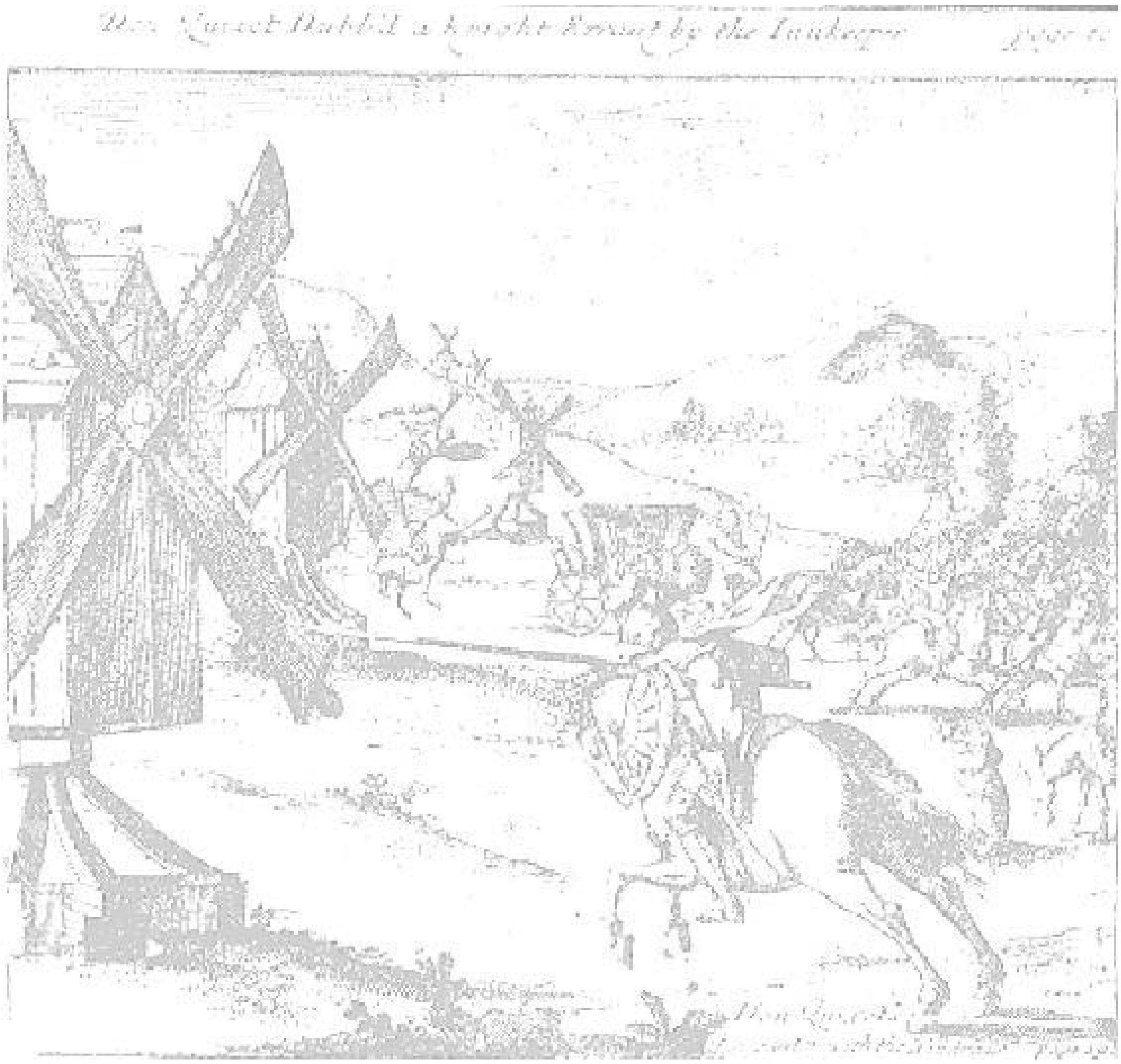
It is not possible to identify a representative pattern of the design process that can be used in practice and there is no guarantee of a predominant theory appropriate for the widely varying behaviour of architects. The most reasonable alternative is to respect the design process as an intrinsically free manifestation. However, it is possible to predict potential actions and to support them with appropriate information (compatible with the HMO’s theory, in subchapter Design theory), as the LTV does. Parametric simulations are done and the architects can choose when and what to look for in the results database.

1.1.5 Energy tools

Sometimes the literature affirms that the use of computer simulation by building professionals is now considered commonplace (Hong, Chou et al. 2000). So far, it might be valid for some specific places, but certainly not for Brisbane and Brazil.

Any intention to produce integrated energy tools reveals an extremely complex issue, such as the COMBINE project (Kenny 2001) and the International Alliance for Interoperability (Bazjanac 1999). While this approach optimizes the use of energy tools, the approach can still only assess a design when it has a high level of detail. In these terms, the majority of energy tools are orientated to test conjectures in detailed design. A good exception is the announced development of an easy-to-use energy analysis software module that will be integrated with an existing 3-D CAD software tool (Conlon 2001).

3 Research method



The research method focuses on three main issues previously discussed. Firstly, methods and issues concerning design process, architecture design decisions and low energy strategies are introduced to four different groups of architects using a questionnaire. The intention is find out when and how important they are in the early stages of design. Secondly, real design processes with emphasis on energy performance are developed by three different groups of architects. The aim is to learn how designers cope with the issue and to get an authentic view of their mental process. Thirdly, the influence of the architect on energy consumption is estimated using parametric analysis developed to quantify the influence of design decisions and to check routines commonly used by architects. At the end of each approach, comments and conclusions are presented. Combined, the three approaches are the base of the conclusions, in the final chapter.

3.1 Influence of architectural variables on energy consumption

Early design decisions play the major role and define building energy performance (Goulding, Lewis et al. 1992; Hiller and Schuler 1999; Wilde, Augenbroe et al. 1999). As early decisions have low level of detail, they tend to be based on generic recommendations, which may have low sensitivity to local characteristics such as climate, occupancies, schedule of use and others. Attempts to quantify the consequence of design decisions increases geometrically the number of cases to be examined for each new variable discussed. Consequently, quantifications are postponed to the detail phase, when the level of detail is enough to reduce the number of examined parameters. Burberry (1983) recognizes the lack of consideration of energy issues in the design process when he states that low energy issues are taken into account during the briefing (pre-design) and during the detailing phases, but not in the schematic design phase. Any reference to the use of quantification as a base of design decisions in the schematic phase remains rare in the bibliography, although it is during the schematic phase that important early design decisions are made.

The proposed research method stresses the importance of studying the consequence of design decisions during the schematic phase. Using parametric analysis as a core of the investigation, details of the approach are illustrated in Fig. 3-1.

The first task is to establish benchmarks from codes and guidelines (box 1), which will provide parameters to control further tasks, such as the definition of the base case (box 2), the selection of alternatives (box 3) and evaluation of the results (box 5) after simulation (box 4). The base case is the initial model, which has representative characteristics for a type of building and for a region and consequently must be extended for the alternative models as a common set of defaults. In task 4 the variables are to be combined generating thousands of permutations, which are to be simulated with DOE2.1E[26]. Thus, a database is built up. Through a graphic interface, the database can then be interrogated and the consequence of design decisions identified.

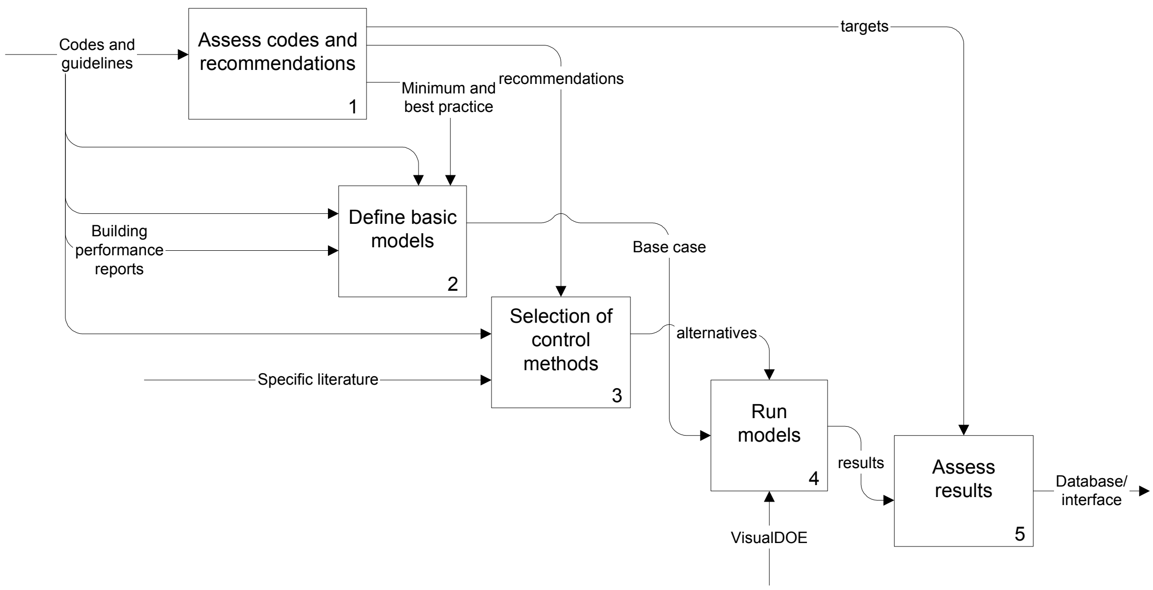


Fig. 3-1. Variables for parametric analysis.

[26] Similar procedure has been used in the LTV development (Pedrini and Hyde 2001)

The 'selection of control methods' task is to define the parameters and the defaults or constant model characteristics, plus other considerations (box 3 of Fig. 3-1). It consists of an exploration of the relationship of architectural design variables and low energy strategies (Fig. 3-2). The selection of architectural variables (box 1) focuses on primary design decisions that are commonly made during the early design stages, such as envelope and broad interior arrangement (as demanded by room and function). The second group consists of variables related to low energy strategies (box 2) that influence the energy performance as they interact with the architectural variables. The use of daylight control interacting with the fenestration is an example because if the designer opts for a particular arrangement, it must be decided early as sketches may imply a commitment.

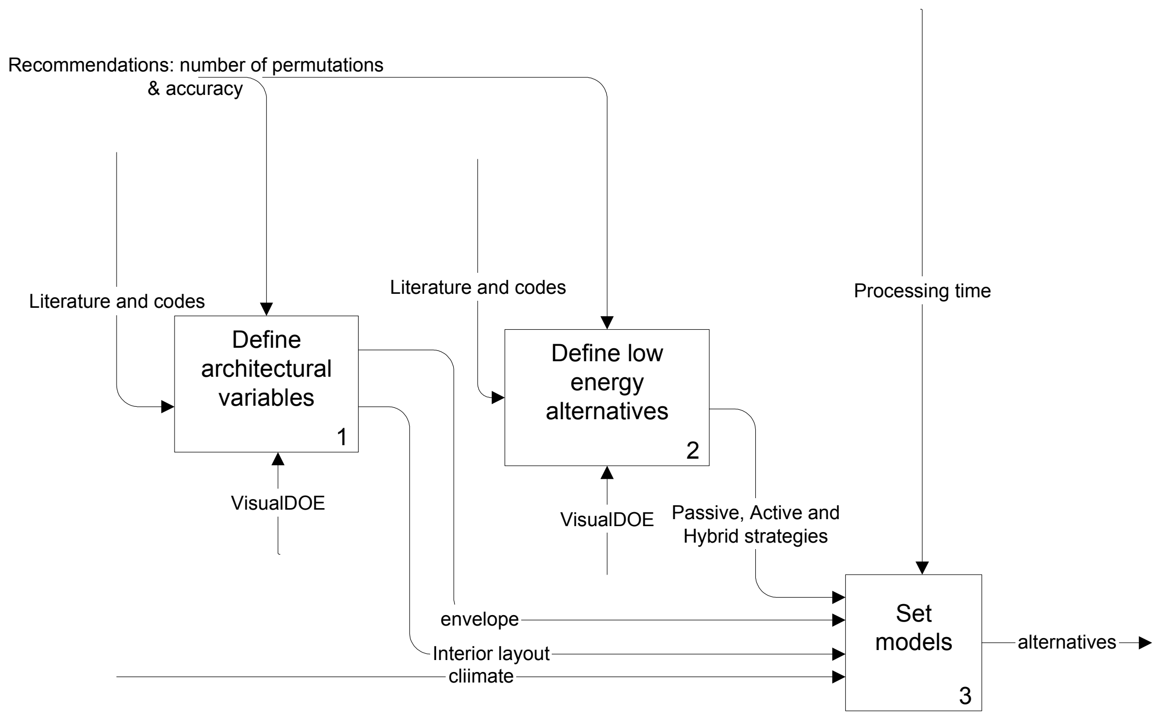


Fig. 3-2. Selection of strategies (amplifying box 3 of Fig. 3-1).

3.1.1 Parametric study

Since computers were introduced in the early seventies (Kusuda 2001), parametric simulations became a very common method to identify the influence of building characteristics on thermal performance and energy consumption. The procedure is simple: a base case is created and replicated many times, with one variable changed each time. The results are correlated with the input variables. The initial aim was to identify the most influential parameters for simplified equations that could generate results equivalent to those produced by detailed computer simulation. One of the most successful example is the OTTV Method (Hui 1997). The most common purposes are exploratory studies to generate energy codes, development of simplified tools such as LT, f-chat[27] (Duffie and Beckman 1980)and EnvStd (Eley Associates 2000b), model calibration and detailed analysis of the influence of components. A recent example is the ABCB calling a tender inviting specialist consultants to assist in the development of energy efficiency measures, also based on parametric simulations (ABCB 2001a).

Considering that the parametric analysis is based on a computer model, it is necessary to discuss its accuracy and alternatives to improve the reliability of the results. Macdonald and Strachan (2001) recognize that there are many sources of uncertainty when using modelling to assess the thermal performance of a proposed building or refurbishment project. Then, they propose a sensitivity analysis as a technique for determining the effect that uncertainties or model variations have on the model predictions. They address the following issues:

A. Model realism: How well (and to what resolution) does the model represent reality?
B. Input parameters: What values should be used in the absence of measured data?
C. Stochastic processes: To what extent does the assumptions made regarding future weather, occupancy and operational factors affect the predictions?
D. Simulation program capabilities: What uncertainties are associated with the particular choice of algorithms for the various heat and mass transfer processes?
E. Design variations: What will be the effect of changing one aspect of the design? '

Following the authors, the analyses can be carried out from testing the influence of a few parameters that are thought to be significant to a comprehensive treatment such as testing all

[27] Method for estimating the annual thermal performance of active heating systems for buildings.

model input parameters. When these concerns are extended to the design (and not real buildings for refurbishment), the following understandings are presupposed:

- **A.** *Model realism and* B. *Input parameters*: There may be considerable differences between how buildings seem to perform and how they really perform (Pedrini, Westphal et al. 2001). Similar differences between a design and its realization (the operative building) are expected. While the performance of building components is easily predicted, the use of equipment and schedules are out of the designer's control. Consequently, there are risks in assumptions or wishes as a representation of (future) reality. One alternative is the adoption of representative values for a specific type of building, such as ABCB (ABCB 2001b) does, and lay the emphasis on comparative accuracy of responses to changes.
- **C.** *Stochastic processes:* Complementing the previous topic, occupancy can be based on field study such as the one of ABCB. Weather prediction is still complex and the most reasonable choice is the use of TRY, TMY or WYEC statistical weather files. Probably the most uncertain aspect of simulation is the prediction of operational factors, i.e., how people will respond to the introduction of new technologies such as daylighting and HVAC controls. It is reasonable to assume that the designer defines a potential that can be achieved during commissioning by management and fine tuning.
- **D.** *Simulation program capabilities:* Every software available has weaknesses, which makes any analysis more or less dependent of the choice of the tool. The alternative is to combine several tools, knowing what tool is more appropriate for each specific task
- **E.** *Design variations:* The consequences of changing one aspect of the design, mainly if organized in successive increments is the parametric simulation, recognized as a method to assess model sensitivity.

Besides attention to external design conditions and desirable internal environmental conditions, other issues are also relevant, such as energy targets and energy analysis, as reported in Building Energy Brief for Commercial & Public for the pre-design stage Buildings (Taylor Oppenheim Architects, Lincolne Scott Australia et al. 2000). The external conditions are depicted by the climatic data. The internal conditions are related to typical real cases and to design interventions, such as adaptive cooling set point versus ISO or ASHRAE standards. As important as the inputs are the outputs. While some tools such as DOE-2 have hundreds of reporting formats (W.F. Buhl November 1993) for different purposes, it is necessary to identify what is relevant from the point of view of architects' concern. Experience has shown that 'less is more' when architects demand feedback from simulations. The use of technical jargon or physical explanation may be pedantic and break the dialogue in some circumstances. Consequently, it is desirable to produce concise and objective information, avoiding unnecessary or distractive data. At the same time, the outputs must be in accordance with codes and guidelines, in terms of units and method (Representatives of the Commercial Building Industry 2000).

None of the previous issues are obstacles to executing the current investigation; Australian literature provides enough information to satisfy the topics. There are many software packages available that can support parametric analysis. Due the long experience with DOE-2.1E algorithm and VisualDOE interface, VISUALDOE 3 (Eley Associates. 2000) is chosen. Furthermore, it also satisfies the document 'Requirements of the Modelling Program' (ABCB 2001f).

3.1.2 Performance, metrics and benchmarks

The use of benchmarks and energy targets demand the identification of what to measure and how to measure. As suggested by Representatives of the Commercial Building Industry (2000), the central characteristic of high-performance building must be measured according to different categories of building use. The main reference is the STANDARD 90.1-1999 of ASHRAE (1999), which establishes the requirements for expressing energy performance, such as energy use in kWh per 12-month period and the quantity for each form of energy delivered to the building: electricity, fuels, heat and cooling. In case of estimating energy performance of new buildings, the standard uses the categories of space heating, space cooling, humidification or dehumidification, indoor lighting, outdoor lighting and HVAC auxiliaries.

In accordance with the previous requirements, the energy codes and benchmarks for Brisbane have been in development in the last two decades. There are the BCC code and Australian Building Greenhouse Rating Scheme benchmark. Nonetheless, the Queensland state government is developing an Energy Code that will specify the minimum energy efficiency requirements for new dwellings and the solar orientation of lots, in conjunction with the Building Codes Authority of Queensland and under the auspices of the Integrated Development Assessment System (the state's planning scheme), (Environs Australia 2002). However, a new one that will cover the whole of Australia is in development by the ABCB and the Australian Greenhouse Office, which aims to introduce energy efficiency provisions into the Building Code of Australia (BCA).

The previous codes and developments do not have necessarily the same philosophy and probably they will raise many questions when effectively introduced to architects. Anticipating the discussion, the next subchapters review the most important aspects of each one and compare their effect on design decisions.

Such codes are aimed at eliminating the worse practice and not at ensuring that 'best practice' is followed. Hence the codes are no substitute for design analysis.

Enersonics

In the early references, ENERSONICS (1986) defines energy consumption targets based on end use categories: cooling, heating, hot water, lighting, lifts, fans and pumps. Considering the 'office building' type with 2500 hours of occupation and location factors for Brisbane, the calculation of expected targets for extreme efficiency ratios are:

- cooling: 44.8 to 224 kWh/m² (corresponding to use of compression or absorption chiller plant);
- heating: 0.9 to 4.7 kWh/m² (corresponding to gas space heater and heat pump);
- others: 1.3 to 1.8 kWh/m² for hot water (corresponding to electric instant and gas storage);
- lighting: 36 kWh/m²;
- lifts: 8 kWh/m²;
- fans and pumps: 14 kWh/m².

The sum of these components results in an energy consumption target for Brisbane offices between 105.0 kWh/m² and 288.5 kWh/m².

Boma 1994

The Energy Guidelines released by BOMA (Building Owners and Managers Association of Australia. Victoria Division. 1994) are based on the major types of energy consumed within the building or complex. The energy targets proposed are based on benchmarks such as existing building analysis, which are updated from time-to-time. The 1994 edition defines the targets for Brisbane offices in Table IX, which specifies the energy for end use.

Table IX. Typical design targets for offices.

source	Electricity kWh/(a.m²)			Gas MJ/(a.m²)
office equipment (energy density= 5W/m²):	12			
lighting (energy density= 14W/m²):	36			
lifts	7			
ventilation and pumping	14			
cooling	24			
heating type	direct	heat pump	gas	
space heating	3	1	0	13
hot water service	2	1	0	7
Totals	98	95	93	20

Note: the summed targets vary from 98.5 to 103.5 kWh/(a.m²) and the 20MJ/a.m² equals 5.5 kWh/a.m².

BCC

The Brisbane City Council (BCC) code is reasonably simple in its presentation, as summarized in Table X (Brisbane City Plan. 2000). There is one prescriptive parameter, which defines the light power density, and there are two performance based parameters: one for the building space loads and the other for air conditioning efficiency.

Table X. Performance criteria and acceptable solutions for office buildings.

	Performance Criteria		Acceptable Solutions
P1	Buildings must be designed such that the building thermal envelope achieves an adequate level of energy efficiency	A1	Buildings achieve an overall Building Space Load of 147 kWh/(a.m²) *or less*, or equivalent greenhouse target.
P2	Buildings must be designed such that the air conditioning plant meets performance requirements, while minimising energy use	A2	Air conditioning plant is operated and maintained to achieve an air conditioning efficiency factor *equal to or greater* than 0.24
P3	Lighting must be designed to maximize natural lighting and meet performance requirements, while minimising energy use	A3	The Average Lighting Power Density for the development does not exceed 18 W/m²

The air conditioning criteria use the ‘air conditioning efficiency factor’, which is the ratio of the building space load divided by the electrical energy input (expressed in kWh/a.m²) of the proposed air conditioning plant. Building space load is the total annual heat load, in kWh/(a.m²) that must removed or added to a building interior by mechanical plant (Brisbane City Plan. 2000). The Energy Efficiency Code suggests as supportive technical literature the 'Technical Guidelines for Assessing Energy Efficiency' (Natural Environment Branch 1999), which says that the building space load is estimated though computer-based thermal simulation programs (used by suitably qualified assessors).

The analysis of the air conditioning efficiency factor (eq. 1) shows that it seems to be acceptable to have an electrical energy input higher than the building space loads. The limiting value is rather unexpected in the light of a similar limits set elsewhere. Actually, the inverse value (1/0.24 = 4.16) would be acceptable for an efficient COP.

$$\text{AC efficiency factor} = \frac{\text{building space loads}}{\text{electrical energy input}} \geq 0.24 \qquad \textbf{eq. 1}$$

The international literature presents a similar ratio to quantify performance, the seasonal energy efficiency ratio (SEER) and the seasonal coefficient of performance for cooling ($SCOP_C$). SEER means the total cooling output of a central air conditioner or central air-conditioning heat pump, expressed in Btu's, during its normal annual usage period for cooling and divided by the total electric power input, expressed in watt-hours, during the same period (Office of Energy Efficiency and Renewable Energy/ Department of Energy. 2000); (ARI 1994; ASHRAE 1995). The usual range of SEER is 10-15 Btu/Wh, although the maximum reached is 18 Btu/Wh (Office of Energy Efficiency and Renewable Energy/ Department of Energy. 2000). These values, converted from Btu/Wh to Wh/Wh are equivalent to a range of 2.93-4.40 Wh/Wh and maximum of 5.28 Wh/Wh. $SCOP_C$ corresponds to the total cooling output of an air conditioner during its normal annual usage period for cooling divided by the total electric energy input during the same period in consistent units (American Society of Heating Refrigerating and Air-Conditioning Engineers and Illuminating Engineering Society of North America. 1999)

There are two other expressions for energy efficiency ratios, both executed in a normative controlled temperature (independent of season):

- the coefficient of performance (COP): 'a ratio of the cooling/heating capacity (cooling/heating power) in watts (W) to the power input values in watts (W) at any given set of rating conditions expressed in watts/watts ' (ARI 2000). The minimum efficiency for water chilling packages is 2.5 - 5.2 W/W (depends on type and capacity) (Pacific Northwest National Laboratory 2000):

$$COP = \frac{kW \; refrigerantion \quad effect}{kW \quad input}$$ **eq. 2** (ARI 1998)

- energy efficiency ratio (EER): '*a ratio of the Cooling Capacity (output) in Btu/h to the power input values in watts at any given set of rating conditions expressed in Btu/Wh*' (ARI 2000). The minimum EER allowed in north American law is between 8 and 9 Btu/Wh or 2.3 - 2.6 Wh/Wh, and the best available is about 13 Btu/Wh or 3.8 Wh/Wh (EREN/DOE. 2001):

$$EER = \frac{BTU/h \; refrigerantion \quad effect}{watt \quad input}$$ **eq. 3** (ARI 1998)

Considering the fact of the magnitude proposed by the BCC doesn't match the previous energy performance targets, the BCC code was applied to a real case modeled in 2000, the Marshew building in UQ- Santa Lucia (Fig. 3-3). The application consisted of running the model of the building in VisualDOE 2.53 (Fig. 3-4), but modelling a hypothetical[28] chiller with COP equivalent to 4.40 W/W (average efficiency). The simulation resulted in AC efficiency factor equal do 2.94 and an overall building space load equivalent to 146.48 kWh/(a.m²). The total annual energy consumption per unit area[29] was equivalent to 172.00 kWh/(a.m²). Although the overall building space loads are within the limits proposed by BCC, the air conditioning efficiency factor is 12.25 times better than the minimum proposed.

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[28] It is out of question to model the current chillers due the degraded condition.

[29] Total area

Fig. 3-3. Marshew building (UQ/ Brisbane)

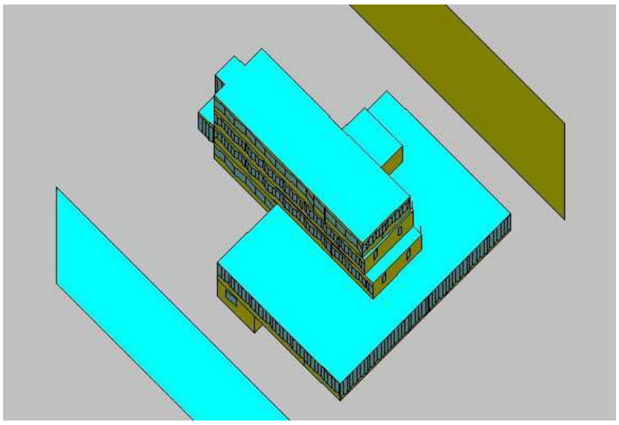


Fig. 3-4. Marshew building modelled in VisualDOE 2.53.

Unfortunately, the source of BCC regulation is not available and some aspects are not really convincing: the energy efficiency factor proposed for air conditioning does not match the most used ratios.

Early BCA (provisional)

The 'Scoping study of minimum energy performance requirements for incorporation into the building code of Australia'(Drogemuller, Delsante et al. 1999) reports average energy consumption based on various sources, Table XI: '

- NERDDP Project 819, 'Energy Budget Levels for Non-Residential Buildings in Australia', listed average energy consumption for offices, shopping centres and hotels for each capital city, based on returned surveys in 1986.
- In 1994 BOMA published 'Energy Guidelines' which included energy targets for office buildings. These targets are set at the 33rd percentile and are based on 2500 hours per annum of operation.'

Table XI. Energy consumption for Brisbane (kWh/a.m²) (Drogemuller, Delsante et al. 1999).

NERDDP 819 average	BOMA energy target	Adopted value by BCA
113.8	93.0	138.9

Australian Building Greenhouse Rating Scheme (ABGR)

The Sustainable Energy Authority Victoria (SEAV) has recently led an effort to support this scheme nationally with the Victorian scheme introduced in October 2000. The scheme is a simplified assessment of actual energy use in office type buildings and allows owners and tenants to rate their energy use on a five star scale (Sustainable Energy Authority Victoria 2000).

Table XII. Normalised greenhouse emission thresholds.

Rating*	Tenancy {($kgCO_2/m^2$) / (kWh/m^2)}	Base Building {($kgCO_2/m^2$) / (kWh/m^2)}	Whole Building {($kgCO_2/m^2$) / (kWh/m^2)}
1 star	171 / 168	215 / 211	387 / 379
1.5 stars	157 / 154	198 / 194	355 / 348
2 stars	142 /139	180 / 176	322 / 316
2.5 stars	127 / 125	163 / 160	290 / 284
3 stars	112 / 110	146 / 143	258 / 253
3.5 stars	97 / 95	129 / 126	226 / 222
4 stars	82 / 80	111 / 109	194 / 190
4.5 stars	67 / 66	94 / 92	162 / 159
5 stars	52 / 51	77 / 75	130 / 127

* 1kWh= 1.02 $kgCO_2$

- Base Building. This assesses the services traditionally supplied as "common" services to tenants, such as air-conditioning, lifts and common area lighting.
- Tenancy Rating. This assesses the energy use associated with services under the control of the building occupier or tenant, such as lighting, office equipment and any supplementary local air-conditioning.
- Whole Building. This assesses the whole building, encompassing all energy use within the building.

The procedure to assess a building performance is reasonable simple. As illustrated in Fig. 3-5, the first window identifies the building and its site, followed by the type of rating: base, tenancy or whole building rating. The inputs required in the second window are the area, hours or occupation, number of people and computers. In the third window the energy consumption is required, which may be obtained from bills (for real buildings) or simulation (for projects). The last window provides the energy performance.

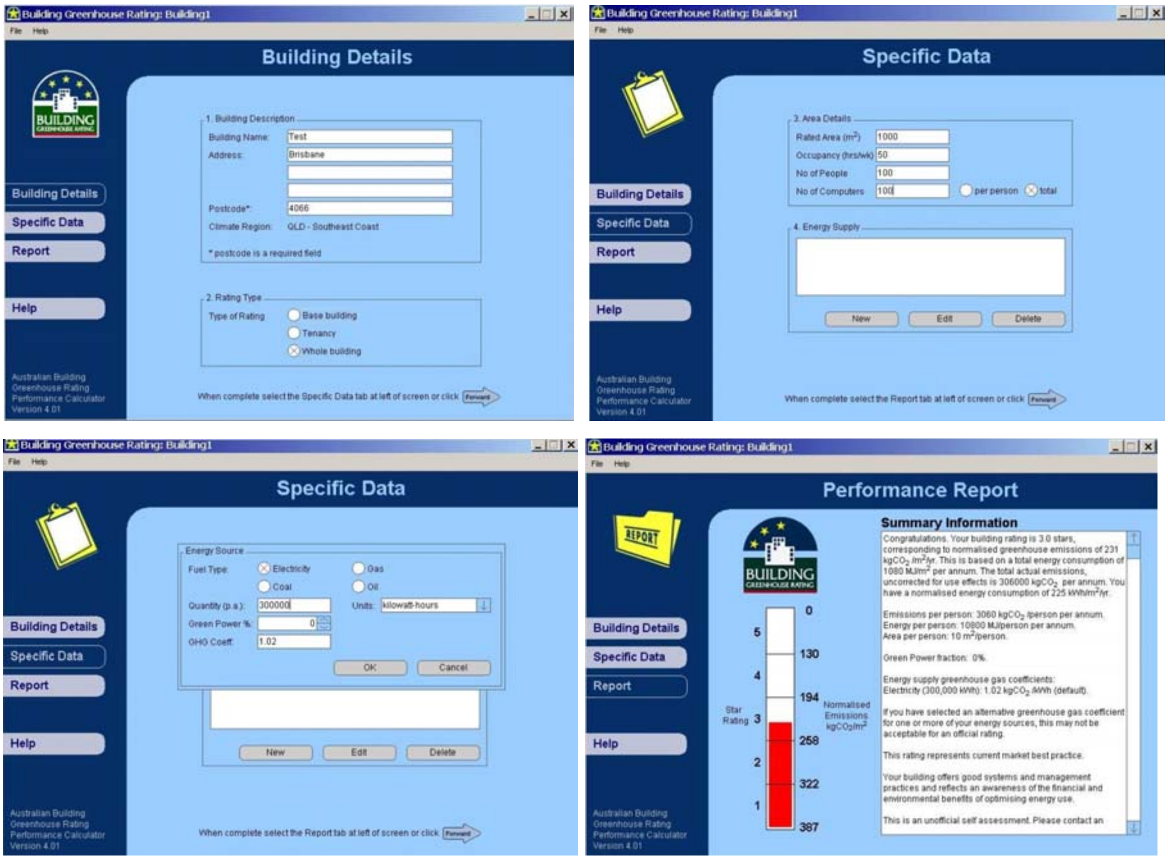


Fig. 3-5. Steps to assess building performance.

The only misunderstanding found happened during some tests regards the area definition. Initially the Table XIII used the area of occupied space for tenancy rating and area of office space plus common areas for base and whole building ratings (page 2 of (ABGR 2001). In a further explanation, all three types of ratings must be done using net lettable area for the tenancy based on the Property Council of Australia publication "Method of Measurement for Lettable Area" (Property Council of Australia 1997). Basically, the floor area must be determined from measurements of floor plans. The doubt was resolved after contacting Erica Kenna, who works for Paul Bannister at Exergy Group in Canberra: 'always use net lettable area'(Kenna 2001), as specified in the methodology: 'In the original scheme, gross conditioned floor area was used as the normalisation factor for floor area. However, feedback during the national extension exercise has led to the decision to use net lettable area as the normalising factor (Bannister 2000).

Table XIII. Data collection (ABGR 2001).

Tenancy	Base building	Whole building
Area of occupied space Energy consumed by the tenant Hours of occupancy Number of computers Number of people	Area of office space and common areas Energy consumed by central services Hours services are required	Area of office space and common areas Energy consumed by the building—office occupants and central services Hours of occupancy Number of computers Number of people

The method demands the energy consumption data as an input. Consequently, if somebody intends to use it as a design support tool, he/she must use another software to generate these data, preferentially based on energy simulation.

The second observation concerns the low number of inputs. For example, the area declaration is the only characterization of building design. However, it does not mean that the design assessment is neglected. Actually, it occurs indirectly through the energy consumption inputs. It becomes clear in the following building simulation exercise that combines two types of envelopes (bad or good) with two building services (bad or good), producing four models[30]. The result shown in Table XIV shows that:

- the 'tenancy' rating relates to the performance of lighting plus equipment: the tenancy rate changes only when the quality of building services changes, such as models 1 and 2 ('bad' building services) to models 3 and 4 ('good' building services);
- the 'base building' rating is mostly influenced by the air conditioning consumption: variations on envelope and consequently changes of thermal loads affect more the base building rating than any other rating, as it happens when models with 'bad' envelope produce base building rating 3.5 and 4 (models 1 and 3) and 'good' envelope results base building rating 5 (models 2 and 4).

Table XIV. Star rating related to components' performance.

model	envelope	building services (lighting and equipments)	tenancy rating	base building rating	whole building rating
1	BAD	BAD	3.5	3.5	3.5
2	GOOD	BAD	3.5	5	5
3	BAD	GOOD	5	4	5
4	GOOD	GOOD	5.1 (sic!)	5	5

[30] The exercise was done for this specific purpose using VisualDOE and based on representative defaults for Brisbane.

ABCB

The AGO and the ABCB formalized an agreement to include energy measures in the BCA, which aims developing as quickly as practicable, cost effective energy efficiency measures suitable for introducing under building law and, in so doing, assist the Australian Governments to reduce greenhouse gas emissions from the operation of buildings (ABCB 2001i).

Although the ABCB 'guide' is not ready at this moment, the Consultancy Brief (ABCB 2001b) reveals that the determination of energy use benchmark will lead to the performance requirements through a 'stringency analysis'. The first is simplified and contains global solutions. It is based on the worst case and uses a prescriptive solution, which is 'Deemed-to-Satisfy' the performance requirements. The second requirement is more accurate and it uses an Alternative Solution that is demonstrated to meet the performance requirements. Then, the owner has the choice as to which approach to use.

The Task Force observes that the ABCB strategy incorporates mandatory and voluntary measures which together aim to encourage a continuous shift towards improved performance across the whole of the building construction industry. Basically, it attacks the worst practice rather than promote the best practice, Fig. 3-6 (Sustainable Energy Building and Construction Taskforce Report 2001).

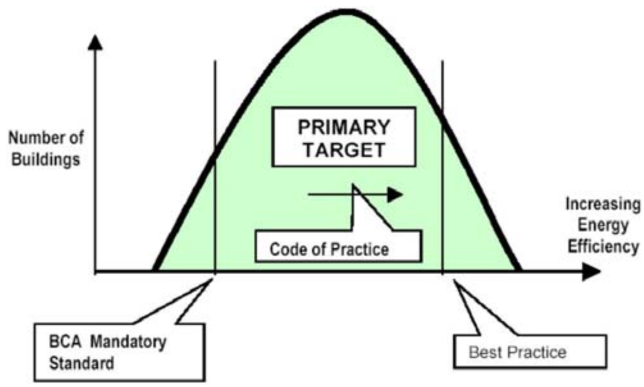


Fig. 3-6. ABEC Industry Forum, November 1999 (Sustainable Energy Building and Construction Taskforce Report 2001)

However, the development of a mandatory design code will not automatically eliminate bad practice or deliver good practice. The Task Force also believes that '*if mandatory BCA energy efficiency standards are not accompanied by other industry wide actions, the market distribution of buildings and level of energy efficiency might shift in counter-productive directions. ... In the absence of such additional actions, possible scenarios of counter-*

productive change are illustrated', Fig. 3-7 and Fig. 3-8. In other words, it may change the current distribution in the wrong direction, i.e. the intended minimum becomes the norm.

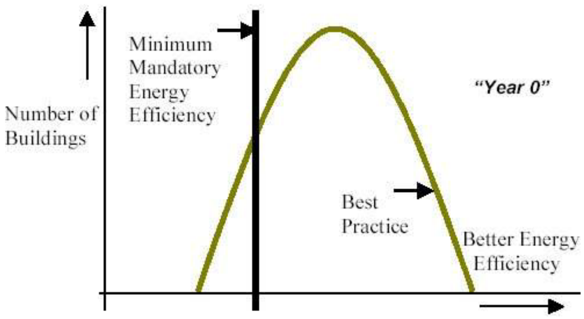


Fig. 3-7. Current distribution of buildings and energy efficiency

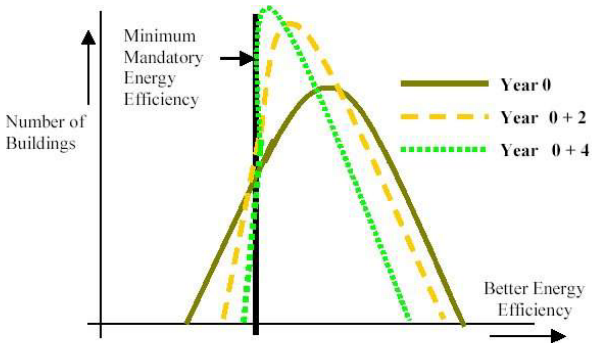


Fig. 3-8. Possible scenario after introduction of minimum mandatory requirements

Commonwealth targets

The Commonwealth departments, agencies and bodies whose operations are substantially budget-dependent are guided by different energy targets, as shown in Table XV (Energy and Environment Division 1999). The first target is the only one that relates the number of occupants to efficiency. The second target is similar to the BCC, 147 kWh/(m².annum), and significantly higher than BOMA, 93-98 kWh/(m².annum).

Table XV - Description of End-Use Categories and Energy Intensity Targets (Energy and Environment Division. 1999).

End-Use Category	Description	Target
Office - Tenant Light and Power	Energy used for tenant operations in buildings whose primary function is office space. It includes tenancy lighting, office equipment, supplementary air conditioners, boiling water units etc. The key indicator recognises that overall energy efficiency is a combination of the efficient use of the space as well as the energy efficiency of the space: $\frac{MJ}{(a.person)}$	10,000 MJ/ (person. annum) or 2.777 MWh/ (person. annum)
Office - Central Service	Energy used in the provision of services in office buildings common to all tenants. It includes building air conditioning, lifts, security and lobby lights, domestic hot water etc. If not directly measured, energy consumption is approximately equal to 30% of electricity and 100% of gas: MJ/(a.m²)	500MJ/ (m².annum) or 138 kWh/ (m².annum)

ASHRAE 90.1- 1999

ASHRAE/IESNA Standard 90.1-1999 - Energy Standard for Buildings Except Low-Rise Residential Buildings (ASHRAE 1999) is probably the most known standard in the world. The first edition was published in 1975, followed by revisions in 1980, 1989 and in 1999. Although it comes from an association of engineers and the second last edition had emphasized the HVAC, the most recent edition of Standard 90.1-1999 (ASHRAE 1999) presents a notable study on the building envelope.

As shown in Fig. 3-9, the majority of the stringency for envelope was developed in the last version (1999). The last version had also developed 60% of the stringency for mechanical and 40% for lighting services. It introduces a comprehensive and detailed prescription for 26 climatic zones, expanded and updated for the U.S. and Canada and international locations (first time ever), including Brisbane.

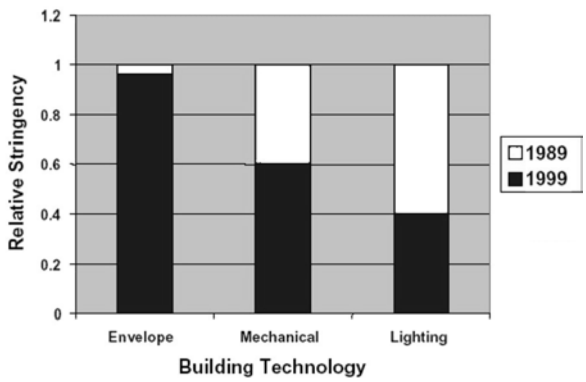


Fig. 3-9. ASHRAE Standard 90.1 Relative Stringency (McBride 2001)

The standard contains mandatory provisions and true prescriptive options that do not require calculation on the part of the designer. Pre-calculated assemblies are included and the designer can select the appropriate R-value for the insulation to show compliance. Of course, calculations may still be done to establish the U-factor for a specific assembly if the designer so desires.

The standard can be satisfied with the ENVSTD software (Eley Associates 2000b), which allows tradeoffs of all of the building envelope components, making extensive use of pull-down menus and provides an extensive library of envelope assemblies for compliance (Fig. 3-10).

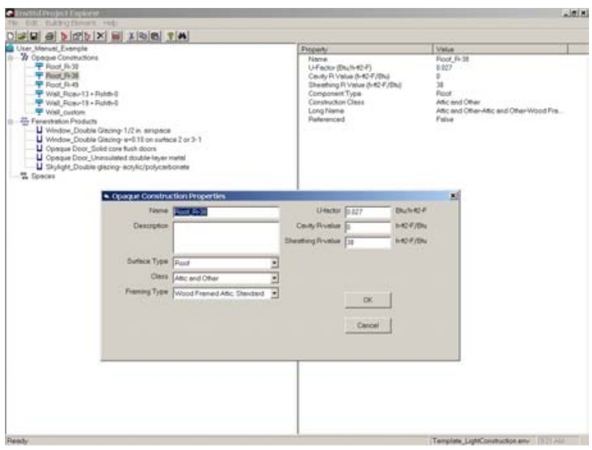


Fig. 3-10. EnvStd.

The mechanical recommendations offer three compliance paths:

1. mandatory provisions and prescriptive requirements;
2. mandatory provisions and the energy cost budget method that allows tradeoffs between prescriptive requirements;
3. simplified approach that includes all mandatory provisions and prescriptive requirements, in terms of the gross floor area.

To be used, the systems must also satisfy 15 specific criteria such as serving only one zone. The purpose of this approach is to reduce a designer's time to locate the requirements for these buildings (Jarnagin, Schwedler et al. 2000). In comparison with the previous codes and targets, the prescription of envelope requirements has a different approach because it defines envelope requirements that will influence the energy consumption. It is not necessary to define an energy target.

As previously mentioned, the Standard 90.1-1999 is also applicable to Brisbane and it relates to the table B-4 (page 94), which contains the building envelope requirements for a specific climate as shown in Table XVI. Aiming at a better understanding of the effect, a hypothetical building is simulated, combining the model proposal of ABCB (ABCB 2001b) complemented by the ASHRAE 90.1 (1999) main requirements, such as envelope, lighting (LPD[31] 14W/m²) and air conditioning efficiency (COP 5.20 , boiler efficiency 80%, fan power 1.17 W/(L/s)[32]. ABCB (2001b) provides the typical Australian characteristics, such as geometry, model A' from Appendix A (ABCB 2001d), schedules, EPD[33] 15 W/m², cooling set-point temperature 22°C, outside air rate 10 L/(s.person), occupancy 10m²/person, infiltration 1.5 air changes/hour, etc. Some observations must be made regarding this exercise. The $SHGC_{north}$, was changed for south when extended to Brisbane. In DOE-2 the outside film is calculated hourly as a function of surface roughness and wind speed, which varies from 0.0 to 113.56 W/(m² °K). For example, for a concrete wall with 50% absorptance under Brisbane climate, the annual average for surface conductance is 14.19 W/(m² °K) and for a similar roof is 81.46 W/(m²°K), as generated as output by DOE2.1E simulations. Assessing the previous result

[31] Lighting Power Density (W/m²): the overall lighting power density with no consideration of diversity Eley Associates (2001). VisualDOE 3.0 Program Documentation. San Francisco, Eley Associates: 332.

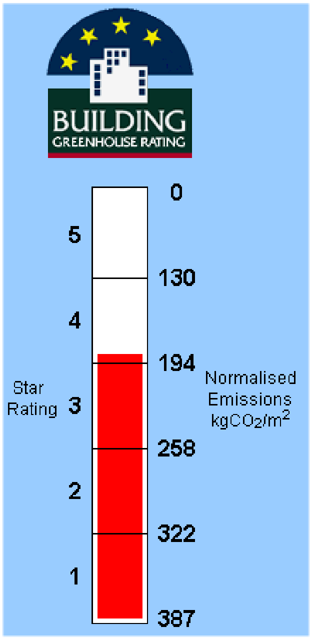
[32] Although the equivalent unit is J/L, it is recommended to keep W/(L/s) to express the ratio of power and flow of fans.

[33] Equipment Power Density (W/m²): the overall equipment power density with no consideration of diversity Eley Associates (2001). VisualDOE 3.0 Program Documentation. San Francisco, Eley Associates: 332.

with the Building Greenhouse Rating and assuming the model schedule has approximately 3746 hours of occupancy, the hypothetical model has 4 stars (Fig. 3-11).

Table XVI. Building envelope requirements from ASHRAE (1999)

Opaque Elements	Nonresidential Assembly Maximum	Nonresidential Insulation Min. R-Value
Roofs		
Insulation Entirely above Deck	U-0.536	R-1.8 ci
Metal Building	U-0.376	R-3.3
Attic and Other	U-0.196	R-5.3
Walls, Above Grade		
Mass	U-3.352	NR
Metal Building	U-0.711	R-1.9
Steel Framed	U-0.718	R-2.3
Wood Framed and Other	U-0.513	R-2.3
Wall, Below Grade		
Below Grade Wall	C-6.589	NR
Floors		
Mass	U-1.858	NR
Steel Joist	U-2.021	NR
Wood Framed and Other	U-1.628	NR
Slab-On-Grade Floors		
Unheated	F-1.26	NR
Heated	F-1.76	R-1.3 for 30.5 cm
Opaque Doors		
Swinging	U-4.046	
Non-Swinging	U-8.381	
Fenestration	**Assembly Max. U (Fixed/ Operable)**	**Assembly Max. SHGC (All Orientations/ North-Oriented)**
Vertical Glazing, % of Wall		
0-10.0%	U_{fixed}-7.05	$SHGC_{all}$-0.61
	U_{oper}-7.34	$SHGC_{north}$-0.61
10.1-20.0%	U_{fixed}-7.05	$SHGC_{all}$-0.40
	U_{oper}-7.34	$SHGC_{north}$-0.61
20.1-30.0%	U_{fixed}-7.05	$SHGC_{all}$-0.40
	U_{oper}-7.34	$SHGC_{north}$-0.61
30.1-40.0%	U_{fixed}-7.05	$SHGC_{all}$-0.40
	U_{oper}-7.34	$SHGC_{north}$-0.61
40.1-50.0%	U_{fixed}-7.05	$SHGC_{all}$-0.31
	U_{oper}-7.34	$SHGC_{north}$-0.46
Skylight with Curb, Glass, % of Roof		
0-2.0%	U_{all}-11.44	$SHGC_{all}$-0.61
2.1-5.0%	U_{all}-11.44	$SHGC_{all}$-0.25
Skylight with Curb, Plastic, % of Roof		
0-2.0%	U_{all}-10.98	$SHGC_{all}$-0.65
2.1-5.0%	U_{all}-10.98	$SHGC_{all}$-0.39
Skylight without Curb, All, % of Roof		
0-2.0%	U_{all}-7.86	$SHGC_{all}$-0.61
2.1-5.0%	U_{all}-7.86	$SHGC_{all}$-0.25



Excellent. Your building rating is 4.0 stars, corresponding to normalised greenhouse emissions of 188 $kgCO_2$ /m²/yr. [sic*] This is based on a total energy consumption of 988 MJ/m² per annum. The total actual emissions, uncorrected for use effects is 2799457 $kgCO_2$ per annum. You have a normalised energy consumption of 184 kWh/m²/yr.

Emissions per person: 3293 $kgCO_2$ /person per annum.
Energy per person: 11624 MJ/person per annum.
Area per person: 11 m²/person.

Green Power fraction: 0%.

Energy supply greenhouse gas coefficients:
Electricity (2,744,566 kWh): 1.02 $kgCO_2$ /kWh (default).

If you have selected an alternative greenhouse gas coefficient for one or more of your energy sources, this may not be acceptable for an official rating.

This rating represents strong performance in the current market.

Your building demonstrates excellent greenhouse performance, reflecting good design and management practices, high-efficiency systems and equipment, and/or energy sources characterised by low greenhouse emissions.

Fig. 3-11. Energy star rating assessment.

*$kgCO_2/m^2/yr = kgCO_2/(m^2.yr)$

Comments

The comparison of the BCC code with other codes leads to some comments. While the indices for overall building performance are based on cooling loads, most indices use energy consumption as the basis, such as energy star ratio (Exergy Group. 1999; Sustainable Energy Authority. 2001) and the methods of 'Measures for Improving Energy Efficiency in Commonwealth Operations'(Energy and Environment Division. 1999).

In comparison with the BOMA typical design targets for offices (Building Owners and Managers Association of Australia - Victoria Division 1994; Building Owners and Managers Association of Australia. Victoria Division 1994), the Australian Building Greenhouse Rating Scheme is more conservative. The simulation and rating of a hypothetical building, which matches the BOMA typical design targets for office produced a 5 stars building (for tenancy, base and whole building). Consequently, the BOMA targets are considerably stricter.

The majority of the previous codes are energy based (or thermal load based, for the BCC); they set performance targets. The extension of them to the design assessment leads to the following observations:

1. The BCC method drastically penalises unsatisfactory designs because it implies that all decisions must be taken before any appraisal. Consequently, the only solution is the re-design.
2. The codes don't support the architect because they are not prescriptive and they do not provide any guideline.
3. Unfortunately there are not enough professionals with an appropriate profile to satisfy the code.

Taking the BCC approach as an example of performance based code (although it is a poor prescriptive method because it provides only one pre-design condition: the lighting power density). The whole process is a complete 'black box' that is assessed in terms of a final performance test (Fig. 3-12), which is only possible using complex and comprehensive energy tools. It is implicit that the code can only be satisfied with a supportive partnership.

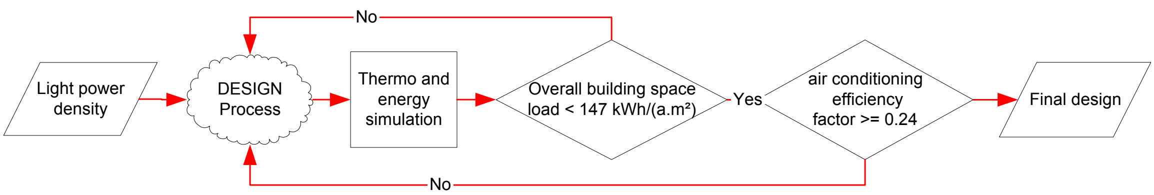


Fig. 3-12. Brisbane City Council criteria.

The previous codes and recommendations define different targets, inhibiting direct comparison, as illustrated in Table XVII. The 'Provisional BCA' only specifies total annual energy consumption per area; Enersonics and BOMA specify total energy and energy end-use. On the other hand, BCC specify only the thermal loads and it does not mention energy consumption while ASHRAE prescribes minimum performance of elements.

To compare these codes, two building models are simulated in VisualDOE. The first one is based on ASHRAE and ABCB recommendations and the second one is a slight variation, which replaces the ABCB recommendations by BCC requirements. Comparing the values in Table XVII, the oldest targets are the most ambitious, when the opposite would be expected. The most recent ones are more coherent and similar. If we consider that the 147 kWh/m² of thermal loads may be equivalent to 160 kWh/m² of energy consumption for BCC [34], and considering that the target of BCA is more conservative than it looks in the table[35], both come close to the result of simulated models using ASHRAE prescriptions and even the four stars (current target tendency). Comparing only the models, the ABCB has more conservative values for building services than the BCC, which generates an overall performance 31% better for the last one. Rating the models as shown in Fig. 3-13 and Fig. 3-14, the influence of building services does make a difference of 1.5 stars.

Table XVII. Comparison of benchmarks for energy end-use, in kWh/m².

	Prescriptions					Simulated results	
end-use	Enersonics 1986	BOMA 1994	BCC 2000	BCA 1999	ABGR* 2000	ASHRAE+ABCB 1999-2001	ASHRAE+BCC 1999-2001
lighting	36	36	-	-		66	45
equipment	-	12	-	-		60	39
cooling	44.8 to 224	38	-	-		149	106
heating	0.9 to 4.7	1	-	-			
total	108 to 288	95		138.9	190	249	172
thermal loads			147			207	158

*Based on 4 stars of Australian Building Greenhouse Rating.

[34] Based on the relation of the simulated model for ASHRAE.

[35] It considers 2500 hours per annum of operation.

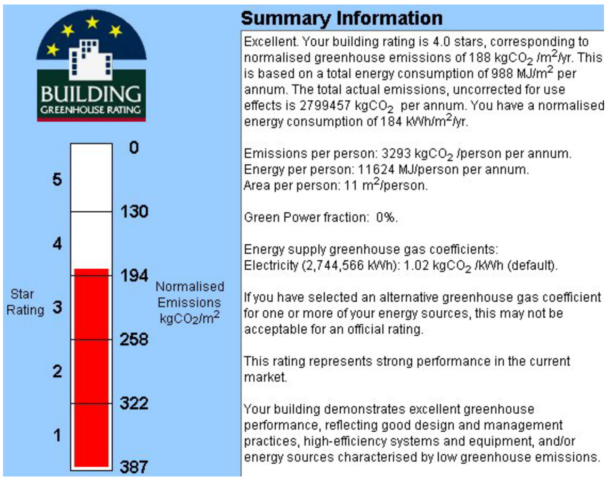


Fig. 3-13. Star ratio for ASHRAE model.

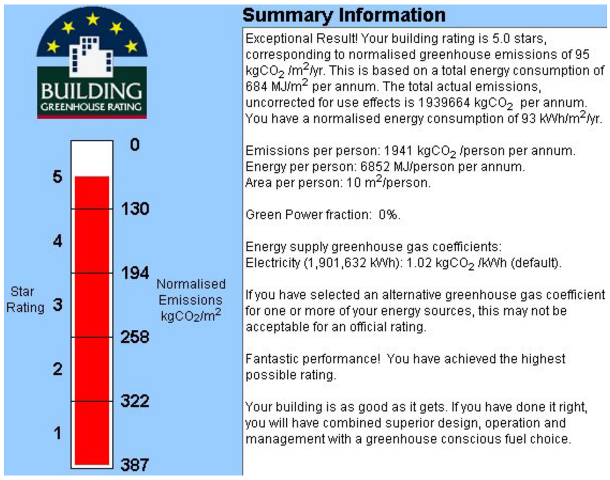


Fig. 3-14. Star ratio for ASHRAE envelope prescription with BBC characteristics.

Unfortunately, none of the recent codes considers the energy end-use target definition, which obscures the assessment of architectural variables. Then, the use of a specific energy targets seems to be pointless when the performance is assessed as an overall result because there is a variance among the previous recommendations and there is the disturbing influence of variables other than architectural. In this case, the use of an energy star rating is more rational because offers a large scale and makes comparisons easier. Although the absolute assessment may have questionable accuracy, the relative assessment is certainly more reliable.

Many inputs must be determined as defaults for every model of the parametric analysis and the ABCB provides them in detail. Comparing with BCC, ABCB is more comprehensive. Furthermore, if ABCB variables are adopted, a further comparison may be carried out with the expected results from the ABCB parametric analysis.

The ASHRAE standard seems to be suitable to support designers targeting satisfactory envelopes. Besides the thesis approach, the issue deserves more discussion with professionals, considering that it can fulfill some current Australian needs regarding energy code development.

3.1.3 Definition of models

The parametric analysis presupposes the definition of the models, which have permanent and variable characteristics. As the prime intention is to assess the 'efficient' design for warm climates, the models are preferentially defined as reproduction of Brisbane buildings. When required information is not available or is not reliable enough, the models are compiled with characteristics of Queensland, Australia and western buildings (preferentially located in warmer area as possible).

The climate adopted corresponds to Brisbane 1996, Table XVIII, the same one used in NatHERS (Delsante 1999), which is a warm humid summer and mild winter (ABCB 2001g). Most comprehensive data are available in the VisualDOE 3 package, which includes hourly data: dry bulb temperature, wet bulb temperature, atmospheric pressure, wind speed, wind direction, cloud amount, cloud type, clearness number, density of air, humidity ratio, specific enthalpy, total horizontal solar and direct normal solar radiation (WX-4 1980).

Table XVIII. Brisbane climate characteristics.

Latitude	Longitude	TRY	GMT+	Post Code	NatHERS identification[36]
-27.4	153.1	1986	10	4000	09

The building type corresponds to the BCA code classification (ABCB 2001i): Class 5, an office building used for professional or commercial purposes.

In comparison with common assumptions adopted during the analysis of commercial buildings (conventional assumptions), Laing, Duffy et al. (1998) discuss the conventional office workplace and suggest that it is wrongly assumed that:

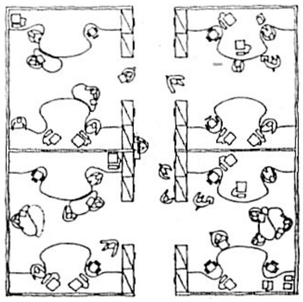
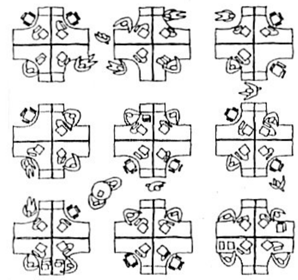
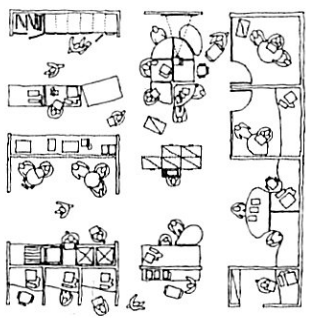
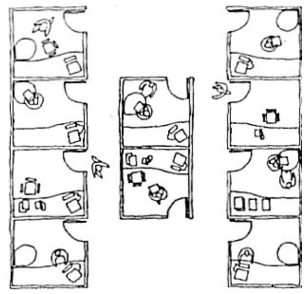
- office work is routine and undertaken largely by individuals working alone,
- most people are in the building during the course of the day and week;
- the range of space standards and settings for office is work is simple and hierarchical.
- information technology is fixed to desk and does not move around.

The authors suggest that such considerations belong to the past due to changes promoted by the organizations. Based on a survey of 400 office buildings during the 1980s, in UK, from

[36] Based on second line of Scratch file: '`0C:\NATHERS\CLIMATE\CLIMAT09`

BRECSU (Building Research Energy Conservation Support Unit) at BRE the authors recognize four modern working patterns: hive, cell, den and club. As detailed in Table XIX, they vary in terms of use, flow of information and types of activities, which contribute to shape the interior layouts.

Table XIX. Work pattern characteristics and interior lay-out (Laing, Duffy et al. 1998).

DEN group process work such as architecture, design, engineering low autonomy high interaction PC, specialized equip 9 to 5 hours, some variation 14.7 m²/person		HIVE individual process work such as banking, telesales, data processing low autonomy low interaction networked PC 9 to 5 hours, shiftwork 10.5 m²/person	
CLUB varied work such as advertising, media, information technology high autonomy high interaction elaborate IT complex timetabling 4.5 m²/person		CELL isolated work such as accountancy, law, academia, research, software develop high autonomy low interaction laptop, network PC individual timetabling 6.0 m²/person	

In practice, DEGW International Consulting Limited provides four examples of such considerations. Den and hive look like the 'old fashioned' office building, with more consistent and uniform use, open areas and higher density of occupation (Fig. 3-15 and Fig. 3-16). In theory, the deep room and absence of divisions favor low energy strategies such as daylighting and natural ventilation.

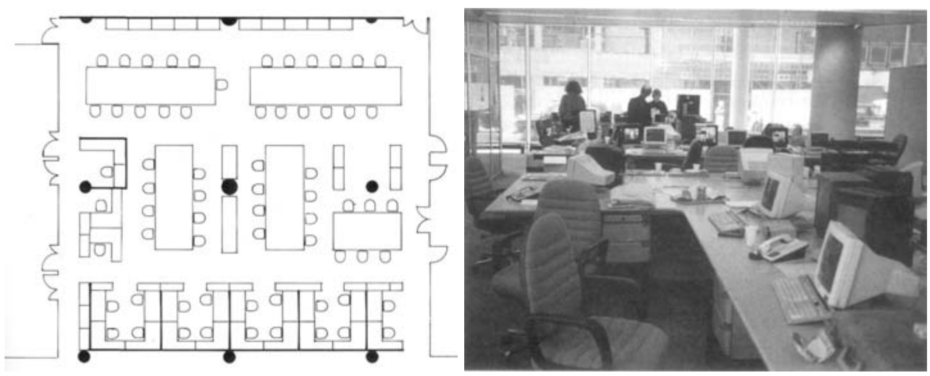


Fig. 3-15. Den case – ITN headquarters – plan view in interior views (Laing, Duffy et al. 1998)

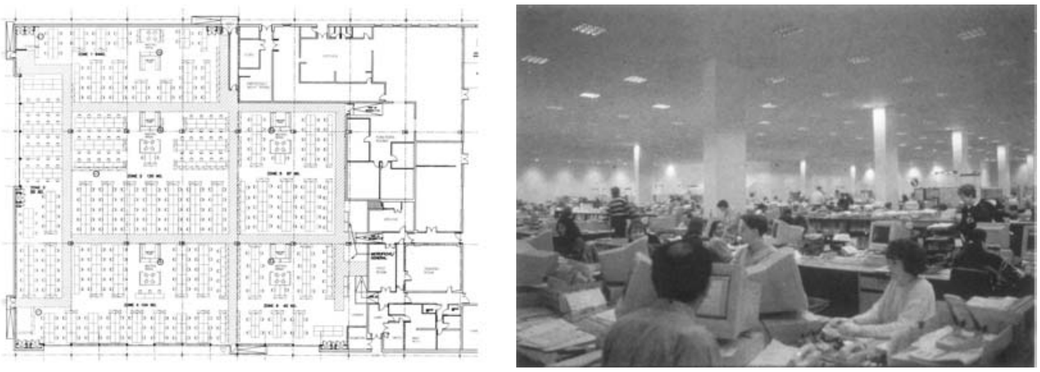


Fig. 3-16. Hive case – British Gas offices – plan and interior views (Laing, Duffy et al. 1998).

The club and cell cases are more complex to model and to assess the impact of low energy strategies, Fig. 3-18 and Fig. 3-67. Due to the tendency of enclosed rooms, the room depths are short, which limits the passive strategies. Apparently, these work patterns tend to favor active strategies based on independent controls and personal preferences. For example, the use of independent lighting controls or sensors of presence, daylight sensors, independent air conditioning settings for more suitable cooling set point(Auliciems 1990),

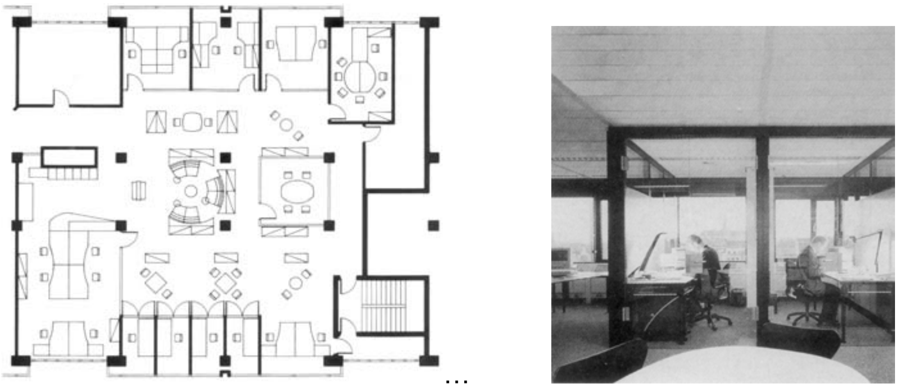


Fig. 3-17. Club case – Rijksgebouwendienst, Netherlands – plan and interior views (Laing, Duffy et al. 1998)

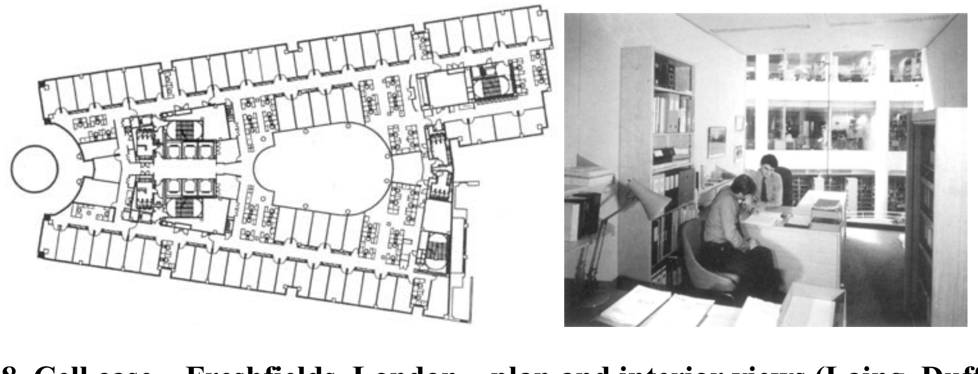


Fig. 3-18. Cell case – Freshfields, London – plan and interior views (Laing, Duffy et al. 1998)

Aware of the complexity of work patterns, the definition of models extend the study for basic factors that determine the overall performance (Baird 1984; Rogers 1998): building fabric, building occupancy and building services plus low energy strategies.

Building architectural variables

Publications such as ‘Environmental Science Handbook for Architects and Builders’ (Szokolay 1980a), ‘National Energy Advisory Committee’ (National Energy Advisory Committee 1981) and ‘Building Energy Brief for Commercial & Public Buildings’ (Taylor Oppenheim Architects, Lincolne Scott Australia et al. 2000), among others, emphasize the most important low energy strategies directly related with the architectural variables,

- shape: surface-to-volume ratio, orientation;
- fabric: shading of surfaces, surface qualities, thermal insulation, thermal inertia, relative position;
- fenestration: size, disposition, orientation, special glasses, blinds, curtains (internal), shading devices (external);
- architectural and master planning site & building envelope opportunities.

Shape

Attempts to define building shape(s) for parametric analysis evidence the complexity of the issue, mainly when the architectural variables are the focus of study. There are different approaches, but every one has its constraints.

The pioneer Olgyay (1963) identifies regional effects on large building shapes, probably based on a knowledge of principles and a good sense (Fig. 3-21). They state that ‘*cool zone closed compacts forms are preferable … temperate zone there is the least stress from any specific direction … hot-arid zone massive shapes are advantageous. Cubical forms, or those slightly elongated toward the east-west axis are most adaptable … hot-humid zone freely elongated in the east-west direction are advantageous.*’ Since than, respectable researches and designers accept this simplification. For example, Burberry suggests the reduction of volume and use of cubical shapes (Burberry 1978; Burberry 1983). His illustration on Fig. 3-22 exemplifies the ratio of surface areas and volume, which must be reduced to avoid heat loss. Steele (2001), who affirms that ‘when designing the Greater London Authority Assembly Building, Sir Norman Forster and Partners also chose a sphere, in this case for environmental reasons – since it has 25 percent less surface area than a cube of the same volume – to reduce heat gain and loss (Fig. 3-19). To achieve optimum performance, the pure geometrical form has been manipulated almost exclusively through computer testing. As an observation, the solar angles for London (Fig. 3-20) are lower than represented in Fig. 3-19.

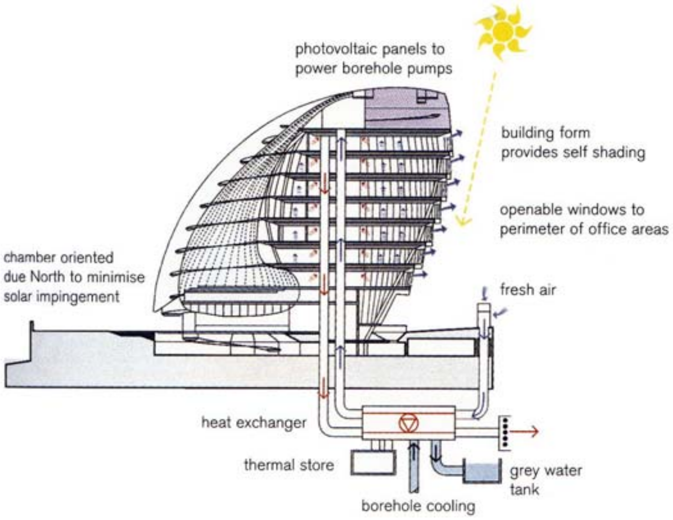


Fig. 3-19. Foster and Partners, Grater London Authority (Steele 2001).

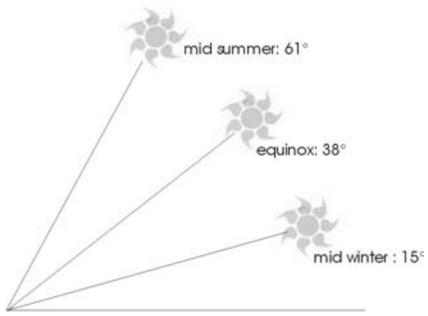


Fig. 3-20. Maximum solar angles for London (noon).

Yeang (1999) also uses a similar method when he argues that optimizing the incoming heat is influenced by the form of the building and the ratio of volume to surface. Then, he proposes a diagram that shows the optimum aspect ratios of building in each climate zone (Fig. 3-23).

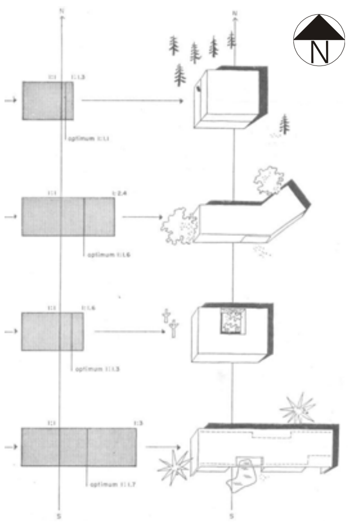


Fig. 3-21. Basic forms and building shapes in different regions (Olgyay 1963).

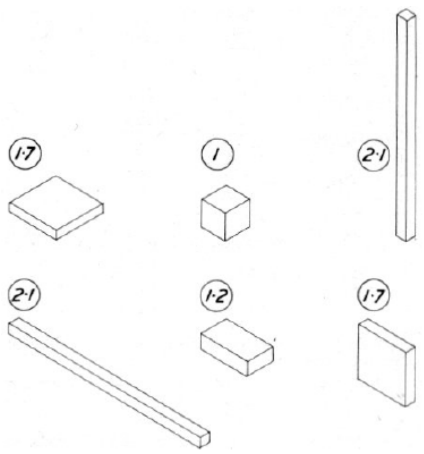


Fig. 3-22. Relative surface areas for a given volume (Burberry 1983).

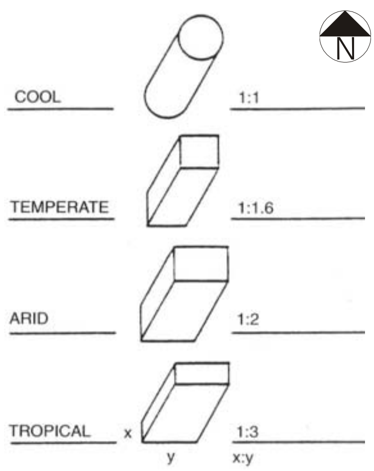


Fig. 3-23. Optimum aspect ratios of buildings

Recent publications show a similar concern. Depecker, Menezo et al. (2001) relate the surface-to-volume ratio of the building to energy consumption for different shapes (Fig. 3-24). LaRoche, Quirós et al. (2001) do similar discussing the volumetric heat loss coefficient (GG), which consists of the envelope heat loss divided by the volume of the building, of the product of the S/V ratio and the mean transmittance of the envelope

$$GG = \frac{S}{V} U_m = \frac{q_c}{V} = \frac{\sum (AU)}{V} \quad \textbf{eq. 4}$$

where:
GG: volumetric heat loss coefficient (W/m³ K)
S/V: surface ratio (m)
S: area of envelope (m²)
V: Building volume (m³)
Um: mean thermal transmittance of the envelope (W/m²K)
q_c: envelope conductance (W/K)
A: area or each component (m²)
U: thermal transmittance of each component (W/m²K)

Marks (1997) proposes a problem solving to determine the optimum dimensions of volume and height. Stasinopoulos (1998) introduces the 'form insulation index', an indication of the performance of a form as 'solar receiver' (Fig. 3-25). In common, they look for optimization methods and indices so support designers in theirs decisions. These approaches have a very simple language and could successfully address the early phases of design, considering 'desirable' shapes. However, due to oversimplifications of the methods, they cannot be taken too seriously, mainly for low latitude zones. The optimization of envelopes in a cold climate is strongly influenced by the reduction of heat loss, reached through the reduction of thermal transfer areas and use of insulation. However, the performance of envelopes in warm climates is strongly affected by features that control solar thermal gains and daylighting. In addition, these features are very sensitive to the orientation.

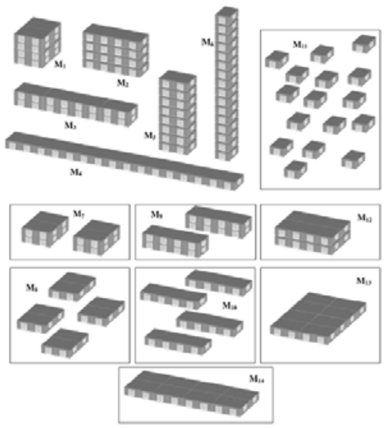


Fig. 3-24. Building shapes (Depecker, Menezo et al. 2001)

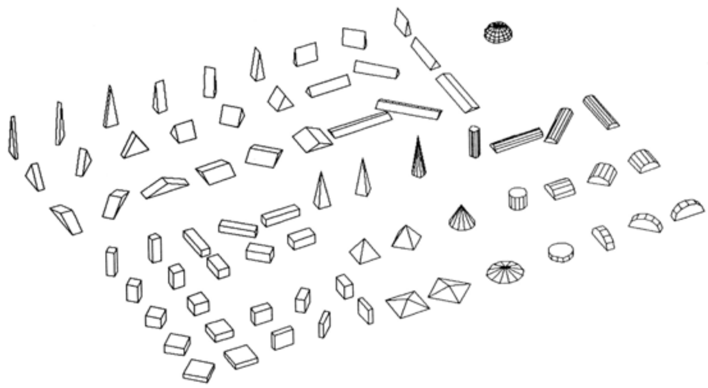
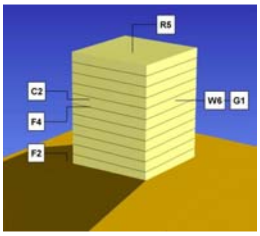
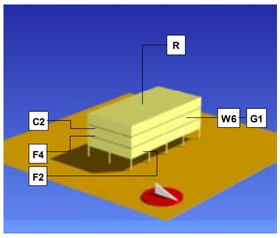


Fig. 3-25. Elementary building shapes (Stasinopoulos 1998)

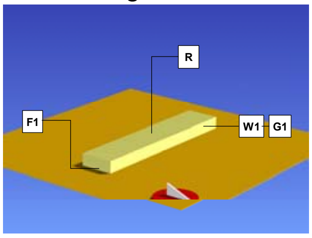
Using a different approach, the ABCB (2001b) proposes to assess some architectural variables and features to support a code development. The method identifies four basic shapes of typical Australian office building, Fig. 3-26. Using association, the method intends to extend the results to similar designs. The Appendix A – Office Building Forms (ABCB 2001d) reveals that the authors are aware of the wide variety in building forms and uses. Using a systematic review to define a small sample of representative buildings, the analysts observed that buildings with the smallest floor areas are the most susceptible to environmental influences. As changing shape has virtually negligible effect on envelope area for buildings bigger than 2,000 m² but becomes rapidly more significant as floor area falls below 1,000m². These findings favor the selection of representative building forms below 2,000 m². Then, a single form may serve for the whole range of larger buildings.



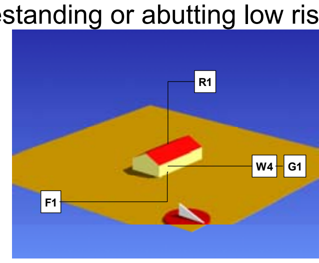
A. Mid-high rise towers



B. Freestanding or abutting low rise blocks



D. Freestanding or abutting, low rise buildings



E. Freestanding or abutting

Fig. 3-26. Proposition for representative building forms (ABCB 2001b).

Coincidently, Laing, Duffy et al. (1998) also identify four types of building geometries, based on the survey of BRECSU (Building Research Energy Conservation Support Unit at BRE), which is a result of 400 office building analysis in the 1980s in UK. The types are:

- shallow depth building: naturally ventilated cellular;
- medium depth building: naturally ventilated open plan;
- deep central core building: air conditioned standard;
- atrium building: air conditioned prestige.

In comparison with the ABCB models, Laing, Duffy et al. ignore the number of storey and orientation, but recognize that the interior layout variations caused by the core and atrium positions defines building types (Fig. 3-27). Although the last authors don't emphasize the relation of layout to energy performance, Yeang does (Yeang 1999). He discusses the variations of the core position (Fig. 3-28) and the effects on energy performance (Fig. 3-29).

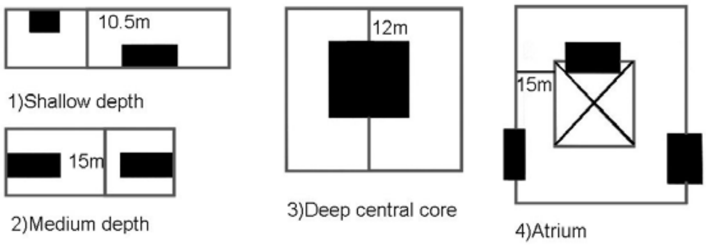


Fig. 3-27. Diagram of four building types (Laing, Duffy et al. 1998).

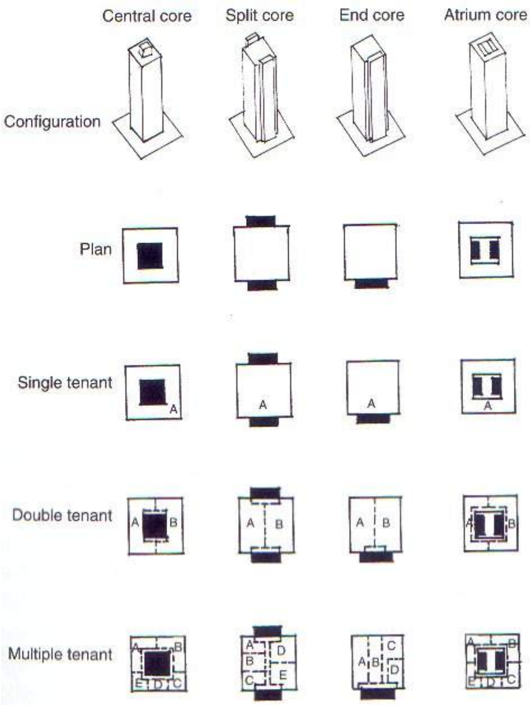


Fig. 3-28. Source core configuration (Yeang 1999).

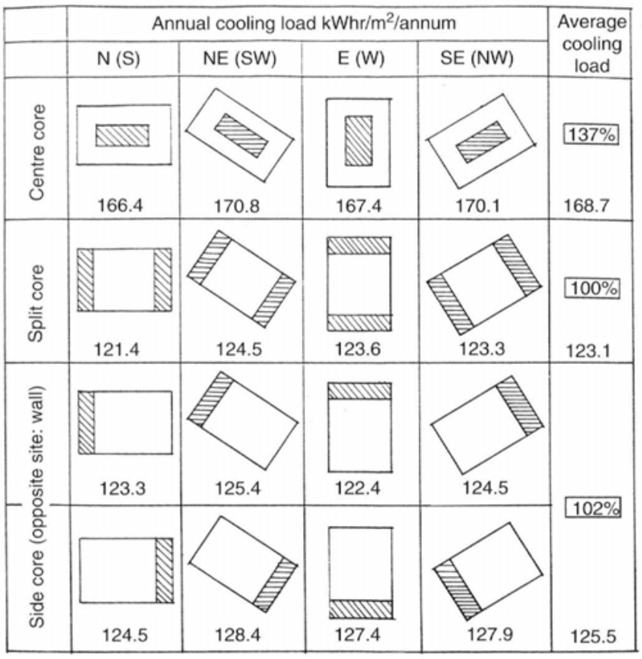


Fig. 3-29. Orientation, core position and cooling load (Yeang 1999).

All of the previous approaches are based on simplification of shapes. ABCB ignores the internal layout variations. Laing, Duffy et al. recognize the position of core as design characteristic of office building. Yeang stresses influence of the core on the energy performance.

Baker and Steemers (1996) propose a different method to model building shape, which relies upon the concept of 'passive zone'. The authors classify zones as passive or active for different orientations on sketch plans (Fig. 3-30). The graphic representation (Fig. 3-31) has a compatible Excel worksheet (Fig. 3-32), which produces the equivalent energy performance

(Fig. 3-33). Contrary to the previous methods that adopt a uniform envelope, LT allows the assessment of façade influence and shading type for each zone (moderate range of values).

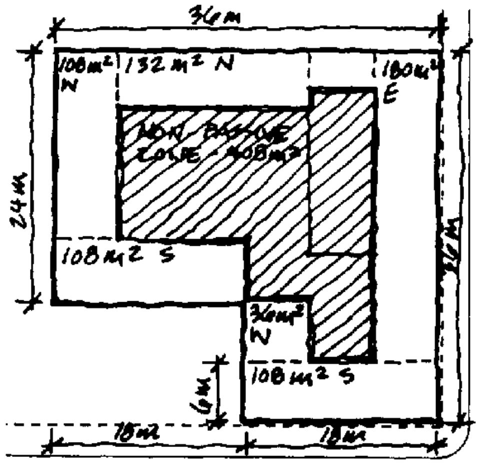


Fig. 3-30. Passive zones and non passive zones on sketch plan (Baker and Steemers 1996)

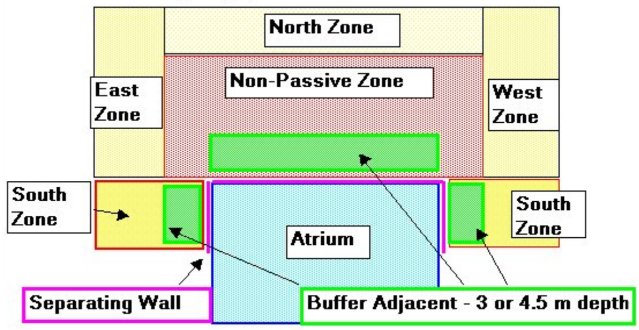


Fig. 3-31. Classification of zones in LT Method.

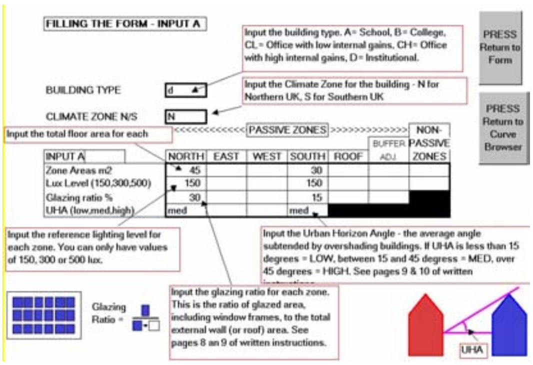


Fig. 3-32. A completed worksheet.

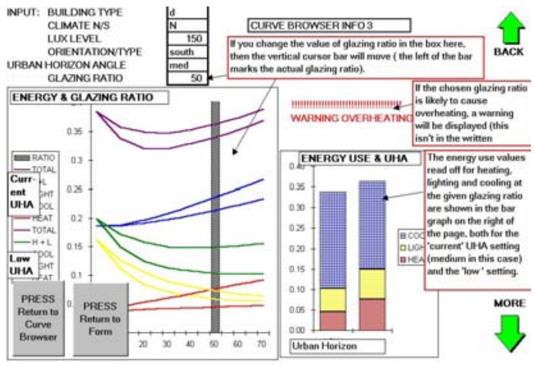


Fig. 3-33. Generation of performance curves.

The LT inspired the development of LTV[37] Method (Pedrini and Hyde 2001): a tool to assess the influence of daylighting, thermal loads and ventilation. The method consists of a database derived from the simulation of cells or building zones, which correspond to a combination of architectural variables: orientation, room depth, window opening ratio, window-wall ratio and vertical exterior shading angle. The declaration of zones starts with the plan (Fig. 3-34, a), where zones are classified in North, South, East, West and Active (Fig. 3-34, b) and their areas are grouped (Fig. 3-34, c). The envelope characterization is done for each zone, which

[37] Light, Thermal and Ventilation Method.

immediately shows the behaviour of the variable and shows the impact of such design decision (Fig. 3-35)

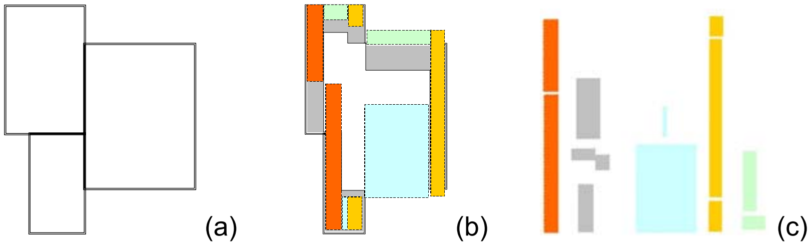


Fig. 3-34. Modelling with cells.

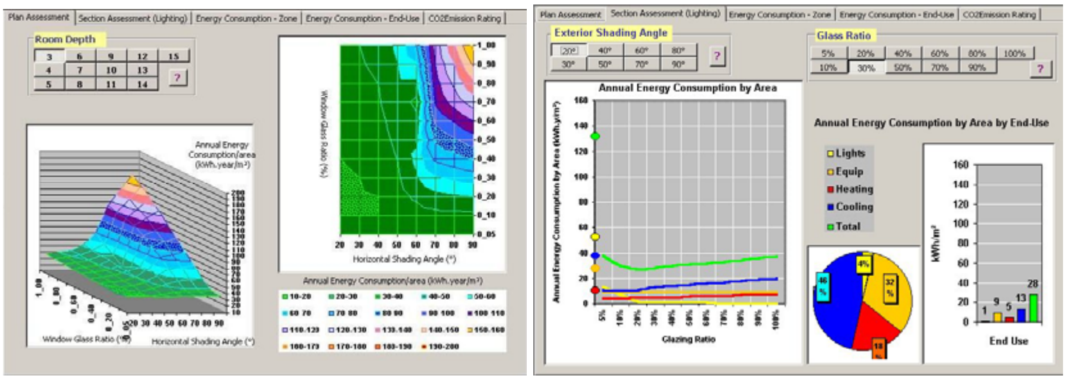
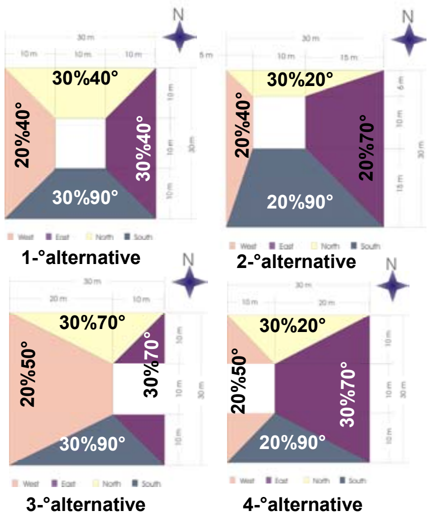


Fig. 3-35. Characterization of zones in LTV.

The method has limitations beyond the graphical interface: it does not recognize the thermal transfer through the roof, ground and internal walls, which are assumed adiabatic. It addresses the analysis of building designs with low influence of these components on the overall performance, such as multi-storey buildings. The method also assumes that every zone has the same schedule for temperature control (i.e., set point and period of occupancy). It is important to highlight that these assumptions have more influence on the results in terms of absolute values because some thermal loads are neglected. However, relative results, such as comparison of alternatives, are affected much less. For example, the determination of vertical shading angle for a specific window is not affected by the limitations.

The main advantage of such a method is the high flexibility to assess extensive variations of shapes and interior layouts in a short time. For example, comparisons such as the four cases illustrated in Fig. 3-36 produce energy performance results (Fig. 3-37) in a few minutes.



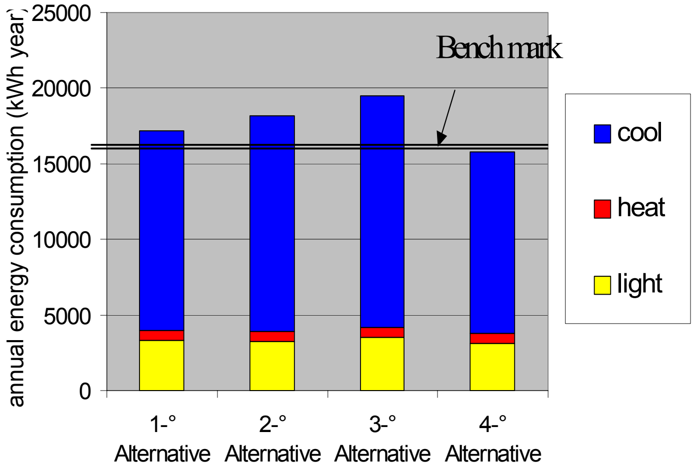


Fig. 3-36. Assessment of core positions.

Fig. 3-37. Comparison of four buildings with different core position.

In conclusion, simplifications are inevitable in parametric analysis and they happen at different levels of abstraction. The analyst has to decide the best compromise between simplifications and accuracy. The relation input & output has a logic: most accurate results demand more detailed models. For example, Balcomb (1997) suggests that the early design decisions use simplified geometries, such as his software ENERGY-10 does, creating a 'shoebox' with two zones, which can be detailed while it is developed.

In this specific case (thesis research) that emphasizes the design decision-making during the schematic phase, a method such as LTV is the most suitable. It matches the variables that Steemers (1994) recognizes as the broad concern of designers during the early development of a building concept:

- form: plan depth, section and orientation;
- building organization: internal planning and space use
- design of facades: glazing percentage and distribution;

Recalling Laseau (2000) in Fig. 3-38, the method also matches, even if in a limited way, the most important variables related to form design and to energy performance: zoning, enclosure, construction type and climate control.

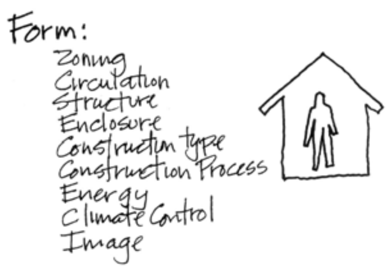


Fig. 3-38. Information of form (Laseau 2000).

The LTV method also has the advantage of exploring the interaction among the variables. Considering that the design process does not have a common sequence of decisions, the method allows reproducing many variations. The building shape may define the envelope and internal layout, as well as the building shape which may be a consequence of envelope and internal layout requirements. The method also fits to the examination of 'if… then…' sequences leading to design decisions because it assesses the current combination of variables and quantifies the impacts on the next decisions.

The use of cells is justified is this parametric analysis due two main reasons. First, cells have been used as representation of buildings since computer simulation is available. Loudon (1968) considered the heat gains through walls negligible and simplified the method of thermal calculation using cells (Fig. 3-39). Balcomb and McFarland (1978) [38] used cells in the late 70s and since then Balcomb's research usually refers to this simplification (Balcomb 1997). Secondly, this simplification is very compatible with the level of details available in design schemes, as proposed in LT and LTV.

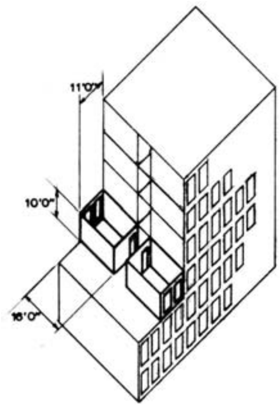


Fig. 3-39. Type of multi-storey block assumed for design calculations

Once having decided to use cells to represent building geometry, the next step concerns the definition of these. The basic dimensions are width, bay width, depth and ceiling height (Fig. 3-40). As tested in LTV, cells with 3 m width and three bays of 1 m produces sufficient accuracy to represent facades of any width. For example, a façade of 9 m corresponds to 3 cells and a bay of 1 m corresponds to 1/3 of it.

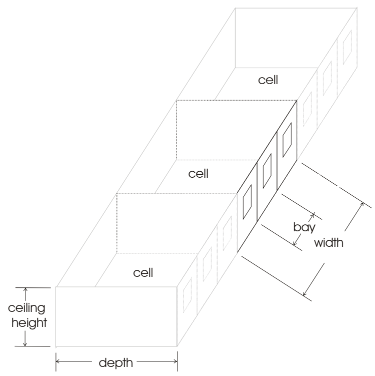


Fig. 3-40. Cell geometry variables.

O'Connor, Lee et al. (1997) show the importance of high windows to increase the depth of 'daylighting zones'. The authors quantify the depth as practically 1.5 times the window head

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[38] The article describes the estimation of the performance of wall thermal storage on passive solar heated buildings

height. Consequently, the definition of ceiling height also influences the size of zones that can use daylight. ABCB (2001h) reviews the typical ceiling heights for Australian buildings (Table XX), which are 2.4m or 2.7m and correspond to floor-to-floor heights 3.3m and 3.6m (Fig. 3-41, sections D-E and A-B). Considering that the floor-to-floor height is the main constraint for increasing window heights, due to economic reasons, the window head height may be hypothetically extended from 2.4m to 3.0m and from 2.7m to 3.30m (Fig. 3-41, sections D-E' and A-B'). Then, four window head heights are available to assess the influence of it on energy performance, from 2.4m to 3.3m, with 0.3m of increments.

Table XX. Building form characteristics (ABCB 2001h).

		Storey height		
ID	**examples**	**floor-flr height**	**floor thickness**	**ceiling height**
A	Mid-high rise towers, covering buildings of 5-100 storeys with 500-3,000 m² per storey (total area 2,500-300,000 m²). Typically freestanding and seen most commonly as Class 5 in business districts (CBD or outlying centres).	3.6	0.2	2.7
B	Freestanding or abutting low rise blocks (2-4 storeys) with 500-20,000 m² per storey (total area 1,000-100,000m²). In built-up areas, the buildings will mostly be aligned to the street layout and may have blank faces adjoining neighbouring buildings. May occur as freestanding buildings in regional towns, outlying centres of major cities, office park precincts or campus developments. Parking may be under the building or in adjacent surface carparks.	3.6	0.2	2.7
D	Freestanding or abutting, low rise buildings (1-2 storeys), of commercial construction (total floor areas up to 1,000 m²). Occur in most cities and towns as drive-up offices and shops with parking immediately adjoining the buildings. May also occur in campus developments and industrial precincts.	3.3	0.15	2.4
E	Freestanding or abutting, low rise (1-2 storeys), residential or commercial buildings of domestic construction, with in-built HVAC provisions. Individual blocks may be as small as 50 m² but, in clusters or adjoining blocks, form facilities totalling several thousand square metres. Seen in most cities and towns as motels and residential duplexes. Parking will typically immediately adjoin the buildings.	3.3	0.15	2.4

note: plenum wall height= 0.9 ms

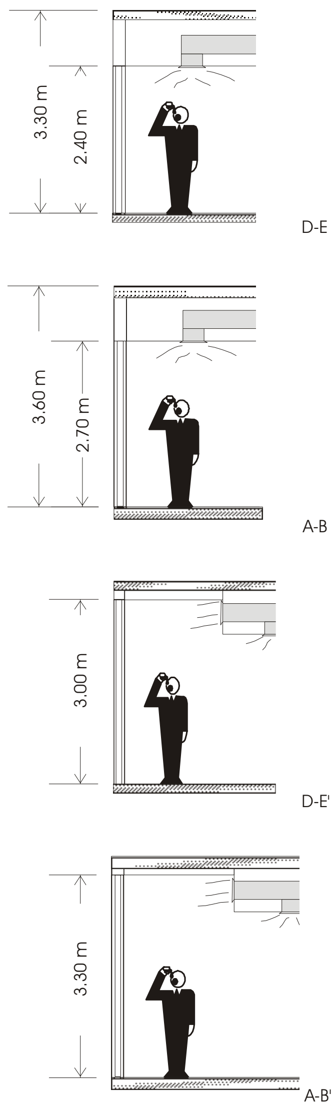

Fig. 3-41. Ceiling height variations.

The room depth influences the optimum balance of daylighting and thermal loads (Hyde and Pedrini 1999C), justifying its parametric analysis. ABCB (2001d) proposes only two values for room depth, previously shown in Fig. 3-26: 3.6m for model A and B; 5.0m for models D and E. These values match the work patterns of Laing, Duffy et al. (1998), respectively for Cell and Club cases (Fig. 3-18 and Fig. 3-17). However, the Den and Hive may allow deeper rooms because these are open areas. In accordance with the building types proposed by the authors in Fig. 3-27, the 'atrium' type has 15m.

The definition of increments benefits the LTV experience, which simulated cells with 3, 5, 6, 8, 10 and 15m room depths. Each case has its best and worst energy performance, resulting from the combinations of architectural variables. As shown in Fig. 3-42, shallow rooms tend to use more energy per unit area than deeper ones and they are much more sensitive to the combination of architectural variables. In this specific case, deep rooms may have energy consumption between 30 and 80 kWh/(m².yr) and shallow rooms may have energy consumption between 40 and 190 kWh/(m².yr).

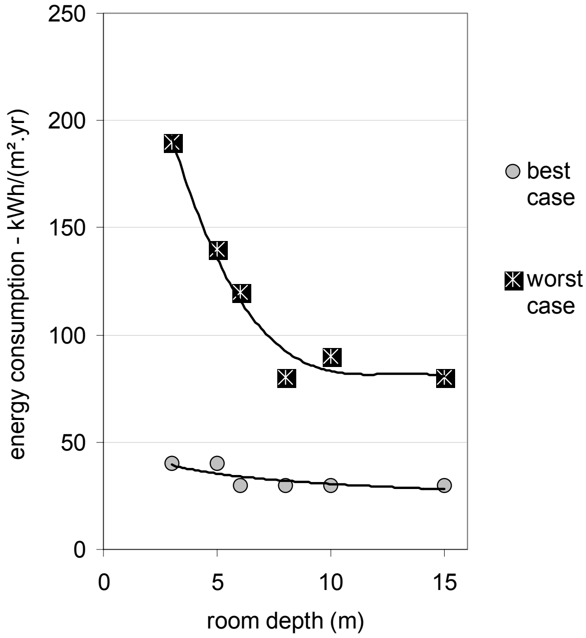

Fig. 3-42. Influence of room depth on energy performance of West cells.

Based on the curves of best and worst cases, it is reasonable to assume a parametric analysis with room depths of 3, 6, 9 and 15m.

Fabric

Olgyay and Olgyay (1957) discuss the effects of the resistance insulation and heat capacity effects. Szokolay (1980a) endorsed them as strategies to improve the energy performance, and Burberry (1983) as elements of the thermal response buildings. Taylor Oppenheim Architects, Lincoln Scott Australia et al.(2000) highlight them as requirements for a thermally efficient envelope.

Due the absence of quantitative methods for classification, authors recommend thermal mass based on qualitative aspects, as shown in Table XXI.

Table XXI. Thermal mass classifications.

thermal mass	CSIRO and Szokolay (2001)	Clarke and Delsante (2000)	Working Group Housing 5 (2002)
low mass	includes timber, fibro cement sheeting, and brick veneer houses on suspended timber flooring systems;	timber framed with cladding or brick veneer hollow block	suspended floor system such as a timber bearer and joist flooring system; light mass inner walls such as plaster, fibro cement sheeting on timber or metal stud frames.
medium mass	includes brick veneer and timber clad houses if built with slab on ground	cavity brick or solid block timber framed with cladding or brick veneer	concrete slab inner walls such as brick or rendered masonry:
high mass	includes houses with a slab on ground as well as a heavy wall construction such as double brick, mud brick or rammed earth	reverse brick veneer or cavity brick filled or solid block, rammed earth or mud brick	concrete slab on ground inner walls as brick, concrete block, mud brick or rammed earth.

In this case, the components of Table XXII fit the classification.

Table XXII. Wall constructions proprieties.

Wall Construction	U-value (W/m²-C°)	Heat capacity (J/m² K)
Light: plywood, timber frame, Mineral Wool (R-7) and plywood	0.609	13.1
Medium: light concrete (100mm) and gypsum board 12.5mm	0.989	49.4
High: medium concrete (100mm) and gypsum board 12.5mm	1.958	117.5

The ABCB proposal (ABCB 2001e) also defines three types of construction, related to the four shapes (Fig. 3-26, page 106), detailed in Table XXIII. Proprieties and detailed fabric components proposed by ABCB (ABCB 2001h). In comparison with the previous components (Table XXII), the ABCB types of walls have considerably high thermal mass.

Table XXIII. Proprieties and detailed fabric components proposed by ABCB (ABCB 2001h).

ID	component materials	thickness (mm)	U-value (W/m²-C°)[39]	Heat capacity (J/m² K)
W1 single leaf conc block	hollow concrete block cavity (furring channels) plasterboard sheet	190 35 10	1.971	713
W4 brick veneer	extruded clay brick cavity steel stud frame fibreglass insulation batts reflective foil vapour barrier plasterboard	110 50 90 50 13	0.534	700
W6 precast concrete	precast concrete cavity steel stud frame fibreglass insulation batts reflective foil vapour barrier plasterboard	200 50 90 50 13	0.427	994

Considering that the intention of the parametric analysis is to assess the influence of the envelope, however using the minimum number of permutations possible, it seems reasonable to assume two types of walls:

- medium concrete and gypsum board (from Table XXII), due the high U-value and low thermal mass;
- W6 precast concrete (from Table XXIII), due the low U-value and high thermal mass.

Windows

In the chapter 'Windows in Building' (Cowan 1991), Givoni highlights the functions of windows, such as providing contact with the outdoors, views to attractive scenery, natural ventilation, daylighting and the potential use for passive solar heating and cooling systems. However, the maximization of openings may lead to excessive use of glass on facades, highly undesirable in terms of efficiency as it stated in The Architect's Journal: '*There is also a trend to label buildings as green when they are manifestly not – for example, building with glass facades. A big part of high-efficiency design is the balance and optimization of glazed areas in facades, to optimize daylighting, glare, heat loss and heat gain –this process would never*

[39] Calculated based on VisualDOE components (minus the inside air film resistance 0.150 m².K/W) and 'Thermal Insulation Plea Notes' (Zold, A. and S. V. Szokolay, 1997).

yield a building where the walls are made completely of glass, no matter how many layers or how well shaded. Adding a heating system that runs on a biomass fuel and cooling through heat pumps and boreholes does not make the building green, it is merely presenting an alibi for the poor performance of the building' (Bellew 2000).

Simulations provide enough information to define the optimum balance of thermal loads and consequently the best design for fenestration[40]. It consists of minimizing the energy consumption of electric lighting through the use of daylighting and minimizing the energy consumption of the air conditioning by reducing thermal loads (mainly from solar radiation). For office buildings in a warm climate, the incident thermal loads are usually undesirable. The low cooling loads and the internal heat generation are enough to avoid heaters and increase the interior temperature to the heating set point. If daylighting is not rationally used, a blank wall may be more desirable than an efficient window. It is inconceivable to deal with windows as an isolated passive strategy in this circumstance. Actually, windows are part of a hybrid strategy that demands complementary components, such as automatic sensors to control internal lighting levels. In practice, very few buildings in Brisbane utilize daylighting as a strategy to reduce energy consumption, which shows lack of interest or knowledge to deal with the problem. Then, it becomes important to show the impact of windows in situations when the use of daylighting is considerable.

As discussed by Olgyay (1963), the need for solar control has been strongly increased by modern developments in architectural planning and construction. The techniques of solar control include window geometry, glazing proprieties and shading devices.

Window geometry

Window geometry has little influence on thermal loads if compared with the influence on daylighting. O'Connor, Lee et al. (1997) suggest to use of higher windows to increase the depth of daylighting zones[41] and to avoid waste glazing areas where they do not contribute to daylighting[42]. Similarly, BOMA (Building Owners and Managers Association of Australia.

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[40] As usual, the criteria is based exclusively on energy performance.

[41] The practical depth of a daylighting zone is typically limited to 1.5 times the window head height. With a reflective light shelf, this zone may be extended up to 2.5 times the head height.

[42] It wastes energy, causes discomfort (especially in winter), and provides little benefit.

Victoria Division 1994) suggest that the glazed areas should be kept to the minimum necessary and located to provide visual relief to occupants, also considering:

- solar penetration should be minimised on east, west and north;
- avoiding glazing below 600mm from floor level and above 2000mm from floor level, unless it provides glare-free lighting and displaces electric lighting;
- the minimum energy consumption occurs when the WWR is between 25-40% for single glazing and up to 50% for double glazing.

Due the unlimited possible configuration of windows, the window-to-wall ratio (WWR) is a helpful index to relate the area of glazing to the walls. It corresponds to the net glazing area (window area minus mullions and framing, or ~80% of rough opening) divided by gross exterior wall area (e.g., multiply width of the bay by floor-to-floor height[43], as described in (O'Connor, Lee et al. 1997):

$$WWR = \frac{net\ glazing\ area}{gross\ \ exterior\ \ wall\ area} \qquad \textbf{eq. 5}$$

The WWR is just a part of the fenestration system. However, it has considerable influence on energy consumption. The ASHRAE 90.1 (ASHRAE 1989) disapproves of facades with glazing ratio higher than 50%[44], independently of the glass proprieties or shadow produced by exterior devices. The influence is easily identified in the database produced by LTV. A room with 3m depth, single glazing, North orientation and no shading device has its total energy consumption more than quadrupled: from 32 kWh/(y.m²) when WWR is 10% to 160 kWh/(y.m²) when WWR is 100%, as plotted in Fig. 3-43.

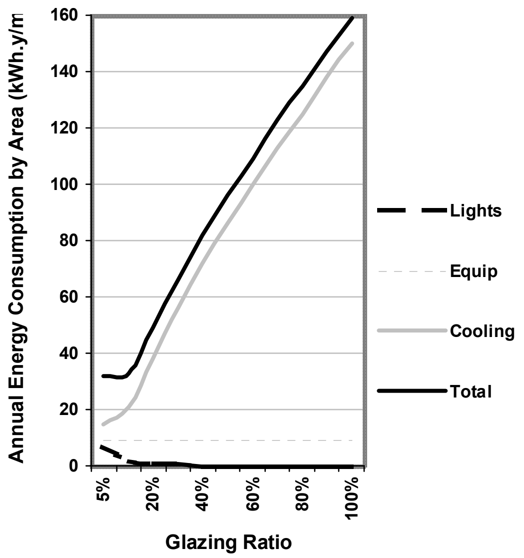

Fig. 3-43. Influence of WWR on energy consumption from LTV.

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[43] 0.35 is typical for strip-glazed building. Larger windows are 0.50 and smaller punched windows are 0.25.

[44] Vide 'table B-4 - Building envelope requirements', for Brisbane, page 94.

The ABCB proposal (ABCB 2001h) characterizes the WWR for typical buildings (Fig. 3-26, page 106). The type A has WWR 50% all faces. B has WWR 50% North and South faces and 20% East and West faces. D has WWR 60% North and South faces and 0% East and West faces. And E has WWR 50% North and South faces and 10% East and West faces.

Based on the two extreme configurations of floor-to-floor height and floor-to-ceiling height (Fig. 3-27), the definition of WWR follows simple steps (Fig. 3-44). The windows have preferentially 1 m of sill height. They increase laterally until to reach the bay width (1 m). After that, they increase in height until reach the floor-to-ceiling height. After that, the window height increases with the reduction of sill height.

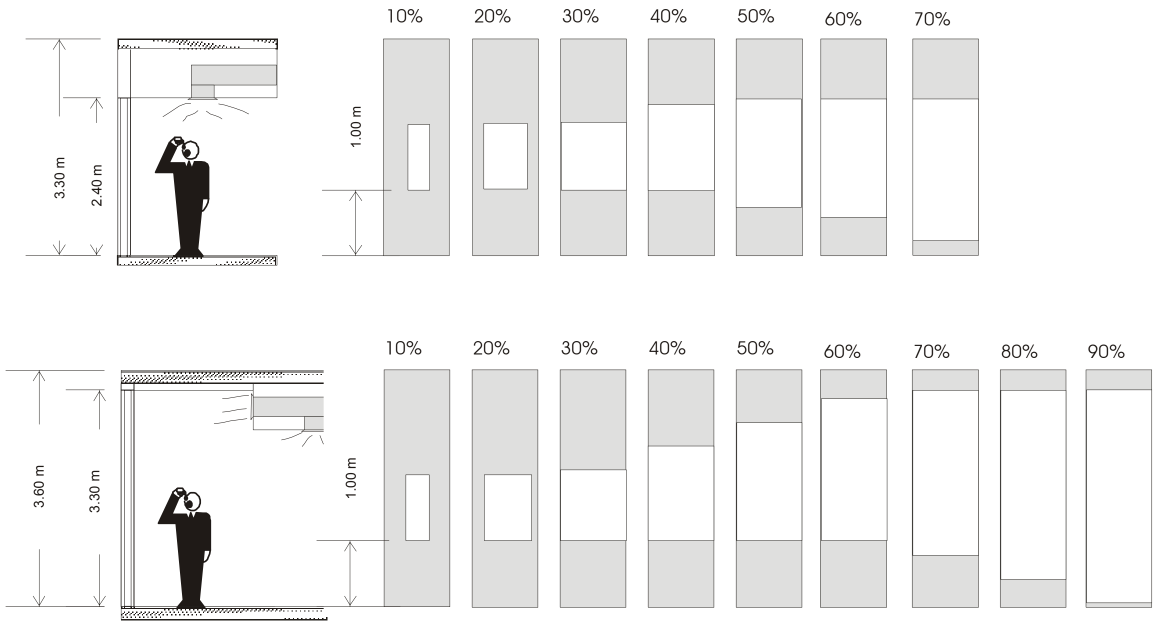

Fig. 3-44. WWR for two basic cells.

Glazing properties

Givoni (1991) classifies window glasses according to their selective transmission, reflection and absorption proprieties for different wavelengths of radiation: clear, heat-reflecting, low-emissivity, heat-absorbing, grey and colored glasses. Energy Authority Victoria suggests reflective glass and double glazing[45] (Sustainable Energy Authority 2001a). O'Connor, Lee et al. (1997) recommend the selection of glass with moderate visible transmittance[46] for glare

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[45] Double glazing fits to the Victoria climate.

[46] Visible Transmittance, or daylight transmittance, is the percentage of visible light striking the glazing that will pass through. Visible transmittance values account for the eyes' relative sensitivity to different wavelengths of light. (O'Connor, Lee et al. 1997).

control (around 50-70%) and the lowest possible solar heat gain coefficient. The intention is simple: improving light gains and reducing thermal loads.

Different indicators of total solar heat gain have been used for windows. Shading coefficient (SC) was the oldest and most used term. It is the ratio of solar heat gain through a glazing system under a specific set of conditions to solar gain through a single light of the reference glass (1/8" or 3 mm clear glass) under identical conditions under the same conditions (ASHRAE 1989), eq. 6. The calculation of solar heat demands a second element, the solar heat gain factor[47] (SHGF), eq. 7. SHGF is calculated for daylight hours of the twenty-first day of each moth and it is available in ASHRAE Fundamentals Handbook. 's tables. (LaRoche, Quirós et al. 2001)

$$SC = \frac{solar\ heat\ gain\ of\ fenestration}{solar\ heat\ gain\ of\ reference\ glass} \qquad \textbf{eq. 6}$$

$$solar\ heat\ gain = SC\ x\ SHGF \qquad \textbf{eq. 7}$$

Some authors refer to SHGF as solar factor (SF), as shown in the OTTV equation[48] for Hong Kong (Li and Lam 2000):

$$OTTV = \frac{[(A_w.U_w.TD_{eq}) + (A_f.U_f.DT) + (A_f.SC.SF)]}{A_i} \qquad \textbf{eq. 8}$$

where
A_w : area of opaque wall (m²)
U_w : U-value of opaque wall (W/(m².°C))
TD_{eq} : equivalent temperature difference (°C)
U_f-: U-value of fenestration (W/(m².°C))
DT : temperature difference between exterior and interior design conditions (°C)
SF : solar factor (W/m²)
A_i : gross area of the walls (m²)

Although SF is a measure of heat gain in W/m², some publications introduce SF as ratio of the total solar energy flux entering the premises through the glass to the incident solar energy

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[47] coincidently adopt SHGF as the fraction of incident solar radiation that is transmitted through element (apparently opaque) when air temperature is the same in both sides. In this case, SHGF depends both on the surface properties and on the U-value of the element.

[48] Overall Thermal Transfer Value: method developed to study the energy performance in buildings through the use of equations, which are derived from building energy simulation methods and multiple regression techniques (Hui, S. C. M. 1997).

flux. The total energy is the sum of the incoming solar energy by direct transmission and the energy re-emitted by the glass to the inside atmosphere after being absorbed by the glass. Calculation is made for sun at 30° above the horizon at right angles to the façade, ambient temperature equal to outside ambient temperature and surface heat exchange coefficients internal (h_i) 8 W/m²K and external (h_e)23W/m²K (Glaverbel 2002). Even the glossary of NRFC (National Fenestration Rating Council Incorporated 2001) suggest similar understanding when defining SF as solar heat gain coefficient (SHGC) .

SC was the primary term used to characterize the solar control proprieties (Olgyay 1963) and widely used in cooling load calculations. However, its simplicity is offset by a lack of accuracy in a number of circumstances and consequently it has been replaced by Solar Heat Gain Coefficient (SHGC) (Carmody, Selkowitz et al. 1996). It is the ratio of the solar heat gain entering the space through the fenestration product to the incident solar radiation. SHGC is expressed as a dimensionless number from 0 to 1.0 as shown in Table XXIV. For old SC publications, the SHGC corresponds roughly to 87% of SC values (Carmody, Selkowitz et al. 1996).

Table XXIV. Solar heat gain characteristics of typical windows.

window				
general glazing description	single-glazed clear	double-glazed clear	double-glazed bronze	triple-glazed low-E
Center of-glass				
SHGC	0.86	0.76	0.62	0.49
SC	1.00	0.89	0.72	0.57
Total window				
SHGC	0.79	0.58	0.48	0.37

Solar heat gain includes directly transmitted solar heat and absorbed solar radiation which is then reradiated, conducted, or convected into the space, as defined by NFRC 200 (Incorporated 1995; National Fenestration Rating Council Incorporated 1995). The NFRC 201 expresses the SHGC as: $SHGC = \tau_S + N_i.\alpha_S$

where:

τ_S = solar transmittance of fenestration system
N_i = inward-flowing fraction of absorbed radiation
α_S = solar absorptance of a single-element

The SHGC is obtained by measurement at laboratories (National Fenestration Rating Council Incorporated 2000), using calorimetry hot box. Alternative methods include scanning radiometer that measures the bi-directional radioactive transmittance and reflectance of each layer of a fenestration system (Klems, Warner et al. 1995) or outdoor measurements using advanced calorimeters.

Parametric analysis of glazing systems may be disappointing. There are many options available: the database of Window 5[49] (Huizenga, Arasteh et al. 2001) has 1036 different types of glass, which may be combined with 18 types of frame and 8 types of gas cavity. Furthermore, the relation of visual transmittance (VT) and SHGC is not uniform (Fig. 3-45), which generates a large number of alternatives. In practice, glass type is not a primarily design decision. There are other equally (or more) important factors influencing this decision such as appearance and cost. For example, the typical Australian buildings has single glass (ABCB 2001d) and the ABCB proposal does not presuppose any study of glass effect on office buildings with more than one level for warm climates (ABCB 2001e).

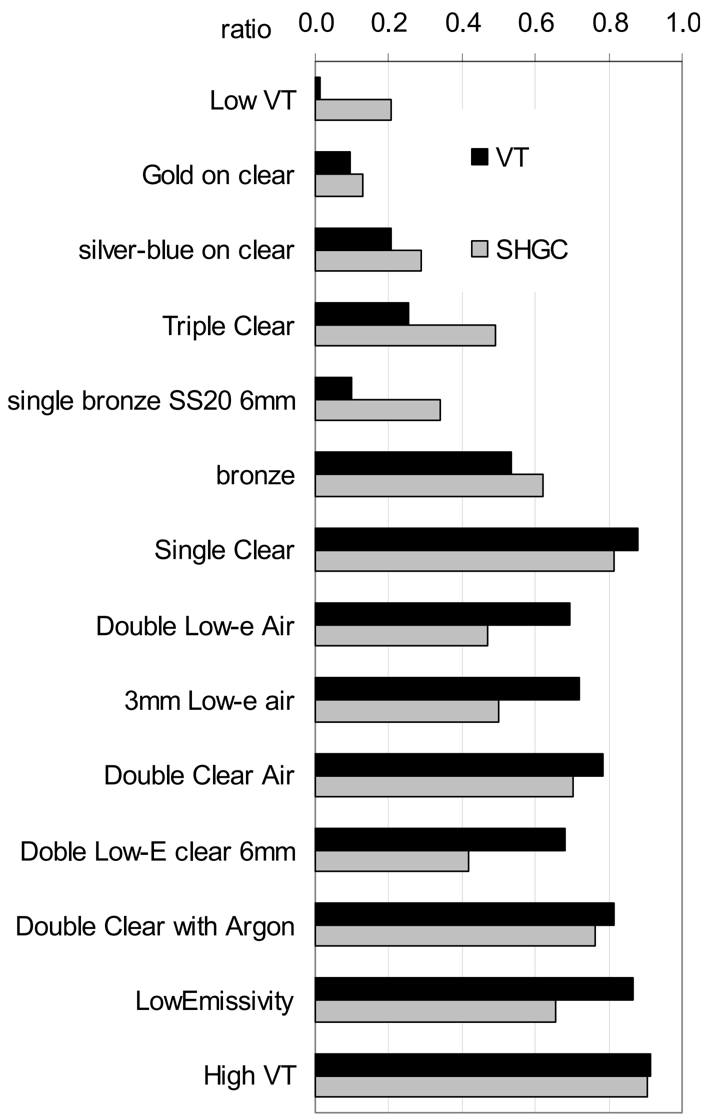

Fig. 3-45. Relations between visible transmittance (VT) and solar heat gain coefficient (SHGC), generated by database from Window 5 (Huizenga, Arasteh et al. 2001).

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[49] WINDOW5 is a state-of-the-art, Microsoft Windows based computer program developed at Lawrence Berkeley National Laboratory (LBL) for use by manufacturers, engineers, educators, students, architects, and others to determine the thermal and solar optical properties of glazing and window systems.

Consequently, it is reasonable to assume only a few types of glass, which give a representative range of characteristics, such as the single clear glass and a second one with low SHGC and low VT, such as the Evergreen® glass (G. James Pty. Ltd. 2001), recently used in buildings in Brisbane (G. James Pty. Ltd. 2002). Both cases are detailed in the Table XXV.

Table XXV. Types of glass for parametric analysis from VisualDOE library.

Name	VT	SHGC	U-value (W/m²K)
Single Clear	0.881	0.815	6.170
6mm Evergreen Solarplus TE/TS series	0.160	0.280	5.3

Shading devices

In practice, the use of SHGC as a guidance as prescribed in ASHRAE/IESNA Standard 90.1-1999[50] shows the lack of information of complex systems such as venetian, blinds, shades or other nonspecular shading devices. There are few references that discuss the subject, most of them using different approaches.

Shading devices may be classified as adjustable and fixed (Givoni 1991; LaRoche, Quirós et al. 2001) or as external shading devices, internal shading devices and double glass (Verma and Suman 2000). Fixed devices are classified as horizontal, vertical and egg-crate (Szokolay 1980a), (Verma and Suman 2000). A horizontal device is characterized by its vertical shadow angle (VSA), Fig. 3-47.

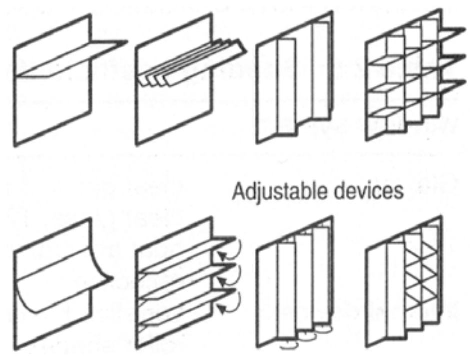

Fig. 3-46. Adjustable and fixed devices: examples (LaRoche, Quirós et al. 2001)

[50] Previously discussed in subchapter ASHRAE/IESNA Standard 90.1-1999. See Table XVI. Building envelope requirements from ASHRAE (1999).

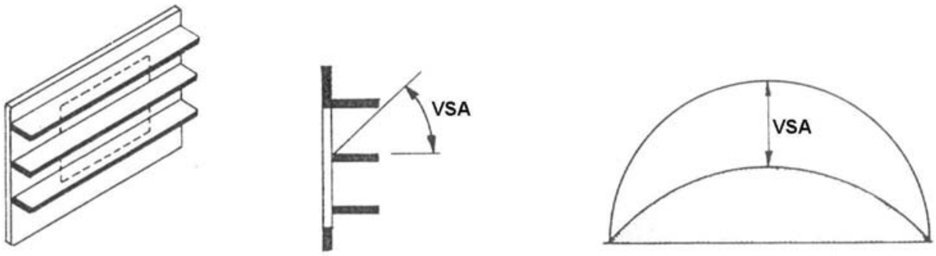

Fig. 3-47. A horizontal device and its shading mask (Szokolay 1980a)

Similarly, vertical device is characterized by its horizontal shadow angle or angles (HSA), Fig. 3-48.

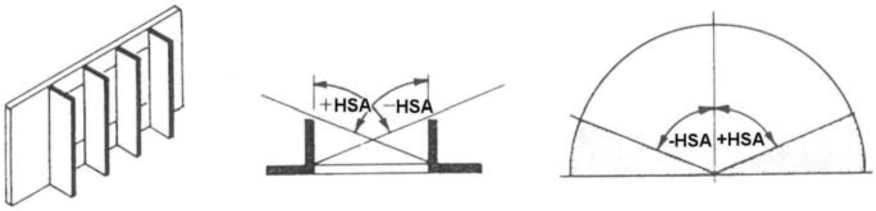

Fig. 3-48. Vertical devices and their shading masks (Szokolay 1980a).

The egg-crate is a combination of vertical and horizontal devices, characterized by both angles: VSA and HSA, Fig. 3-49.

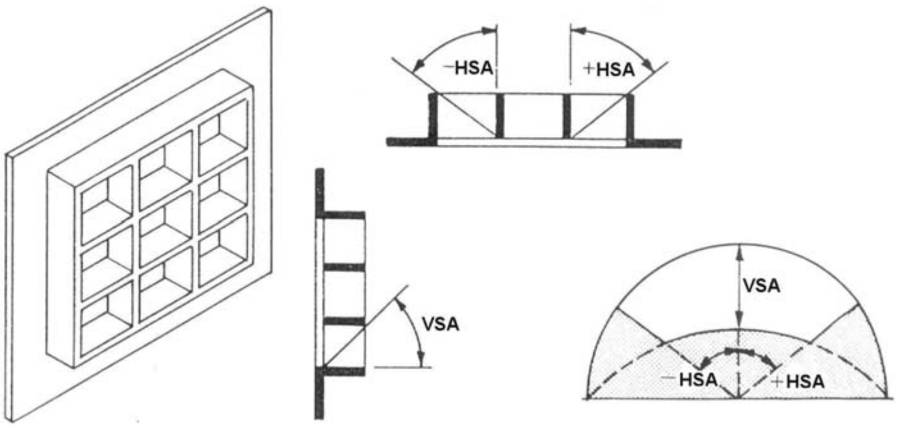

Fig. 3-49. An egg-crate device and its shading mask (Szokolay 1980a).

The parametric analysis from LTV shows how important is the design of horizontal shading devices on energy performance. Results from LTV, based on cells with 3m depth, West orientation and WWR 100%, had the energy consumption decreased to one quarter: from 192 kWh/(y.m²) when the vertical shadow angle is 90% (or nonexistent) to 45 kWh/(y.m²) when vertical shadow angle is 20° (Fig. 3-43). Although it is a simulation exercise, such impact leads to question the current methods and incorporate them in the design process.

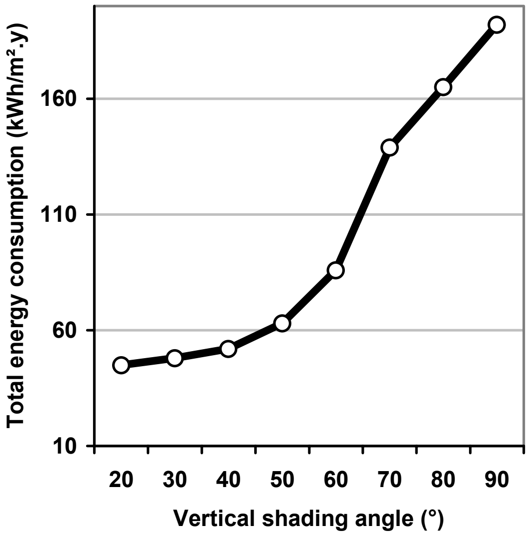

Fig. 3-50. Influence of vertical shading angle on energy consumption.

ASHRAE 90.1-1999 considers only the vertical shading angle in their code for demonstrating compliance: '*The SHGC in the proposed building shall be allowed to be reduced by using the multipliers in Table XXVI for each fenestration product shaded by permanent projections that will last as long as the building itself*' (ASHRAE 1999). Analogue to the vertical shadow angle, The Seattle Energy Code defines: '*projection factor (PF) is the ratio of the horizontal depth of the external shading projection (A) divided by the sum of the height of the fenestration and the distance from the top to the bottom of the farthest point of the external shading projection (B), in consistent units'* (Department of Design Construction and Land Use of Seattle 2002). The relation is: PF = tan (90-VSA), Fig. 3-52.

Table XXVI. SHGC for different values of projection factor (ASHRAE 1999; Department of Design Construction and Land Use 2002)

Projection factor	SHGC Multiplier (All orientations except North-oriented*	SHGC Multiplier (North-oriented)*
0-0.10	1.00	1.00
<0.10 - 0.20	0.91	0.95
<0.20 - 0.30	0.82	0.91
<0.30 - 0.40	0.74	0.87
<0.40 - 0.50	0.67	0.84
<0.50 - 0.60	0.61	0.81
<0.60 - 0.70	0.56	0.78
<0.70 - 0.80	0.51	0.76
<0.80 - 0.90	0.47	0.75
<0.90 - 1.00	0.44	0.73

* for northern hemisphere.

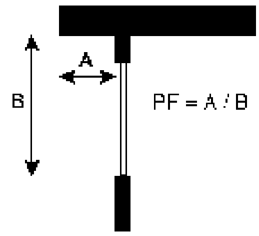

Fig. 3-51. Projection factor.

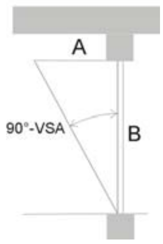

Fig. 3-52. Relation of PF and VSA.

The California Standards (California Energy Commission 2001) also reports the use of SHGC in accordance with the NFRC publications and it employs a correction for external shading, which is calculated by multiplying the SHGC of the fenestration product by the overhang factor, Fig. 3-53. The overhang factor may either be calculated automatically using:

$$\mathbf{RSHG = SHGC_{win} \times \{1 + aH/V + b(H/V)^2\}} \qquad \textbf{eq. 9}$$

RSHG: relative solar heat gain;
$SHGC_{win}$: solar heat gain coefficient of the window;
H: horizontal projection of the overhang from the surface of the window, but no greater than V;
V: vertical distance from the window sill to the bottom of the overhang;
a: -0.41 for North-facing windows, -1.22 for South-facing windows, and –0.92 for East and West facing window;
b: -0.20 for North-facing windows, 0.66 for South-facing windows, and 0.35 for East and West facing window;
H/V = tan (90-VSA).

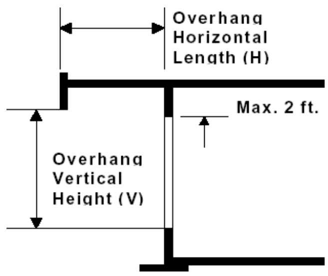

Fig. 3-53. Overhang projection for SHGC correction(California Energy Commission 2001).

The Hawaii County Code (County of Hawaii 2000) characterizes the effect of a side fin through the ‘side fin projection factor’ (SPF), which is proportional to the horizontal shading angle: SPF = tan (90-HSA), Fig. 3-54.

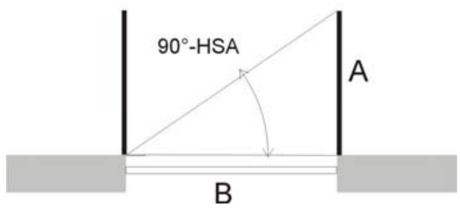

Fig. 3-54. Relation of PF and HSA.

It is the ratio of side fin[51] depth and the distance between side fins[52], and the side fins must extend the full height of the window to receive credit for shading. The equations oddly involve SC, projection factors and specific coefficients for different orientations.

The OTTV for Hong Kong (Building Department 1995) defines a multiplier for exterior shading devices, the ESM (eq. 10). The code of practice relates PF tables for overhangs orientated for N NE/NW, S/E/W and SE/SW, and SFP tables for side fins orientated for N, NE, E, SE, S, SW, W and NW.

$$OTTV_W = \frac{[(A_w.U.\alpha.TD_{eq}) + (Af_W.SC.ESM.SF)]}{Ao_W}$$ **eq. 10**

where

A_w : area of opaque wall (m²)
U : thermal transmittance of opaque wall, (W/(m².°C))
α : Absorptivity of the opaque wall
TD_{EQw} : equivalent temperature difference for wall, (°C)
Af_W : area of fenestration in wall, (m²)
SC : shading coefficient of fenestration in roof
ESM : external shading multiplier
SF : solar factor for the vertical surface, (W/m²)
U_f: U-value of fenestration (W/(m².°C))
DT : temperature difference between exterior and interior design conditions (°C)
Ao_W : gross area of external walls (m²)

[51] measured perpendicular to the window surface. If the left and right side fins have different depths, then A is the average of the two depths.

[52] If the window width is less than the side fin spacing, then the average of the distance between the left sidefin and the right edge of the window and the distance between the right side fin and the left edge of the window may be used. The average provides a larger SPF and, therefore, a larger side fin.

The code of Massachusetts (Commonwealth of Massachusetts 2001) has the most simplified approach. It specifies maximum values of SHGC for three values of PF:

- SHGC = 0.4 for PF <0.25;
- SHGC = 0.5 for 0.25<=PF 0.50;
- SHGC = 0.6 for PF >=0.50.

The 'Residential manual for compliance with the 1998 energy efficiency standards' (Ross, Leber et al. 1999) lists seven types of devices, neglecting detailed geometries (Table XXVII).

Table XXVII. Solar heat gain coefficients used for window with exterior shading attachments.

Exterior Shading Device	w/ single pane clear glass & metal framing
1) Standard Bug Screens	0.76
2) Exterior Sunscreens with weave 53*16/inch	0.30
3) Louvered Sunscreens w/louvers as wide as openings	0.27
4) Low Sun Angle (LSA) Louvered Sunscreens	0.13
5) Roll-down Awning	0.13
6) Roll Down Blinds or Slats	0.13
7) None (for skylights only)	1.00

Apparently, SHGC for exterior shading is a measure with low accuracy for exclusive calculation of heat gains. Worse, the factor is assumed constant and uniform, when a shading device, such as an overhang, has the heat gains varying for different solar inclinations. For a better understanding, a simulation exercise explored the issue. It reproduced the methods of determination of SHGC as recommended by NFRC 201(National Fenestration Rating Council Incorporated 2000), through simulation instead of field measures. A insulated cell with window orientated to North[53] was modeled to keep the inside temperature close to outside and the weather file for Brisbane was modified to keep the temperatures constant during whole year and with a value close to the cooling set point of the cell. Then, the thermal loads were produced due to solar radiation the values integrated during the year. The initial simulations with uniform glasses provided close results to the nominal values, as shown in Table XXVIII. The variations of SHGC were considerably lower and they are almost constant during the day (Fig. 3-55).

[53] The model was simulated with Brisbane climate (Southern hemisphere).

Table XXVIII. SHGC for windows systems based on simulation with DOE-2.1E.

Glass types	PUBLISHED	SIMULATING RESULTS average	max	min
single glass	0.815	0.82	0.86	0.77
Double Low-E clear 6mm	0.42	0.43	0.47	0.38
single bronze SS20 6mm	0.34	0.33	0.46	0.23

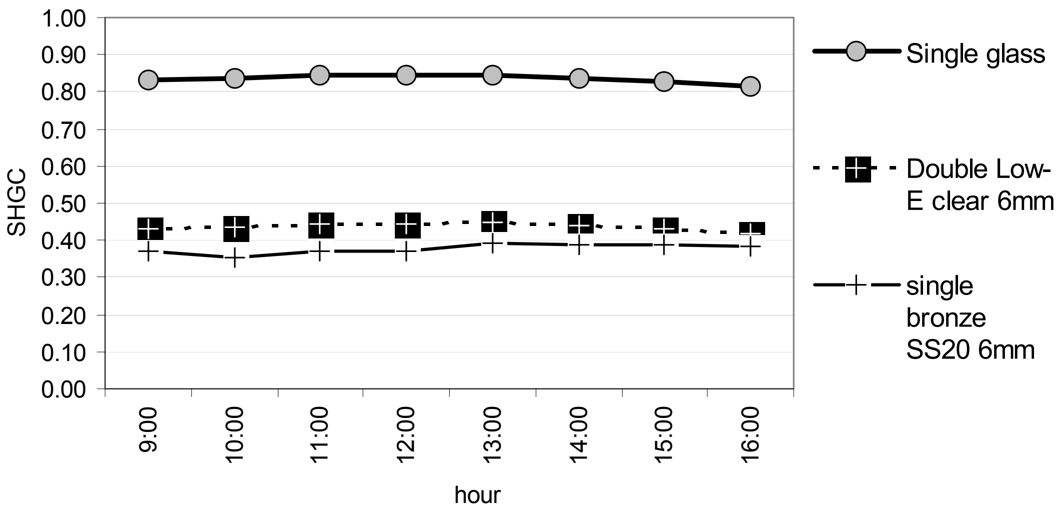

Fig. 3-55. Estimation of hourly SHGC for three types of glass, North, June 21.

Encouraged by the previous results, the exercise was applied to estimate the SHGC of external shading devices. Initially, some hourly SHGC results were suspiciously wrong. It happened for low solar radiation and for solar incidence behind the main façade. It may be caused by the considerations on diffuse solar calculations and solar angle simulation. The problems were avoided when the hourly SHGC calculations were selected for values of solar irradiance above 500 W/m². Then, the hourly SHGC during winter produced more consistent results than summer.

The analysis of overhangs shows large variations of SHGC during the day when there is more shading, such as VSA lower 50° (Fig. 3-56). Side fins are more sensitive yet, for HSA lower than 70° (Fig. 3-57). This behaviour is expected because the shading is not uniform. However the combination of both shading devices produce more uniform patterns (Fig. 3-58).

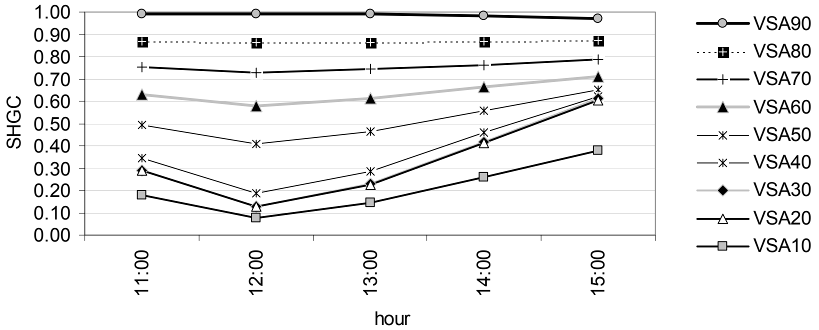

Fig. 3-56. Estimation of hourly SHGC for 21 June, single clear glass with different vertical shading angles (overhangs), North orientation.

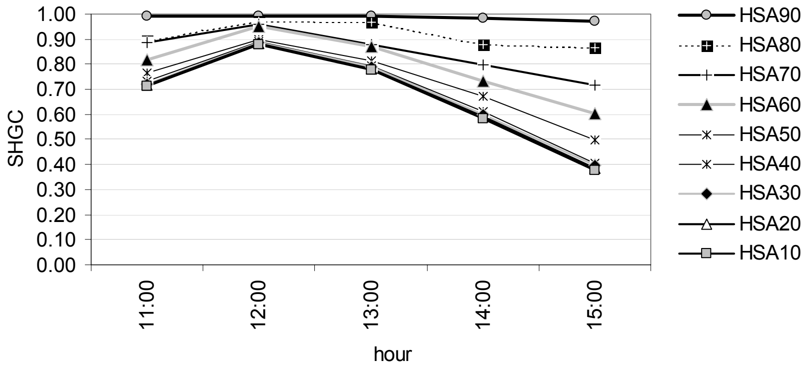

Fig. 3-57. Estimation of hourly SHGC for 21 June, single clear glass with different horizontal shading angles (overhangs), North orientation.

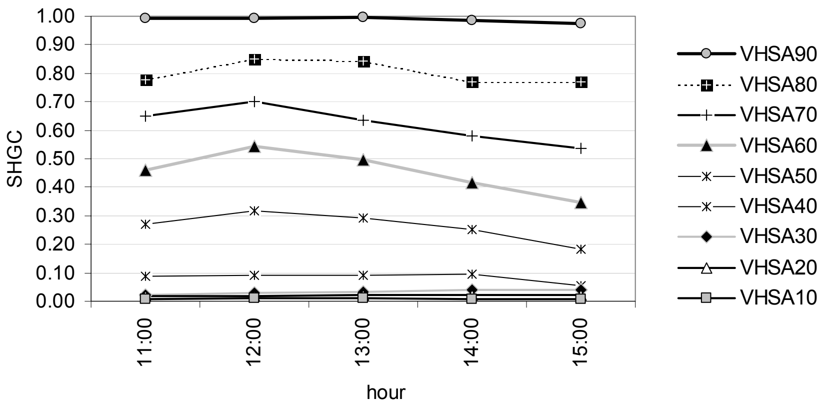

Fig. 3-58. Estimation of hourly SHGC for 21 June, single clear glass with different horizontal (both sides) and vertical shading angles (overhangs), North orientation.

The variation of SHGC during a year is highlighted in Fig. 3-59, where the maximum, average and minimum values are compared for each VSA. The differences between the maximum and minimum values are large for VSA below 60°. This would indicate that at VSA 40° the max is six times higher than the minimum value. The HSA (Fig. 3-60) and the combination of both (Fig. 3-61) have similar behaviour.

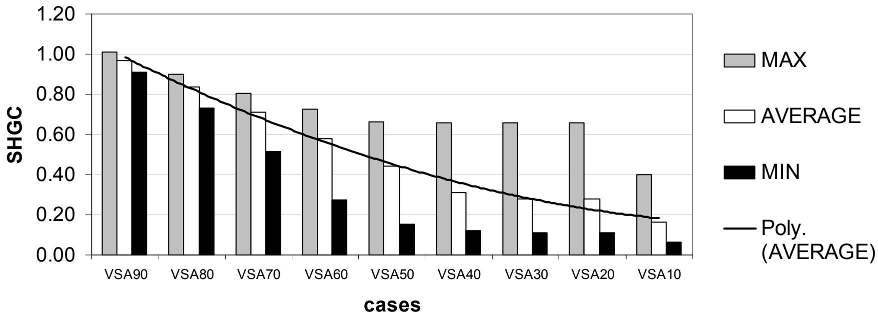

Fig. 3-59. Estimation of variation of SHGC for single clear glass with different vertical shading angles (overhangs), North orientation.

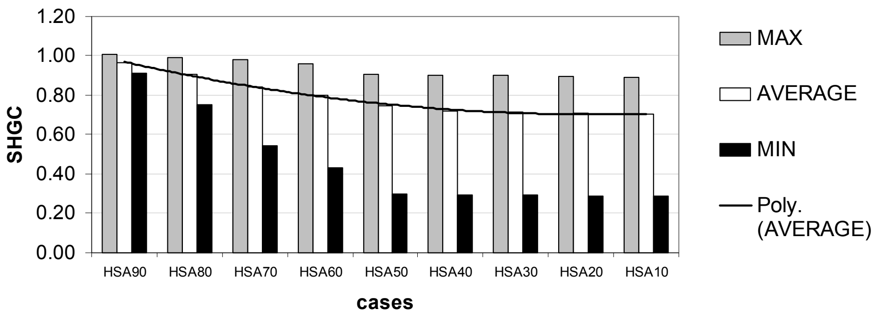

Fig. 3-60. Estimation of variation of SHGC for single clear glass with different horizontal shading angles (side fins, both side), North orientation.

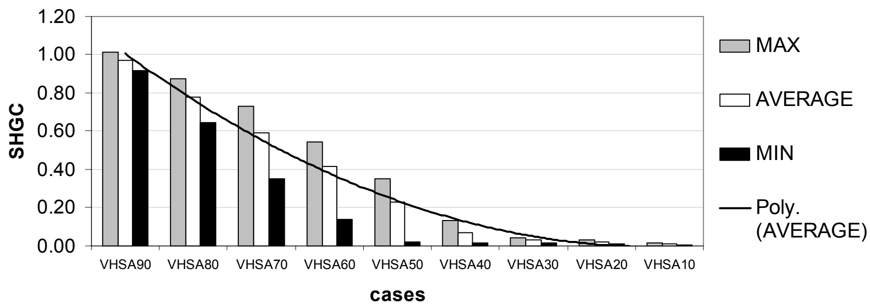

Fig. 3-61. Estimation of variation of SHGC for single clear glass with different vertical (overhangs) and horizontal (side fins) shading angles (egg crate) North orientation.

The average SHGC for VSA is well represented by a polynomial equation, where:

$SHGC = 0.00008.VSA^2 - 0.0019.VSA + 0.1546, (R^2 = 0.9892)$ **eq. 11**

The average SHGC for HSA is represented by:

$SHGC = 5E\text{-}05.\ HSA^2 - 0.0018.HSA + 0.719, (R^2 = 0.997)$ **eq. 12**

The so-called VHSA[54] are related with the average SHGC by:

$SHGC = 0.0002\ VHSA^2 - 0.0038.VHSA + 0.017, (R^2 = 0.9922)$ **eq. 13**

Using the 'office' characteristics from VisualDOE templates (schedules, LPD, EPD, etc), a preliminary set of simulations relate the impact of VSA on energy consumption with and without use of daylighting. Modelling the shading geometry instead of declaring the SHGC, the results of one-year simulation were plotted in Fig. 3-62. The energy consumption varies more in offices with no daylighting use than offices with daylighting energy saving strategies (for different values of VSA). Using the maximum SHGC prescribed by ASHRAE 90.1 (ASHRAE 1989), SHGC = 0.61 for WWR <10% (highlighted by a circle), the expected maximum energy consumption would be between 120 and 160 kWh/(y.m²), with daylighting and without daylighting use, respectively. In this case, the maximum VSA allowed by the code is close to 60°.

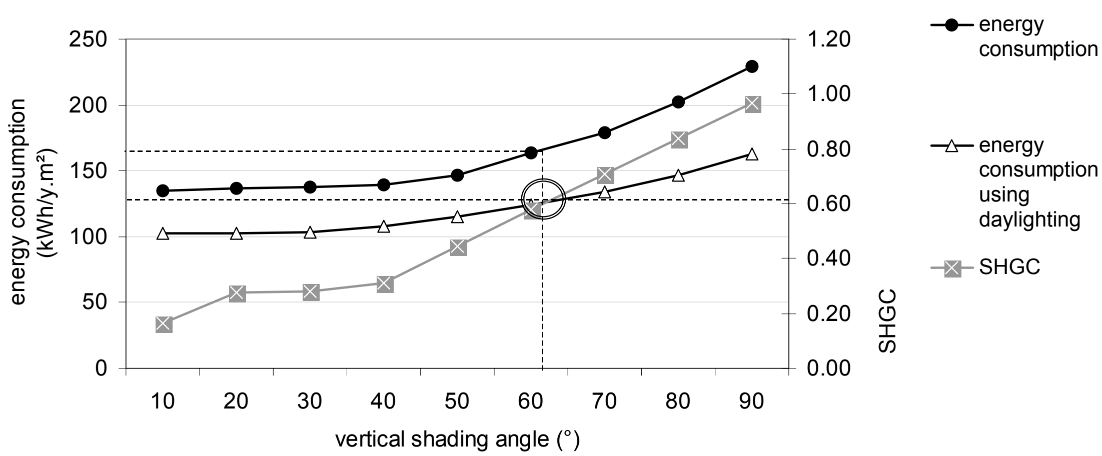

Fig. 3-62. Comparison of estimated SHGC and annual energy consumption of a cell with 'office' characteristics and North façade with single clear glass and overhang.

[54] Notation used to represent equal vertical and horizontal shading angles.

The same analysis disqualifies side fins as a strategy because there is no HSA able to reach a SHGC lower than 0.61 (Fig. 3-63).

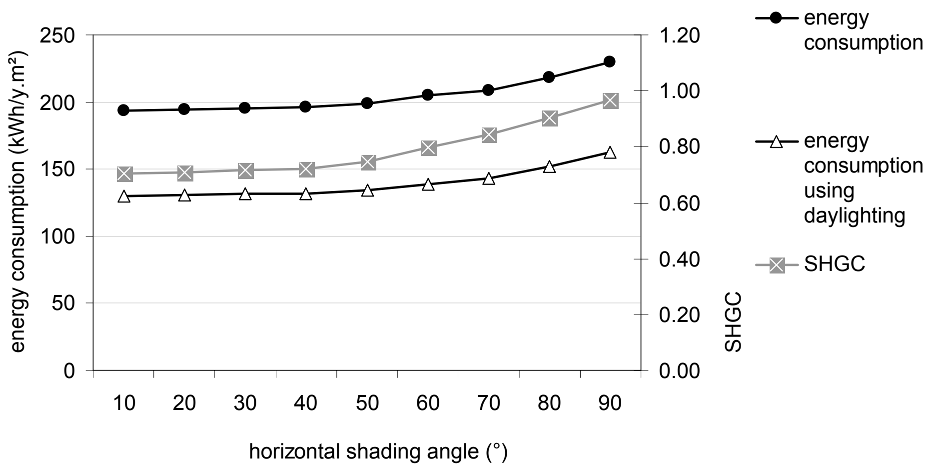

Fig. 3-63. Comparison of estimated SHGC and annual energy consumption of a cell with 'office' characteristics and North façade with single clear glass and side fins.

The combination of both types of shading devices allows to relax the maximum angle of VHSA (and consequently less device projections). The minimum prescribed by ASHRAE 90.1 (ASHRAE 1989) matches an angle around 70°, which produces an energy consumption between 130 and 200 kWh/(y.m²) (Fig. 3-64). Cases without daylight use has a proportional variation for the angles: more protection means less energy consumption. However the use of daylighting produces better performance for a specific angle, 40°. In this case, more protection causes more energy consumption.

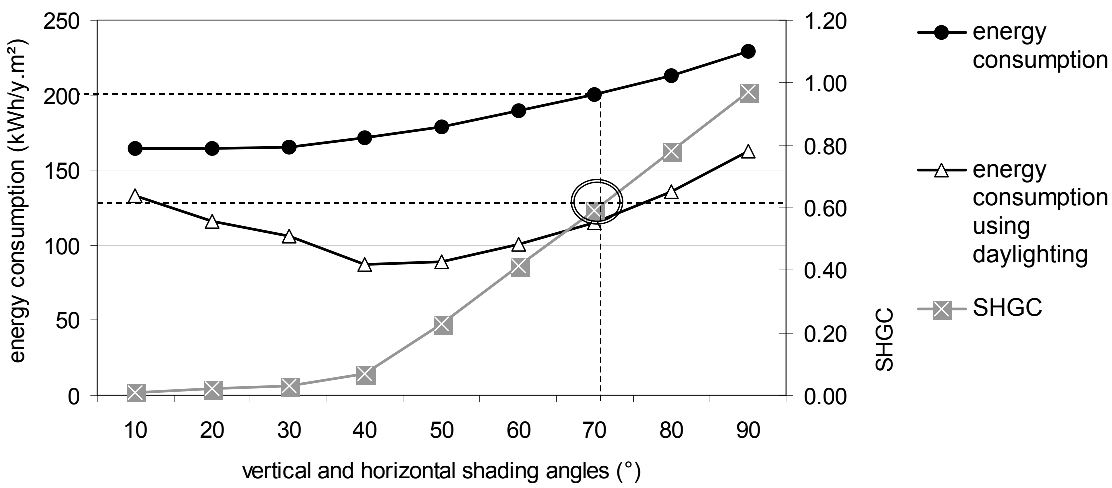

Fig. 3-64. Comparison of estimated SHGC and annual energy consumption of a cell with 'office' characteristics and North façade with single clear glass, overhang and side fins.

Although SHGC should be constant (at least it is for uniform glass), the previous simulations attest that it varies for windows partially shaded. The use of SHGC in prescriptive codes, instead of VSA, HSA or VHSA, seems to be a simplification for designers. However, there are no practical and comprehensive resources to quantify SHGC for shading devices, which make it inappropriate in many situations. Then, the matrix for parametric analysis opts to define angles instead of SHGC. More accuracy demands the reproduction of further cases than used in the previous simulations.

The definition of VSA intervals depends on the influence of VSA on the energy consumption. Based on the LTV results, the most drastic variations happen for a room with depth 3, oriented for West (Fig. 3-65). In this chart, the influence of the VSA becomes more sinuous for higher values of the WWR. Twisting the chart in clockwise, it is possible to highlight the influence of VSA on energy consumption (Fig. 3-66: a). Increasing the room depth for 5 and 8m, the influence of VSA decreases and the curves become flatter (Fig. 3-66: b and c). Therefore, it is reasonable to adopt at least four intervals for VSA, as described in Table XXIX. The study of SHGC evidenced that vertical devices has less influence, consequently, the study opted for three intervals (Table XXIX).

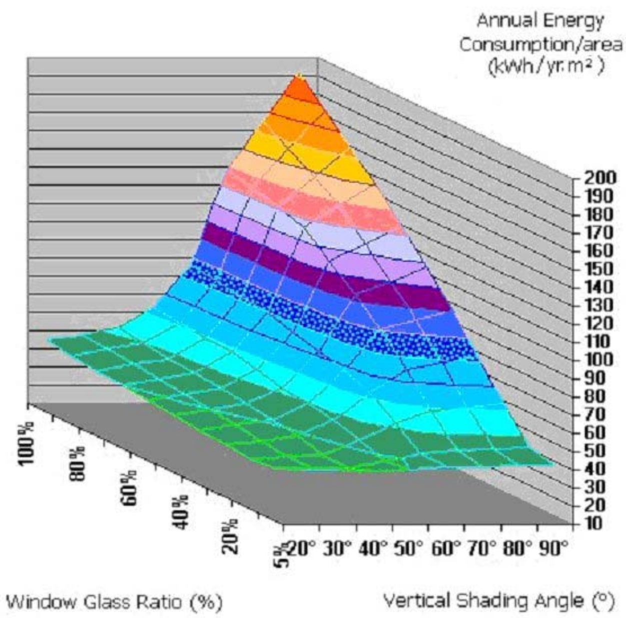

Fig. 3-65. Influence of VSA and WWR on energy consumption.

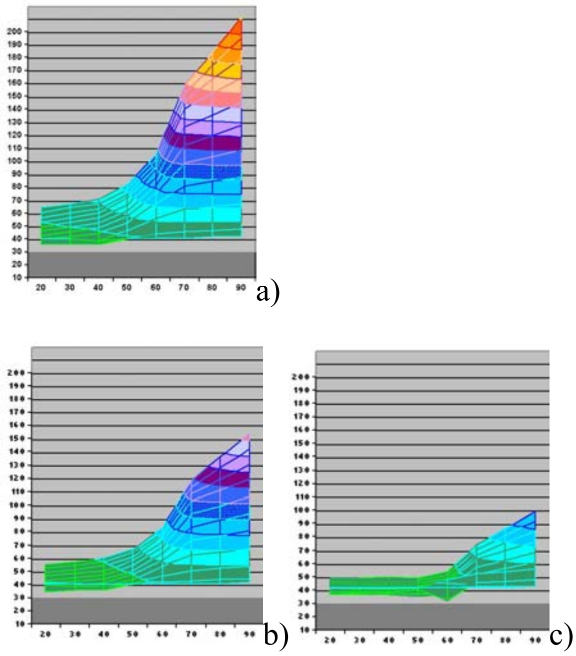

Fig. 3-66. Influence of VSA on energy consumption for different values of room depth: a) 3m, b) 5m and c) 8m.

Table XXIX. Angles for parametric analysis.

device angles	minimum	intermediate*		maximum
VSA	20°	50°	70°	90°
VHSA	20°	60°		90°

* Equivalent to the maximum SHGC prescribed by ASHRAE 90.1, when it is possible.

Building use and services

Work patterns and building occupancy strongly influence building energy performance. They concern human factors and needs, such as routines and internal environment, influencing the building performance directly and indirectly. For example, the use of equipment consumes energy (direct effect) and generates internal heat that affects the balance-point temperatures[55], influencing the selection of materials and building shape to manage the heat flows (indirect effect).

Some work patterns are related to low energy strategies, such as the occupancy schedule that leads to the use of daylighting, reason why some regions adopt the 'summer time' or 'daylight saving time. Occupants are also responsible for adjusting the cooling set point temperature of air conditioners, which has a major impact on its energy consumption. Basically, work patterns may affect forms, building services and low energy strategies, becoming part of the design problem. Consequently, the models demand representative characteristics to produce reliable results.

The Consultancy Brief (ABCB 2001b) is so far the most reliable, comprehensive and detailed source of building use information. The Appendix A (ABCB 2001d) reports the maximum occupancy of 1 person/10 m² and peak loads for lighting and equipment, i.e., the power densities to be taken into account are 20W/m² and 15W/m², respectively. Based on these indices, ABCB defines profiles that have the percentage of use for each hour, for weekdays and weekends. ABCB introduces two different profiles for weekdays, denominated ID1 (Fig. 3-67) and ID2 (Fig. 3-68). Both have the same profile for Saturday and public holidays (Fig. 3-69) and for Sundays (Fig. 3-70), while the weekday profiles are slightly different. The illumination in ID1 is active until the early evening hours, even when the occupation is very low. ID2 profile is more conservative and reflects a smarter use of lighting. Then, ID2 is more appropriate for cells that intend to employ low energy architecture.

[55] Condition of equilibrium of thermal loads: at which loss equals gain.

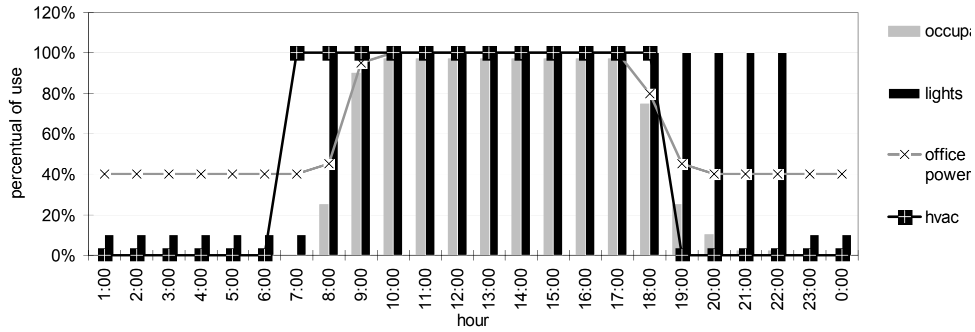

Fig. 3-67. Proposed baseline profiles for ID1, weekday.

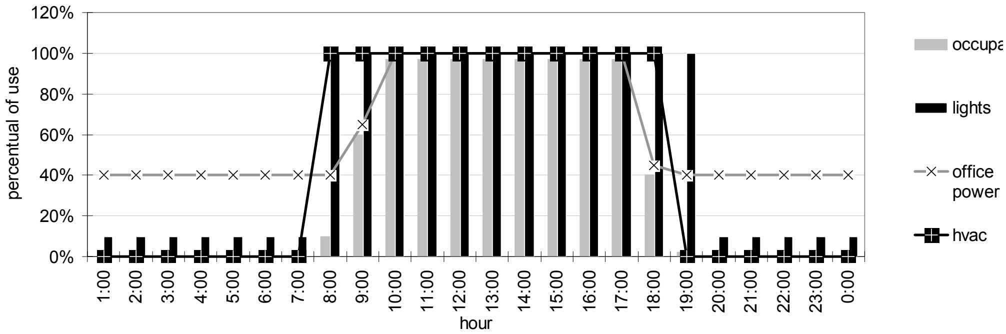

Fig. 3-68. Proposed baseline profiles for ID2, weekday.

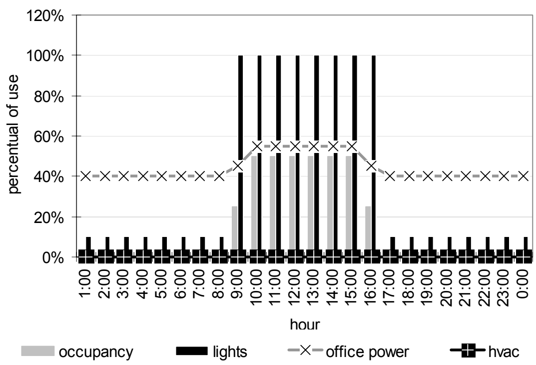

Fig. 3-69. Proposed baseline profiles for ID1 and ID2, Saturday and public holidays.

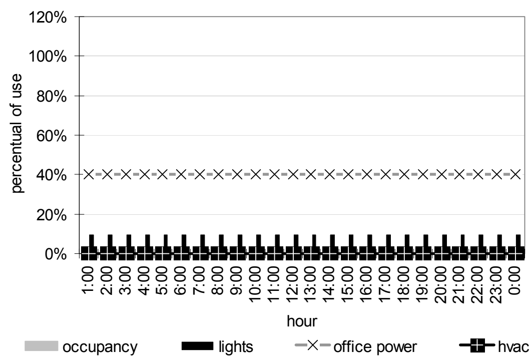

Fig. 3-70. Proposed baseline profiles for ID1 and ID2, Sunday.

Australian standards define a large range of lighting levels for office areas. From 160 lux for simple tasks to 600 lux for difficult task (Standards Association of Australia. 1990). Entrance halls, lobbies, foyers and waiting rooms also have minimum lighting levels prescribed as 160 lux (Standards Association of Australia. 1993). Activities that involve screen–based tasks (such as computers) must have 320 lux plus provision for supplementary task lighting available to assist with maintenance as the general lighting may not be sufficient.(Standards

Association of Australia. 1994) Similarly, O'Connor, Lee et al. (1997) recommend to keep ambient lighting low for computer screens.

ABCB (2001d) defines two basic HVAC systems: central cooling water (CCW) for office towers and single zone DX for other offices. The HVAC services' design is the same for all building forms and it is in accordance with the AS 1668.2 (1991).

Table XXX. HVAC services' design - Baseline buildings office for warm humid climate (ABCB 2001d)

criteria	Requirement
Outside air rate	10L/s / person
Core area	exhaust ventilated at 6ac/h
Infiltration	1.5 air changes per hour when the air conditioning is off and 1 air change per hour when it is on.
minimum supply air	$\geq$ 6 air changes per hour and zone
return air	below ceiling

Unfortunately the ABCB does not specify the efficiency of any system. However the ASHRAE STANDARD 90.1 (ASHRAE 1999) has a detailed minimum efficiency requirements for every type of cooling system, which is discussed as strategy in subchapter HVAC, page 140.

Strategies beyond architectural characteristics

The next definitions concern the strategies that are strongly related to architectural design, but depend on special features. While the correct choice of thermal insulation provides predictable heat transfer process, some strategies such as daylighting and natural air ventilation relay on specific devices and/or occupants' behaviour. Taylor Oppenheim Architects, Lincoln Scott Australia et al. (2000), Drogemuller, Delsante et al. (1999) suggest some:

- Mechanical HVAC opportunities: HVAC controls; HVAC system selection & design; thermal storage, co-generation, heat recovery / exchange / storage; economy cycles for HVAC systems (in suitable building types and climate zones); time switches to control HVAC systems; exhaust to fresh air heat exchangers for HVAC systems; limiting the floor area controlled by a single light switch; sub-metering requirements; and maintenance provisions for energy systems
- Electrical opportunities: lighting controls / dimmer / sensors, lamps and luminaires

- Control strategies: supply air temperature reset; terminal regulated air volume; night time free cooling; cooling set point reset optimum start; condenser water reset; chilled water temperature reset; hot water temperature reset.

Lighting

The improvement of lighting system efficiency is a common strategy and it has a significant impact on the overall efficiency. The lighting energy consumption can account for 25-50% of the total electric energy usage in a building and the thermal load resulted can add more 10-20% of energy consumption to the air-conditioning (Rea and Illuminating Engineering Society of North America. 1993).

As defined by The Consultancy Brief (ABCB 2001b), the typical Australian building has 20W/m² of lighting power densities. The ASHRAE 90.1(1999) prescribes an maximum of 14 W/m², the California Energy Commission (1999) prescribes 13 W/m², which corresponds to the value adopted by Building Greenhouse Rating Scheme (Bannister 2001). These values are very conservative, as recognized by the Model Technical Specifications for Commercial and Public Buildings (Sustainable Energy Authority Victoria 2000):

'In office type situations, installed lighting power density may be in the order of 15W/m². With high efficiency luminaires 10-11W/m² is typical. Where the luminaire spacing and floor to ceiling height can be optimised for the lighting system, an installed lighting power density of 8-9W/m² is possible.'

In another reference, T-8 lamps and electronic ballasts provide a high-quality lighting environment with a power density of 11.4 W/m² (Office of Energy Efficiency 1999). Considering the purpose of the parametric analysis, it is reasonable to assume two conditions: one in accordance with the ABCB (2001b) and a second one 50% better, which corresponds to 10 W/m².

Daylighting

"*Until 1900, most buildings were 'daylit' in the sense that daylight was the major source of daytime illumination. Due to the electricity use and increased cooling load that is created by electric lighting, there is a renewed interest in daylighting commercial buildings"* (Schrum and Parker 2002)

The effective use of daylight can improve the occupant satisfaction and reduce the energy consumption for artificial lighting (Rea and Illuminating Engineering Society of North

America. 1993). Lighting and its associated cooling energy use constitute 30 to 40% of a commercial building's total energy use and daylighting is the most cost effective strategy for targeting these uses (O'Connor, Lee et al. 1997). Although the strategy is economically interesting, its design is more complex than most of the other strategies. In practice, there are few buildings with daylighting and less work properly.

The choice of daylighting as strategy must occur as earlier as possible and the most critical of the design phases is the schematic[56] (O'Connor, Lee et al. 1997). For example, it has been suggested that windows must have at least 20% window/ wall ratio to satisfy most workers (Rea and Illuminating Engineering Society of North America. 1993). However, the development of the strategy must be carried out during the other phases to assess other consequences of it, such as glare that can produce discomfort. O'Connor, Lee et al. (1997) suggest the following actions:

1. Pre-design, Programming. The goals established at this early planning stage will set the foundation for an integrated, comfortable, and energy-efficient building design. Establish performance goals together with the owner and make achieving these high performance goals a priority. Use the easy tool in the COST/BENEFIT section to quickly determine if daylighting holds good investment potential.
2. Schematic Design. The first design decisions are critical to energy efficiency and daylighting. Get started on the right foot by reviewing key idea.
3. Design Development. Refine envelope, room, and shading design.. This is a critical time for coordination among design team members.
4. Construction Documents. Make sure glazing, shading, lighting, and control systems are properly specified. Include calibration, commissioning, and maintenance plans as part of the construction documents (review those sections now).
5. Pre-Occupancy. Based on calibration and commissioning activities.
6. Post-Occupancy. Based on maintenance activities.

The project cannot purely depend on human behaviour. As described in Schrum and Parker (2002), a study by Hunt and Cockram showed that continually occupied offices experienced little manual switching during occupancy. Most of the switching was at the start and the end

[56] Previously discussed in 'Building architectural variables', page 103

of the work day. Thus, reliable savings are likely only with automated controls (Schrum and Parker 2002).

Modelling daylighting

In comparison with software oriented to daylight assessment, DOE-2 has a series of limitations for a complex analysis in a detail design phase [57] . However, it has practical ways to quantify the energy savings of operation of window shading devices. DOE2.1E makes a daylighting calculation for the space if a point is specified for a photocell. It controls the electric lighting system response to the set light levels at the specified reference points. Although these sensors may be located at a specific point in the room, they generally "view" the reflected light from a larger area in the room. Thus, the sensor itself tends to see an average light level. The criteria for switching is the work plane illuminance. For example, if the sensor measures 1/3 of the minimum illuminance required, the software takes the decision to turn on 2/3 of the lights. Then, the software assumes the light power density is proportional to the artificial illuminance, which is satisfactory to this study. The VisualDOE graphic interface offers four options to control the fraction of artificial light that is switched on to keep the minimum light levels: OFF/ON, OFF/50%/ON, OFF/33%/67%ON and dimming (WX-4 1980).

[57] The built-in daylighting illuminance calculation works best when most of the illuminance point directly from the windows and when the shading devices on the windows act like diffusers (W.F. Buhl 1993).

Control of blinds

Edmonds (2000) questioned the massive use of glazing wall areas for the purpose of a scenic view. He argued that occupants might decline such advantage in favor of comfort, as illustrated in Fig. 3-71 and Fig. 3-72. Although the excessive glare and thermal radiation from the fenestration are the main reason to the use of blinds, a visual inspection evidence that internal shading devices remain closed even after discomfort hours. Human behaviour has the tendency to adjust venetian blinds infrequently, having preferred blind positions (Rea and Illuminating Engineering Society of North America. 1993).

Fig. 3-71. Coronation drive building.

Fig. 3-72. Millhouse building.

The Supplement, Version 2.1E (W.F. Buhl 1993) details controls when solar gain exceed user-specified values. VisualDOE (Eley Associates 2001) brings an option to assume the blind will be open any time solar gains through the window are less than 94 W/m². When solar gains exceed this threshold, the interior shade will be closed.

HVAC

The ASHRAE STANDARD 90.1 (ASHRAE 1999) has detailed minimum efficiency requirements for every type of cooling system. For the method of cell modelling, the single zone[58] air conditioning system is more appropriate, which may use single package or split

[58] A single-zone system is best described as a constant volume, variable air temperature distribution a system. As the name implies, a single-zone system commonly serves one thermal zone or multiple zones with loads that react, at least thermally, in a similar manner (Tri-State Generation and Transmission Association Inc (2000). Cooling System Alternatives, APOGEE Interactive, Inc. **2002**.).

system. In accordance with ASHRAE (1999), the minimum efficiency is prescribed for ranges of cooling capacity and de COP varies as function of it[59], from 2.40 to 3.08 kW/kW. The adoption of such values is questionable because they are specific for the North American market. In comparison with the COP of package units available in the Australian market published in A.R.E.M.A. (1999), the Table XXXI shows that the majority of the manufactures could not attend such requirement. Only 35% of the maximum COP for models in each range is above the minimum prescribed (as highlighted in the table).

Table XXXI. COP of package units of Australian air conditioning manufactures from A.R.E.M.A. (1999), classified in terms of ASHRAE (1999) requirements.

manufactures	cool cap. <19 kW COP ≥ 2.72		19kW < cool cap. < 40kW COP ≥ 3.08		cool cap. > 40 kW COP ≥ 2.81	
	minimum	maximum	minimum	maximum	minimum	maximum
Actron	2.55	2.63				
Alcair	2.17	3.02	2.59	2.98	2.44	2.44
Airfact	2.47	2.78	2.24	2.70	2.21	2.68
Apac	2.39	2.80	2.70	3.10	2.70	3.00
Carrier	2.40	2.50	2.30	2.70		
Daikin	2.39	2.64	2.30	2.75	2.47	2.47
Emailar	2.16	2.44	2.15	2.57	2.16	2.20
Lennox			2.60	3.30	2.90	3.30
Paragon	2.25	2.83	2.35	2.83	2.25	2.38

Due the absence of local recommendations and due the optimistic requirements of (ASHRAE 1999), therefore the parametric analysis adopts the minimum and maximum efficiency of package units of the Australian market: 1.63 and 3.30 kW/kW.

Natural and artificial ventilation

Until recently, the controlling of exterior air supply was managed to save energy and increase indoor comfort: cooling the building mass and producing physiological cooling by air velocity (Szokolay 1980a; Givoni 1991). Although less known, a third option consists of reducing the cooling consumption of air conditioning through the replacement of recirculated air by exterior air, if its temperature or enthalpy is lower; the strategy is recognized as enthalpic control or economizers (GroupQ-11. 1989).

[59] For PTAC systems, the formula corresponds to COPc = 2.93 – (0.16 x Cap/1000)*COPc.

Recommendations

Exterior air has been used with reasonable success in Mediterranean, temperate and cold climates. For example, Gids, (2001) mentions the achievements of Commerz Bank in Frankfurt from architect Norman Foster; Aggerholm (2001) discusses the PROBE and the IVEG buildings in Belgium, Pfizer office building in Norway, the Enschede Tax Office in Netherlands and the B&O Headquarters in Denmark. However, there are few examples regarding office buildings in warm climate and even less with any success story. Probably the most expressive achievements come from Yeang (1999), who argues that the taller the building, the greater should be its potential to ventilate itself by the stack effect. The architect recommends the use of wing walls that can be used to capture wind using a 'fin' at the façade to channel wind into the insides to increase the internal airflow, similar to the effects of a ceiling fan. Jones and Yeang (1999) analyze the wing feature in the Menara Umno building and they highlight some obstacles:

'For the stack only situation the ventilation rate is not very high, at about 1ac/h … The internal air speed is low and would not provide a significant comfort cooling effect[60]*. For the window opening situations, where there are large openings up-wind and down-wind, the ventilation rates are very high. Obviously this is too high for comfort as the corresponding internal air speeds are between 0.4 and 0.5m/s in the vicinity of the openings, which could give rise to mechanical problems, such as papers moving. Closing down the openings on the up-wind side appears to be the best solution for controlling ventilation without excessive internal air speeds … The ventilation strategy should be to ensure that windows and doors can be opened wide, for low wind and calm conditions, but that they can have adjustable openings to allow them to be operated under average and high wind conditions. During medium to high wind situations it appears to be advisable to close down on the windward direction openings to a minimum.'.*

The architect's intention is more straight forward when he refers to the Menara Messiniaga building: Yeang (1996) describes the use of natural ventilation of different areas:

- lift hobbies area: 'openable windows at minimum 25% of floor area';

[60] Personal visit to the building proved such prediction. The air speed measurements evidenced unsatisfactory comfort conditions.

- toilet areas: '0.2m² openable windows minimum per WC or urinal and free uninterrupted passage of air';
- main user spaces: despite the use of air conditioning, the architect suggests 'the designer has to provide the option of natural ventilation … window area of 5% per 10% of the clear floor area for free uninterrupted passage of air'.

Despite such efforts in his design, a personal visit to the building verified that the occupants do not use natural ventilation in the main spaces.

Obstacles

There is a significant influence of architectural characteristics. Consequently, the development of such a strategy is recommend during the schematic phase (Taylor Oppenheim Architects, Lincolne Scott Australia et al. 2000). Such interdependence demands discussion of methods of prediction during the design, as discussed in this thesis.

The assessment of the natural ventilation and infiltration effects involves many guesses and uncertainty. The simplest method is based on number of volume changes per hour as Archipak and DOE.2 do. A step further, software like ESP-r uses coefficients of pressure at the opening. Although both methods depend on guesses, they are simple enough to assess a sketch. On the other hand, software that are more rigorous to estimate the phenomenon, such as COMIS, demands a detailed building geometry, incompatible with sketches. This method also suffers from the same uncertainty that CFD method does, resulting from the characterization of boundary conditions or the typical weather. Boundary conditions are quite acceptable to assess conditions of project, but not appropriate to assess the energy savings in one typical year or to provide a statistical result. Weather files are usually obtained from monitoring at open spaces, as airports, which do not describe the wind flow in CBDs. Furthermore, wind speed and direction are measured at only one height, neglecting wind profiles. Although the intention is not to discourage the analysis of natural ventilation, Gleick (1987) recalls the complexity of the issue:

"Turbulence was a problem with pedigree. The great physicists all thought about it, formally or informally. A smooth flow breaks up into whorls and eddies. Wild patterns disrupt the boundary between fluid and solid. Energy drains rapidly from large-scale motion to small. Why? The best ideas came from mathematicians; for most physicists, turbulence was too dangerous to waste time on. It seemed almost unknowable. There is a story about the quantum theorist Werner Heisenberg, on his deathbed, declaring that he will have two

questions for God: why relativity, and why turbulence? Heisenberg says, 'I really think He may have an answer to the first question' "

Hybrid ventilation

Due the characteristics of warm climate and aggravated by the internal heat generation in office buildings, natural ventilation is not enough to guarantee indoor comfort. Then, a cooling system is necessary and the occupants or automatic controls must decide for when to use it. However, as previously mentioned, occupants are not sympathetic to control daylighting or even blinds (subchapter Daylighting, page 137); therefore, similar behaviour is expected for the operation of windows.

Cauberg, et al. (2001) discuss the concept of hybrid ventilation, which consists of a combination of natural ventilation and active systems. Hybrid systems are classified as (1) alternate use of natural and mechanical ventilation, (2) fan assisted natural ventilation and (3) stack and wind supported mechanical ventilation (Gids 2001). Heiselberg, Delsante et al. (2001) define the concept : '*A hybrid ventilation control system must be able to control the mechanical (e.g. fans) as well as the natural ventilation components of the system (e.g. windows or other apertures, special inlets). Other components may also need to be controlled to ensure satisfactory thermal performance, for example shading devices or lighting'.*

The survey includes 22 existing buildings from ten of the countries participating in this Annex. The buildings surveyed are low to medium-rise buildings. It is clear from the descriptions of the overall design philosophy that a successful hybrid ventilation design depends on an integrated approach, in which optimal use is made of sustainable technologies such as passive solar gains, daylight and natural ventilation. In particular it requires good thermal design, and in a number of buildings thermal mass combined with intensive night ventilation (using natural forces or fan assistance) is exploited to stabilize temperatures during the day.

Modelling

Due the complexity of such issues, the parametric analysis concerns two strategies, both using outside air: natural ventilation and enthalpic control.

In DOE.2.ID significant additions have been made to the capabilities of the natural ventilation model in the residential system (SYSTEM-TYPE = RESYS) simulation in SYSTEMS. The capabilities previous to 2.ID are described in the *Reference* Manual (2.1A) pp.IV.217-19 (WX-4 1980). Basically, the modeler has considerable control over when venting occurs (i.e., when the windows were opened or closed) through the commands. However, the modelers are forced to estimate (or guess) the air changes due to natural ventilation when the windows were open. DOE-2.ID increased the user's ability to control when venting occurred; more importantly, it added the capability to estimate the amount of venting that takes place when the windows were opened. The model used to calculate the amount of natural ventilation is identical to one of E.2's infiltration models - the Sherman-Grimsrud (S-G) model. DOE-2 allows defining two methods of ventilation.

- AIR-CHANGE: ventilation must be defined in terms of air changes per hour. This sets a fixed air change rate that is used whenever the windows are open.
- S-G: it is set to 0.6 times the open window area divided by the floor area. The most common value is 0.05, depending on the situation being modelled. A schedule defines the probable hourly values that the windows will be opened that hour, given that the conditions set such as temperature set point.

Enthalpic control simulates an economizer that returns the outside air damper to minimum if the outside air enthalpy is higher than the return air enthalpy or if the outside air temperature is higher than a limit. In the parametric models, an enthalpy limit of 70 kJ/kg is assumed, which was defined as the optimum limit for Brisbane climate through parametric simulations (by the author).

Cooling set point

Cooling set point temperature depends basically on user's preference. In theory, it relates to the other variables of thermal comfort[61]. In practice, measurements[62] have shown a large variation of cooling settings, some of them outside of the comfort range. However, estimation of energy performance requires its definition because the performance is strongly influenced by this variable, as much air conditioning design does. The Mechanical Engineering Services Design Aids (Wickham 1982) defines inside comfort design conditions are to be taken as 24°C DB, 50% RH for summer, and 21°C DB, 30% RH for winter. The other way, The

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[61] Variables such as humidity, thermal radiation, wind speed, thermal resistance of clothing, metabolism.

[62] The measurement of average temperature in conditioned zones is part of the method of modelling calibration, executed in more than 10 buildings in Brazil. Vide Pedrini, A., F. S. Westphal, et al. (2002). "A methodology for building energy modelling and calibration in warm climates." Building and Environment **37**(8-9): 903-912.

Consultancy Brief (ABCB 2001b) characterizes air conditioning with cooling set point set of 22 ^{o}C $\pm$ 2K with a 1K deadband.

As discussed in 'Thermal Comfort PLEA Notes '(Auliciems and Szokolay 1997), the neutrality temperature (T_n) has a geographic component. For free-running and conditioned spaces, Auliciems suggest the eq. 14, for T_n between 18 and 28°C, based on average monthly temperature (T_m): The formula assumes people at sedentary work, in their normal environment, wearing the clothing of their choice. The comfort limits can then be taken as Tn ± 2.5°C.

T_n -= 17.6 + 0.31 T_m **eq. 14**

The range of Tn ± 2.5°C is illustrated in Fig. 3-73, which has a shadowed zone that represents the limits prescribed by The Mechanical Engineering Services Design Aids (24°C) and The Consultancy Brief (22°C).

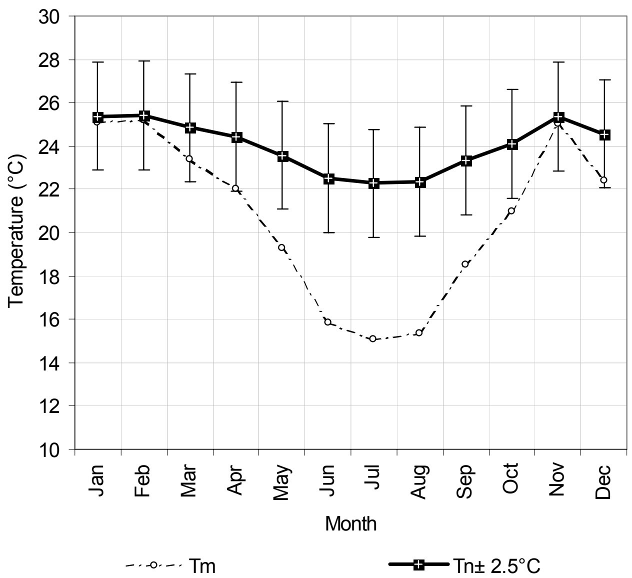

Fig. 3-73. Temperatures of comfort for Brisbane.

Table XXXII. Minimum and maximum temperatures

	Tm	Tn	Tn+2.5	Tn-2.5
average	21.0	24.1	26.6	21.6
maximum	25.2	25.4	27.9	22.9
minimum	15.3	22.4	24.9	19.8

Table XXXIII. Adopted set points.

	Tm	Tn± 2.5°C
Jan	25.06	25
Feb	25.18	25
Mar	23.38	25
Apr	22.03	24
May	19.28	24
Jun	15.87	23
Jul	15.15	23
Aug	15.34	22
Sep	18.53	23
Oct	21.00	24
Nov	25.03	25
Dec	22.42	25

3.2 Questionnaire: assessment of design process in practice

The conception of a survey to explore the design process began with the literature review (Design theory, page 20). The initial sketches wonder if it could be possible to represent the design decisions, the mechanisms, the inputs and outputs in a very transparent way, such as the codes proposed in the IDEF0 method (page 33). However the involvement with case studies ('Case studies', page 159) lead to another level of understanding. The flow of information becomes more complex to be organized while the level of details increases. Not everybody is able to accept such rational method to represent their actions, exposing the risks and mistakes of design decisions. Then, the survey adopted a different approach. It searches for behaviour referenced in theory and possible related with energy tools, that may support the design decision, rather than to understand the meaning of the actions. The survey has two parts (Fig. 3-74). The first is designed to identify methods that support decisions in the design process (reproduced in Appendix A). The second hopes to find out how architects make use of methods to improve energy efficiency (reproduced in Appendix B). Most of the survey consists of statements which can be weighted on a scale of 1 to 5. There are also a few questions to be answered with marks or comments. The questionnaire is based in Temple-Heal et al. (2000), Lam et al. (1999), Lima (1997) and Radovic (2000).

Design process – Part 1

Indicate what importance (if any) you attribute to these methods during the three main stages of the design process:	pre-design (Low Medium High)	schematic (Low Medium High)	detail (Low Medium High)
1. Use of intuition, experience or/and human feel	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
2. Established techniques and proven solutions	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
3. Rules, routines and methods previously tested	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
4. Pictorial precedents (what the building is going to look like), such as in periodicals and books	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
5. Following earlier designs (tested), learning from case studies	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
6. Use of guidelines and rules-of-thumb	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
7. Rational or scientific thinking, based on prior analyses	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
8. 'Lateral' thinking (searching for different ways to solve problems, avoiding dominant and established ideas)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
9. Hypotheses followed by test	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
10. Breaking down problems into smaller parts	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
11. Developing alternative solutions then combining/discarding	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
12. Diagrams, charts and mathematical models	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
13. 3-D thinking	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
14. 2-D thinking	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
15. Integration with other consultants	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
16. Considering the 'meaning' of the building itself for the client, architect, occupants and the surrounding environment	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
17. Consideration of the impact of the design on interior conditions (e.g. light and thermal) and its interaction with the occupants	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
18. Dominance of a central idea (an 'organizing principle) that influences the whole design conception	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

Indicate when and what importance you attribute to the following design decisions	pre-design (Low Medium High)	schematic (Low Medium High)	detail (Low Medium High)
• building volume	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• building orientation	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• façade and fenestration geometries (exterior shadings, overhangs, side fin, etc)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• interior layout	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• properties of components (elements of construction, such as wall, glass, roof, floor, etc)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• artificial lighting systems	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• air conditioning systems	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

Low energy strategies – Part 2

What is the importance of the energy efficiency performance of your design, in relation to other variables, such as function, aesthetics, context, cost, etc)?	1 2 3 4 5 (Low Medium High)
At which phases of your design do you assess energy efficiency?	☐ *conceptual or pre-design* ☐ *schematic* ☐ *detail or development* ☐ *conclusion*
What design (yours or some other architect) would you identify as representative of your work projects? (location of the building or reference in books or articles)	

Mark (☑) the climatic information and sources that you use to support you design decisions

source of data	maps	visit to the site	statistical analysis	hourly-annual data	Monitoring
• *temperature*	☐	☐	☐	☐	☐
• *humidity*	☐	☐	☐	☐	☐
• *solar radiation*	☐	☐	☐	☐	☐
• *wind*	☐	☐	☐	☐	☐
• *microclimate*	☐	☐	☐	☐	☐

If you use some of the following tools, what is their importance in your view?	pre-design (Low Medium High)	schematic (Low Medium High)	detail (Low Medium High)
• Olgyay's Bioclimatic chart	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *Szokolay's CPZ or 'psychometric' chart method*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *Givoni's 'building bioclimatic chart'*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *Mahoney tables*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *'principles'*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *Guidelines and rules-of-thumb*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *Case studies*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *Modelling (wind tunnel, water table, solarscope)*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *software packages (indicate):*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

What importance do you attribute to the following strategies?	pre-design (Low Medium High)	schematic (Low Medium High)	detail (Low Medium High)
• *building orientation*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *building form*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *facade geometries*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *exterior shading (windows)*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *thermal insulation*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *thermal mass effect*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *passive solar heating*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *landscape (microclimate manipulation)*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *daylighting*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *natural ventilation*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *artificial ventilation*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *efficient air conditioning*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
• *efficient artificial lighting*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

Fig. 3-74. Questionnaire: parts 1 and 2.

3.2.1 Background

A useful precedent is a survey conducted by Wittmann (1998) among 650 architects members of the RAIA. The response taken was 65% and the results revealed that the 59% of the architects have low commitment levels regarding energy efficient/ ecological approach. Using the author's classification - least committed, somewhat committed and most committed – the survey suggests that:

- there were 19% of most committed architects and 23% of somewhat committed architects;
- 85% of the least committed architects agreed that energy efficient/ecological design was important;
- those architects who are not as committed as others appear to perceive their own lack of expertise relatively objectively;
- the author suspects that architects may perceive themselves as more committed than they may actually be.

The survey was carried out in 1997 and since than the issue has been increasing in importance, due to regulations and codes of practice. Consulting the RAIA website[63], Fig. 3-75. RAIA website (http://www.raia.com.au/)., there are 451 architects who offer solar/ecologically sustainable development[64] (the RAIA website has 1559 registered as practitioners).

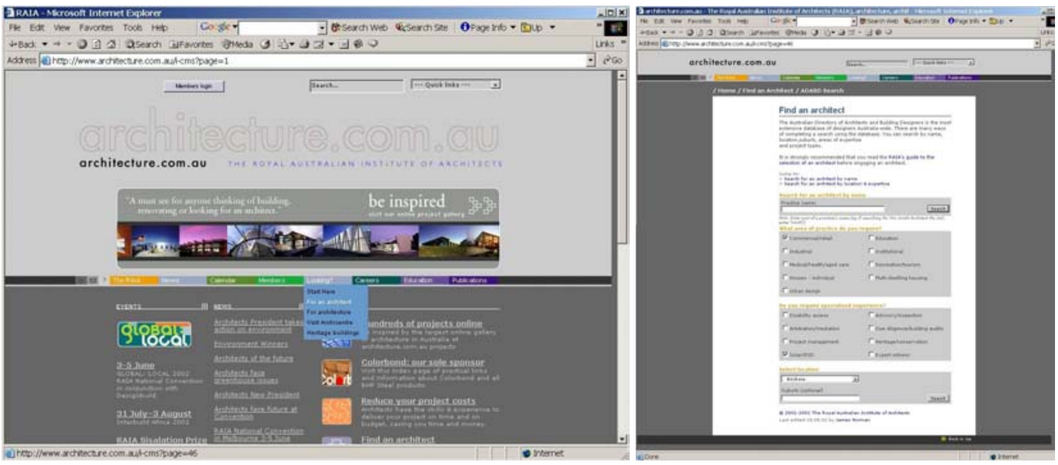

Fig. 3-75. RAIA website (http://www.raia.com.au/).

[63] http://www.raia.com.au/, consultancy occurred in 12 June 2002.

[64] ESD is the area of expertise closest to low energy design, available in the search.

3.2.2 Design process: part 1

The literature review showed some attempts to represent the creative process and the design decisions. The theories are polemic[65] and none of them have received anything approaching unanimous acceptance, nor are any likely to in the future (AIA 1999). In practice, the issue is more obscure. The language adopted is usually peculiar and it may transcend the scientific[66] [67]. In some cases, the technical information assumes metaphorical meaning [68]. The other aggravations are the use of inaccurate terms and misuse of the words. For example, heurist or heuristics (the science of heuristic procedure) are commonly used, although the words have a broad meaning:

- serving to discover (of computer problem solving), proceeding by trial and error – heuristic method is an education system where pupil is trained to find out things for himself (The Concise Oxford Dictionary 1976);
- a computational method that uses trial and error methods to approximate a solution for computationally difficult problems (GIS Dictionary 1999).
- a method of analysing outcome through comparison to previously recognized patterns. For example, an antivirus program, familiar with behaviour typical of viruses (such as deleting files in sequence), could use heuristics to identify unknown virus strains by their behaviour (CNET Networks 1995).

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[65] '*Regardless of their source, most design methodologies share the unquestionable assumption that it is possible to reduce design to a singular, linear process'* AIA (1999). Understanding the Design Process. **2000**.

[66] '*Often, these methods borrow freely from the theory and practice of other disciplines such as literature, science, sociology or fine arts'* Ibid.

[67] In complementation of the previous reference, terms may also be borrowed from esoteric areas and used in combination with 'holistic' approaches. The book 'Green House Plans' describes a variety of design techniques: such as Feng Shui, local space astrology, spiritual design process, vaasty and sacred geometry, Gray, a. T., Ed. (2002). Green house plans. Victoria, Earth Garden Books..

[68] In a book about 'green architecture', a house in Canada is designed to be built using tradition in Maritimes '*treating buildings like boats – lighting, mobile structures on land, ice and water*' (The Danielson Cottage, page116). In other case, a house in Arizona's desert uses a high thermal mass (rammed-earth) construction because it fits to the clean-lined vernacular of the desert (Palmer/Rose house, page 96). Trulove, J. G. and N. R. Greer, Eds. (2001). Hot dirt coll straw. Nature-friendly houses for 21st century living. New York, HBI. Even worse is New Mexico, where the adobe forms are imitated in timber frame+ stucco.

- etymology (German heuristisch, from New Latin heuristicus, from Greek heuriskein to discover; akin to Old Irish fo-fúair he found. Date: 1821): involving or serving as an aid to learning, discovery, or problem-solving by experimental and especially trial-and-error methods <heuristic techniques><a heuristic assumption>; also: of or relating to exploratory problem solving techniques that utilize self-educating techniques (as the evaluation of feedback) to improve performance <a heuristic computer program> (Merriam-Webster 2002).
- Heath (1984) defines Heuristic: searches to make use of information already obtained to guide the remaining steps of the problem-solving process; the search process is redefined as a search for information which will limit the area of search, ultimately to the point at which generate-and-test or recognition methods become practicable.
- Bay (2001) defines heuristics as '*thinking relying on the use of intuition, human feel, experience, rules-of-thumb, examples by analogy for judgement and decision making in real life condition, without normative analysis based on mathematical representations'*[69]
- Polya (1957) describes the original meaning of heuristics as 'serving to discover': a certain branch of study, not very clearly circumscribed, belonging to logic, or to philosophy, or to psychology, often outlined, seldom presented in detail. The aim is to study the methods and rules of discovery and invention (as discussed by Euclid, Descartes, Leibnitz and Bernard Bolzano). The 'Modern Heuristic' endeavours to understand the process of solving problems, especially the mental operations typically useful in this process. In the author's words, '*heuristics reasoning is often based on induction, or on analogy…heuristic reason is good in itself. What is bad is to mix up heuristic reasoning with rigourous proof'*.

To avoid the misuse of theories and techniques as well as the misreading of expressions of designers, traces of design behaviour that may lead to the integration of energy prediction are converted to straight questions in a survey format (Appendix A. Design process questionnaires, page 244). It consists of statements that can be weighted on a scale of 1 to 5. There are also a few questions to be answered with marks or comments. The questionnaire

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[69] His definition is based on Tversky and Kahneman and Schon. Schon, D. A. (1983). The reflective practitioner : how professionals think in action. New York, Basic Books. (Kahneman, d., and A. Tversky. 1982a. On the psychology of prediction . In Judgment under uncertainty: Heuristics and biases, edited by D. Kahneman, P. slovic, A. Tversky, 46-68. Cambridge, UK: Cambridge University Press, 1982

went through many alterations, thanks to the support of Dr. Szokolay and Michael Leo. The first 18 topics relates to the following subjects:

1. Recognition[70], guessing and intuition which emphasizes experience and background are very common behaviour in design practice (Broadbent 1968; Lawson 1997). This behaviour seems common in 'green design'. Bay (2001) exposes in 'A case study of a specific building project' (page 99). In recent seminar promoted by AGO, 'Moving to Mainstream' (Vale, Vale et al. 2002), the speakers emphasized the use common sense instead of calculations. At the end, Robert Vale suggested that there is no need of computer simulation or more calculation than what could be done 'in a back of envelope' to reach a sustainable design[71].
2. Is the designer using the conservative 'professional know-how' method, based on precedents? This would indicate how much he/she is receptive to incorporate new design tools and methods and, more important, how important is to have a good understanding of previous experience and proven 'solutions'. Although the examination of an architect concerns the 'understanding of thermal proprieties of building, heat transfer and the factor involved in the analysis of the thermal and ventilation loads of spaces' (RIBA 1972), the current scenario leads to doubts (vide discussion in 'Design method: in practice', page 35 and 'Case studies', page 40). Consequently, the methods of energy diagnostics and the appropriate assessment may have considerable influence.
3. How important are the methods based on straight information that rule the design decision process? If they are important, a parametric analysis such as previously introduced ('Parametric study', page81) is appropriate as well as the development of a method to deal with them in further developments during the design process. A parallel in energy tools equals to the availability of a construction library, Availability of codes and guidelines.
4. Involves searching innovations and finding solutions already applied in previous designs, however emphasizing images instead of deep analysis (and long texts). This behaviour evokes the influence of such common media among architects, which is totally neglected by energy tools.

[70] Recognition ('knowing the answer'): basic procedure of unselfconscious design and the most common penultimate stage of more complex design procedures (Broadbent 1966).

[71] The seminar concerned house design and not office.

5. Most of the case studies referenced (‘Case studies’, page 40) discuss the questionable support that case studies may provide[72], there is no doubt that they may support design decision. Energy tools could be more useful if representative buildings were modelled and shared among users, instead of fictitious base cases, similar to ‘shoe box’.
6. The use of guidelines and rules of thumb are simple and accessible for designers with low experience. Pragmatic for a brief, these methods may be simplistic for later stages. Considering that they are usually products of parametric analysis, energy tools also could provide similar approach using simplified outputs.
7. Scientific analysis followed by synthesis is a theory largely accepted by engineers and scientists. The issue is polemic when extended to architects and apparently there are not many supporters[73]. However, it may happen in many situations of ‘low energy’ design, mainly during parametric analysis, which may be provided by a consultant[74].
8. Lateral thinking: is an alternative to the linear scientific thinking (also referred to as vertical thinking) and possible closest to the way of some architects think. For example, Leo[75](2001) makes large use of such concept and many times demonstrated total objection to any other design method[76]. An example of explicit reference to the method is found in the introduction of 12 Cribb St Office Building Alter & Ext: ‘… Ceccato Hall+Associates in association with Tony John, Architect, put on their lateral thinking caps and reconfigured the building in a way that addressed all the buildings functional and technical shortcomings…’ (RAIA 2002). The implication of this method is the test of hypothesis it happens in the previous method.

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[72] While some authors refuse to accept total glazing facades Bellew, P. (2000). "Special report: energy." The Architects' Journal: 45-47.previously discussed in ‘Windows’, page 115), such designs are still used Wigginton, M. and J. Harris (2002). Intelligent skins. Oxford, Architectural Press..

[73] The affirmative is based on contacts in the department of architecture and some professionals contacted before the survey.

[74] Personally, this is the most common approach in consultancy.

[75] Architect, builder, designer and candidate to master degree in the Department of Architecture/ UQ, developer of the ‘Guitar Building’ house concept

[76] Based on many informal meetings.

9. The test of hypothesis concerns many situations. It may be a natural consequence of the previous topic (guessing) as well as a structured or predictable sequence of actions[77] [78]. Most of the energy tools have a potential[79] to fit to this approach because hypotheses may be converted in models and then assessed through simulations.
10. Alexander's theory attempted to break problems into its tiniest parts. In 'low energy' design, it may happen in certain level due the difficulty in to integrate so many technical concerns (thermal, energy, lighting and comfort) with usual ones (cost, appearance, function etc).
11. The creation of alternatives is often proposed in the literature, even if designers do not largely adopt it. Energy tools such as VisualDOE and similar provide specific features to facilitate it, as a basic procedure of investigation.
12. The use of tangible methods to support decisions, which might be associated with A/S (analysis and synthesis) and C/T (conjecture and test), may not be popular among architects. However they must be teached[80] and they are presented in energy codes.
13. Few energy tools have 3-D capabilities of modelling/visualization, which usually happen with some level of restriction. Nonetheless, '6B' sketching shows how necessary 3-D visualization is to develop ideas and even to precede 2-D refinement (discussed in 'Design phases', page 74).
14. Many energy tools have a simplified representation of buildings, usually in 2D, however there is a belief that the integration of commercial CADs to energy tools could facilitate the use for designers (vide 'Tendencies', page 69). The intention is to check how much useful is it useful for a designer.
15. Considering that the creativity is very much personal, the integration with other professionals may indicate how the design is able to share decisions and the efficacy of such proposition. There is no doubt about the importance in to work with consultants for

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[77] Popper's theory, detailed in Bamford, G. (2002). "From analysis/synthesis to conjecture/analysis: a review of Karl Popper's influence on design methodology in architecture." Design Studies **23**(3): 245-261.

[78] Test of hypothesis is recommended in different theories, as advised by deBono (1971) in the use of lateral thinking.

[79] There are many obstacles in terms of software constraints to the designer, which are discussed in further development.

[80] In according with the RIBA, Ed. (1972). Guidance notes and regulations. London, Royal Institute of British Architects.

specialized tasks, however personal experiences have been showing how frustrating it can be in terms of results.

16. This relates to the ‘symbolic linguistic’ idea and looks for the importance of building ‘meaning’. As referenced in ‘Table IV. Case study for briefing and design strategy.’, page 41, the image was important to define the form of the building. In another example, Cox Rayner Architects assumes “… the building's expression is an evocation of the client's focus in environmental, mining and construction sectors through combination of passive energy systems, 'raw' materials and finessed detailing”, regarding The Thiess Centre (RAIA 2002).
17. It indicates how designers deal with internal environmental control and occupants’ behaviour.
18. The last one reflects when the designer chooses (if chooses) a dominant theme that drives the others decisions.

The second set of statements concerns design decisions related to building systems. It assesses the importance of the major design decisions that influence energy performance, such as building volume and orientation, façade and fenestration, interior layout, thermal properties of components, artificial lighting and air conditioning systems. The intention is to verify when and what intensity the designer attributes to them. Later, the results are used to demonstrate the impact of such actions, using the database produced by the parametric analysis.

3.2.3 Low energy strategies: part 2

Any proposition to integrate energy tools with the design process must distinguish architects interested in creating environment-friendly products those ‘somewhat’ interested and those least committed. At this stage, the questionnaire explores how these committed architects are dealing with the issue, intending to learn from them and identifying opportunities and possible misunderstandings.

The questionnaire is split into four parts, as shown in ‘Appendix B. Questionnaire for low energy design process.’ (page 245). The first set focuses on the architect and his/her product. It questions the level of commitment that the architect believes he/she has, how much attention he/she gives to the energy prediction, the influence of climate on his/her design and what type of design is representative of his/her products or ideas.

The second set is to identify the site information that the architect includes in his/her analysis. It varies from the simplest visit to site to comprehensive data collection. The intention is to identify what type of information is more relevant to the architect and correlate the answers with phases of design when the architect pays more attention to particular factors.

The third set correlates the use of tools and methods with the main design phases and gauges how important they are. Considering that each tool is intended for a specific phase, the questions are focused on the architect's understanding of them, plus the identification of the most popular of them.

As proposed in the previous set, the fourth section attempts a similar assessment of design controls. The answers are to be evaluated in relation to the database provided by the parametric analysis.

3.2.4 Selection of candidates to survey

Architects with practice in sustainable design[81] concerning office building in warm climates are the most suitable to support the survey. However there are architects without such practice, but able to contribute in some way. The survey is split in four groups, with different purposes.

Architects with knowledge in low energy design

The postgraduate students involved with sustainable design have experienced the most up-to-date methods to improve energy efficiency in buildings (most of them, for residential). Their survey aims to collect impressions of the suitability of the low energy interventions.

Architects with understanding of sustainable design in the department of architecture/ UQ and QUT

The curse of architecture at UQ is well known for the emphasis on design. The majority of the staff has practice in some area and their consciousness of the importance of sustainable design is unquestionable. Their profile as well the academics of QUT suits the analysis of the design process and low energy strategies rather than the application of energy tools.

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[81] Although 'sustainable design' is not necessarily 'low energy design', 'sustainable design' was chosen as criterion of selection of architects' expertise because it was the closest term (related to the subject of analysis) in the RAIA's website.

Architects with expertise in sustainable design

This is the most representative group of surveyed because it includes professionals with different levels of knowledge, as discussed by Wittmann' survey (1998). Apparently there are professionals with low expertise who are using or will use low energy strategies and there are others with some level of expertise who are already practising in this manner. Both types of designers are or will be interested to make use of energy tools. Consequently, it is expected to diagnose the most common actions during the design process, when the architectural decisions are taken, what support the adoption of low energy strategies and when they are decided. Considering the broad type of professionals' knowledge, the intention is to find the most relevant obstacles to the integration of energy tools into the design process.

The group is defined through searching the RAIA website. What is required is architects with expertise in office building and ESD, for Brisbane area. The result is 65 contacts[82], most of them known by staff members of the department of Architecture.

Architects with recognized knowledge in low energy strategies

It concerns architects recognized by achievements in low energy design. Due the low number of architects that fit such condition, the intention is to find out how each one interacts with energy tools rather than to look for a cause of mismatch.

The selection of the group is simple because buildings with low energy strategies are well known. Furthermore, the RAIA website endorsed most of the following choices.

Neville Bonner Building by Davenport Campbell & Partners Pty Ltd in assoc Donovan Hill and Powell Dods & Thorpe

Fig. 3-76. Neville Bonner Buildings.

[82] The search occurred in 12 June 2002.

IN THE ARCHITECTS WORDS: 'The project brief prepared by Department of Public Works specified 18,600 m square of net useable office area with 125 car parks and height limit of six storeys… The layering of the facades and the articulation of the surfaces are driven by the needs: To insulate and fortify interior spaces from the close vehicular environment surrounding the site. To express the fabric of the building in a way which invigorates and enlivens the material, and to use colour, materials and textures which reinforce the visual character of the William Street precinct.' (RAIA 2002)

The Theiss Centre, by Cox Rayner Architects & Planners

IN THE ARCHITECTS WORDS:'The Thiess Centre is the first major office development in the planned revitalization of Brisbane's South Bank Parklands. Comprising a 6 storey tower set back over a 4 level podium, the design responds to a series of prescriptive and performance guidelines prepared by Denton Corver Marshall to foster a distinctive urban character for Grey Street…. Scale and environmental control are dually addressed by horizontal interplay of façade banding and exaggerated sunscreens and by vertical articulation of the building into two slivers. The west facing of these is a robust 'solid' form to combat western heat loads and adjacent railway noise as well as withstand de-railed train impact. The east (street) facing part is a lightweight more diaphanous form seen to project out from the rear mass, accentuated by its soaring roof canopy. The building's expression is an evocation of the client's focus in environmental, mining and construction sectors through combination of passive energy systems, 'raw' materials and finessed detailing.' (RAIA 2002)

Fig. 3-77. The Theiss Centre.

Mincom World Headquarters, by Robinson Design Inc Pty Ltd

IN THE ARCHITECTS WORDS:'Mincom World headquarters has delivered to the Brisbane market place a unique product encompassing Brisbane's largest floor plates in a 'ground scraper' configuration. …. The Hi-tech light tactile skin of the tower has been designed to control the external heat load on the glazing.

Fig. 3-78. Mincom World Headquarters

An economy cycle air conditioning system has been incorporated to improve every efficiency and reduce energy costs. Mincom is designed for the Queensland climate, its language demonstrates it geographic location and respect'. (RAIA 2002)

Riverside Centre, by Harry Seidler & Associates

IN THE ARCHITECTS WORDS:'A forty storey commercial office building of triangular configuration allowing two thirds of tenants direct water views…. The windows are shaded with aluminum sunblades on the north and west facades following the Queensland tradition of awnings. The south side is left sheer.' (RAIA 2002)

Fig. 3-79. Riverside Centre

12 Cribb St Office Building Alter & Ext, by Ceccato Hall & Associates in assoc w/ Antony John Architect

IN THE ARCHITECTS WORDS:' Ceccato Hall + Associates in association with Tony John, Architect, put on their lateral thinking caps and reconfigured the building in a way that addressed all the buildings functional and technical shortcomings…. The re-organisation of the floor planning involving the introduction of a light well, replanning the central core and the construction of a facetted and angled façade with passive solar controls dramatically enhanced the building's desirability and aesthetic appeal thus completing the transformation.' (RAIA 2002)

Fig. 3-80. 12 Cribb St.

Education House Brisbane, by Peddle Thorp Architects

IN THE ARCHITECTS WORDS: 'Designed for the Queensland State Government as a 30 level office building, the design concept features a rectangular plan with splayed corners ….. The sun shading and passive solar control features to the facades on the external walls was a first for Brisbane high rise and are contrast by the varied treatment of the midheight transfer floor on Level 12. …. Lettable floor area of 997 square metres low-rise and 1,064 square metres high-rise is enhanced by retail tenancy space on the ground floor.

Fig. 3-81. Education House.

111 George Street, by Robin Gibson and Partners

Fig. 3-82. 111 George Street.

Hall Chadwick, by Hassell PTY LTD

Fig. 3-83. Hall Chadwick Centre (120 Edwards Street).

3.3 Case studies of design process

There are many obstacles to investigate design process in practice. When design strategies are discussed (Yeang 1996; Powell 1999; Yeang 1999), the authors emphasize the aesthetics consequences rather than the process that leads to such design decisions. Any report concerning the circumstance of the decisions is difficult to find. When design processes are exposed (rarely), they are represented by graphics or general tasks. Recently, I witnessed a short representation of a design process that I was involved with. Despite the good presentation, it did not seem the same process that I knew. Certainly, nobody would describe the mistakes or unsuccessful decisions.

Facing these predictable obstacles, since the early stages of the PhD study I had expressed intention of working with architects, aiming efficient energy designs. Thanks to Dr. Richard Hyde and Peter Skinner, both lecturers of the department of architecture/ UQ, the 4th year students were advised that they could have a support to improve the energy efficiency of their designs. Aware of the importance of such experience, Dr. Richard Hyde also provided two other major opportunities, both with architecture offices.

4 Results

4.1 Questionnaire

The questionnaire had a reasonable acceptance from the four surveyed groups. As expected, some architects are more receptive to the issue than others. Another factor that contributed to the response was the relationship of the researcher and the surveyed. The closest ones provided more feedback. For example, 90% of the 'post graduate students group' and 71% of the 'recognized architects' to whom Dr. Szokolay introduced the survey returned the answers (Table XXXIV), sometimes with comments. In comparison, 33% of the 'recognized architects' who were invited to collaborate with the research by other means returned the questionnaire. Then, the average response of 'recognized architects' was 54%. The 'ESD architects' had a 56% of response which is very satisfactory considering that this group is the most diversified in terms of expertise related to low energy strategies. The staff members of the Department of Architecture produced a very low response with 36%, while 43% of the staff members of QUT responded. The average response was 38%. In comparison with similar studies, Wittmann (1998) surveyed 650 architects with a response of 62% and Hien, Poh et al. (2000) surveyed 584 firms with 28% of response.

The four groups recognized the importance of the energy efficiency on their design, varying from 3.5 to 'staff members' to 4.2 to 'recognized' architects and 'PG students', on a scale 1-5 (Table XXXIV). The 'staff members' demonstrated the lowest interest for feedback with only 25% of the surveyed while the 'ESD' architects had the most expressive with 60% (Table XXXIV). Although some architects surveyed may have no interest for the thesis subject, another reason for such low demonstration of interest is the necessity to identify himself/herself in the survey. For example, only 25% of the 'staff members' identified themselves.

Table XXXIV. Feedback from the questionnaires and level of commitments.

	questionnaires		interest for feedback / identification	importance of energy efficiency
group	sent	answered (%)		(1 to 5)
post graduate students (PG)	10	9 (90%)	33% / 45%	4.2
staff members of department of architecture/ UQ and QUT	21	8 (38%)	25% / 25%	3.5
ESD architects	27	15 (56%)	60% / 80%	3.8
recognized architects	13	7 (54%)	38% / 71%	4.2

Importance of design issues

This set of questions had the highest response compared to the others. As displayed in the Fig. 4-1, the importance of methods and routines that influence design decisions are roughly similar for the four groups: intuition is highly rated while charts and diagrams are not. The differences are more noticeable in relation to the importance during the design phases, however 13% of the surveyed express similar or identical importance to issues. The methods for the pre-design phase are ordered in Table XXXV and the notes are followed:

Table XXXV. Importance of design issues for pre-design stage.

	PG	staff members	ESD architects	recognized architects
1	'Meaning' of the building	'Meaning' of the building	Intuition	Development of alternative
2	Impact of the design	Impact of the design on	(3-D) thinking	(3-D) thinking
3	(3-D) thinking	(3-D) thinking	'Meaning' of the building	'Meaning' of the building
4	Intuition	Intuition	Impact of the design on	Intuition
5	Dominance of an idea	Breaking down problems	**'Lateral' thinking'**	**'Lateral' thinking'**
6	**'Lateral' thinking'**	**Hypotheses and test**	Guidelines and rules	Dominance of an idea
7	Development of alternative	**'Lateral' thinking'**	Dominance of an idea	Impact of the design on
8	Pictorial precedents	Development of alternative	Established techniques	Guidelines and rules-of-thumb
9	Plan (2-D) thinking	Established techniques…	Plan (2-D) thinking	Earlier designs
10	*Integration with others*	Earlier designs	Earlier designs	Rules, routines
11	**scientific thinking**	Guidelines and rules	Rules, routines	Plan (2-D) thinking
12	Earlier designs	Dominance of an idea	*Integration with others*	*Integration with others*
13	Established techniques…	Rules, routines	Development of alternative	Established techniques
14	**Hypotheses and test**	**scientific thinking**	**scientific thinking**	Breaking problems
15	Rules, routines	Plan (2-D) thinking	Breaking problems	**scientific thinking**
16	Guidelines and rules	**Diagrams, charts**	**Hypotheses and test**	Pictorial precedents
17	Breaking problems	*Integration with others*	Pictorial precedents	**Hypotheses and test**
18	**Diagrams, charts**	Pictorial precedents	**Diagrams, charts**	**Diagrams, charts**

- the meaning of the building is the most important driver for design decisions for 'PG students' and for 'Staff members' while it is the third most important for the other groups;
- 'ESD' architects prefer intuition to any other method;
- 'recognized' architects ranked development of alternatives as the most important method, which is of an average concern for 'PG students' and 'staff members' and a low concern for 'ESD' architects;
- lateral thinking is a common method for the groups, mainly for the 'ESD' and 'recognized' architects;

- the use of test of hypothesis is important for the ‘staff members’, however is one of the lowest routine for ‘PG’, ‘ESD’ and ‘recognized’ architects;
- among the groups, scientific method is more popular for ‘PG’ students (11th), while other groups classify it as one of the lowest importance;
- diagrams and charts are the lowest preference, by all groups;
- on average, integration with other professionals is of a medium preference, although the ‘staff members’ classify it as the least important.

Ordering the routines for the schematic phase, Table XXXVI, the most relevant notes are:

Table XXXVI. Importance of design methods for schematic stage.

	PG	staff members	ESD architects	recognized architects
1	Impact of the design	'Meaning' of the	(3-D) thinking	(3-D) thinking
2	'Meaning' of the	Impact of the design on	Intuition	'Meaning' of the building
3	(3-D) thinking	Intuition	Impact of the design on	Intuition
4	*Integration with others*	(3-D) thinking	Established techniques…	**'Lateral' thinking'**
5	Intuition	**'Lateral' thinking'**	'Meaning' of the building	Impact of the design on
6	Dominance of an idea	Dominance of an idea	**'Lateral' thinking'**	Development of alternative
7	**'Lateral' thinking'**	**Hypotheses and test**	Guidelines and rules-of-thumb	Dominance of an idea
8	Plan (2-D) thinking	Development of alternative	Dominance of a central idea	*Integration with others*
9	Development of alternative	Established techniques	Plan (2-D) thinking	Established techniques…
10	**scientific thinking**	**scientific thinking**	Rules, routines	Guidelines and rules
11	Established techniques…	Breaking down problems	*Integration with others*	Rules, routines
12	Pictorial precedents	Earlier designs	Development of alternative	Breaking down problems
13	Earlier designs	Plan (2-D) thinking	Earlier designs	Earlier designs
14	Rules, routines	Rules, routines	**scientific thinking**	Plan (2-D) thinking
15	Guidelines and rules-of-thumb	*Integration with others*	Breaking down problems	**scientific thinking**
16	Breaking down problems	Guidelines and rules-of-thumb	**Hypotheses and test**	**Hypotheses and test**
17	**Hypotheses and test**	Pictorial precedents	**Diagrams, charts**	Pictorial precedents
18	**Diagrams, charts**	**Diagrams, charts**	Pictorial precedents	**Diagrams, charts**

- 3-D thinking and intuition are the most important bases for design decisions for 'ESD' and 'recognized' architects, followed by the meaning of the building and its impact;
- 'staff members' and 'PG' students have similar tendency, with difference in relation to the order but not much in terms of ratio;
- the use of hypothesis and test, diagrams and charts and rational or scientific thinking are the lowest preference of 'ESD' and 'recognized' architects;
- 'PG' students have similar preference, however they emphasize a little more the use of scientific thinking;
- 'staff members' agrees with the lowest score for the use of diagrams and charts, however classify the use of rational or scientific thinking in 10th and the use of hypothesis and test as 7th, i.e. these two last methods are not related with the use of charts.

Ordering the routines for the detailing phase, Table XXXVII, the most relevant notes are:

Table XXXVII. Importance of design methods for detailing stage.

	PG	staff members	ESD architects	recognized architects
1	Impact of the design	Impact of the design	(3-D) thinking	(3-D) thinking
2	'Meaning' of the building	(3-D) thinking	Impact of the design	*Integration with others*
3	Established techniques	Intuition	Established techniques	Rules, routines
4	(3-D) thinking	'Meaning' of the building	Rules, routines	Established techniques…
5	*Integration with others*	techniques…	*Integration with others*	'Meaning' of the building
6	Rules, routines	Rules, routines	'Meaning' of the building	Intuition
7	Plan (2-D) thinking	**'Lateral' thinking'**	Intuition	Impact of the design on
8	**'Lateral' thinking'**	Breaking problems	Plan (2-D) thinking	Breaking down problems
9	**scientific thinking**	**Hypotheses and test**	**scientific thinking**	Dominance of an idea
10	Guidelines and rules-of-thumb	Dominance of an idea	Breaking problems	**'Lateral' thinking'**
11	Dominance of an idea	**scientific thinking**	**'Lateral' thinking'**	Development of alternative
12	Development of alternative	Plan (2-D) thinking	Guidelines and rules-of-thumb	Earlier designs
13	Earlier designs	*Integration with others*	Development of alternative	Plan (2-D) thinking
14	Intuition	Development of alternative	Dominance of an idea	Guidelines and rules-of-thumb
15	Breaking problems	Earlier designs	Earlier designs	**scientific thinking**
16	**Hypotheses and test**	Guidelines and rules-of-thumb	**Hypotheses and test**	**Hypotheses and test**
17	Pictorial precedents	Pictorial precedents	Pictorial precedents	Pictorial precedents
18	**Diagrams, charts**	**Diagrams, charts**	**Diagrams, charts**	**Diagrams, charts**

- the most important influences in this phase are similar to the previous one, however the 'recognized' architects bring the importance of *integration with others professionals* to a second place;
- for 'PG' and 'ESD' architects, *rational or scientific thinking* becomes the 9th in importance, the highest score so far, while 'recognized' architects classify it as one the lowest importance;
- 'PG', 'ESD' and 'recognized' architects classify the use of *hypothesis and test* and use *of charts* as the least important.

The analysis of the Fig. 4-1 allows comparing how the same method or routine varies in relation to the design phase:

- every group agrees that the integration with other professionals becomes more important as the design progresses;
- the use of rational or scientific thinking also increases in importance with the progress of the design, with the exception of the ‘recognized’ architects;
- intuition becomes less important with the design progressing, with the exception of ‘staff members’;

In general, the methods and routines have a similar importance in relation to the design stages; most of them vary less than 1 (scale 1-5). For example, intuition has a minimum of importance of 4.5 during pre-design and a maximum of 4.8 during detailing for the ‘staff members’. For ‘PG students’ group, the exception is the use of *established techniques*, which varies from 3.0 during briefing to 4.4 during detailing. For ‘staff members’ group, the exceptions is use of 2-D thinking, which varies from 3.0 during pre-design to 4.0 during detailing. Exceptions for the ‘recognized’ architects group are:

- use of lateral thinking, which varies from 4.6 during the briefing to 3.5 during detailing;
- development of alternatives, which varies from 4.8 during the briefing to 3.4 during detailing.

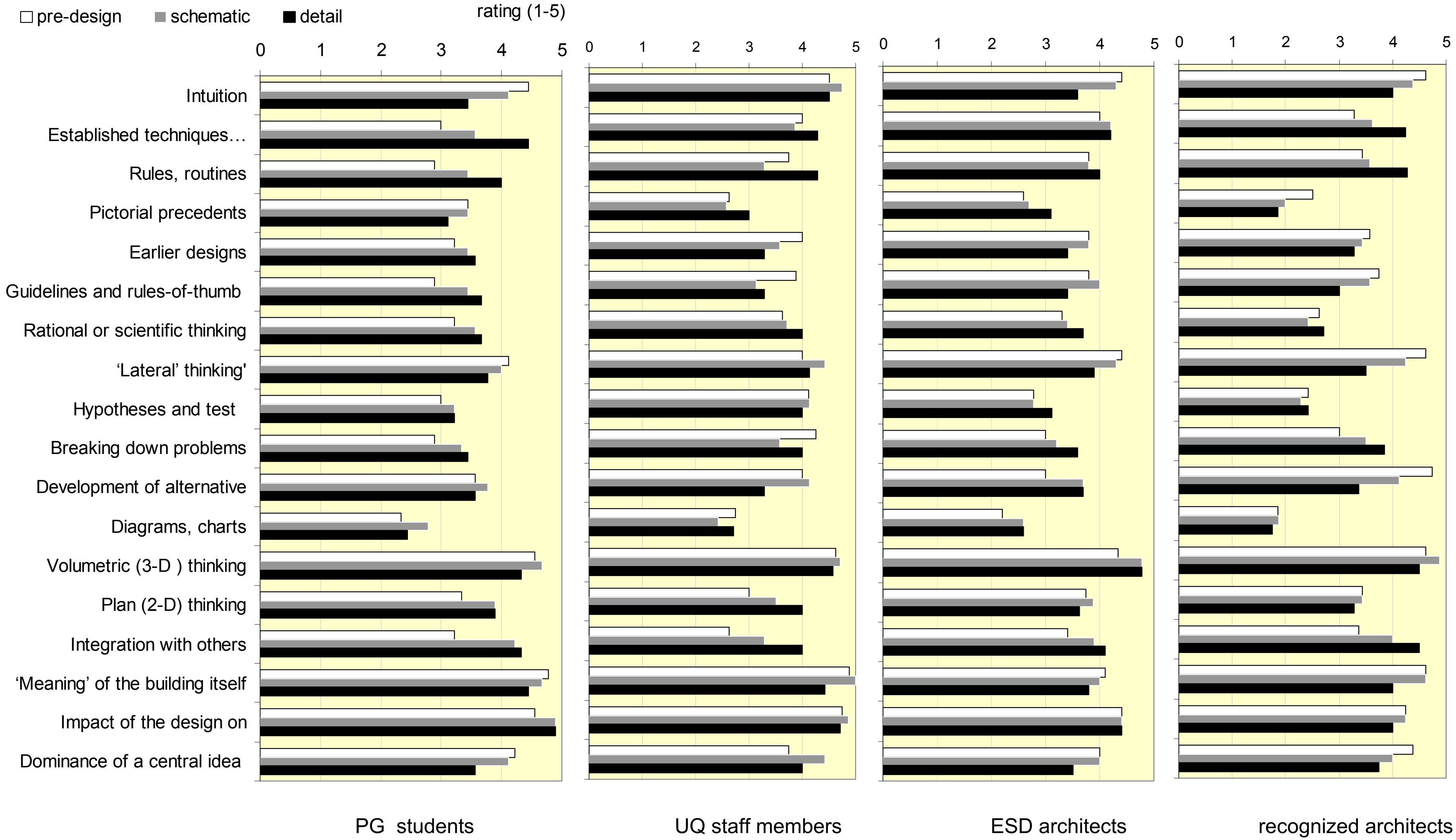

Fig. 4-1. Importance of design issues.

Importance of design decisions related to architecture and building services

In general, 92% of the surveyed answered this set of questions. Ordering the importance of design decisions during the pre-design phase (Table XXXVIII), there is a general agreement among the four surveyed groups. The highest importance is attributed to the definition of geometry such as building orientation, building volume, interior layout and envelope geometry. Components proprieties are a second concern, followed by air conditioning systems and artificial lighting systems.

Table XXXVIII. Importance of design decisions for the pre-design phase.

	PG	Staff members	ESD	Recognized architects
1	building orientation	building orientation	building orientation	building volume
2	building volume	building volume	building volume	building orientation
3	interior layout	envelope geometry	envelope geometry	interior layout
4	envelope geometry	components proprieties	interior layout	envelope geometry
5	components proprieties	interior layout	components proprieties …	components proprieties
6	air conditioning systems	air conditioning systems	air conditioning systems	air conditioning systems
7	artificial lighting systems	artificial lighting systems	artificial lighting systems	artificial lighting systems

In relation to the schematic phase (Table XXXIX), there is a consensus of the high importance of building orientation and volume and the interior layout, as well as the low importance of deciding building services systems. The importance of envelope geometry varies from second to third and components proprieties vary from third to 5th.

Table XXXIX. Importance of design decisions for the schematic phase.

	PG	Staff members	ESD	Recognized architects
1	building orientation	building orientation	building orientation	building orientation
2	interior layout	envelope geometry	interior layout	building volume
3	envelope geometry	components proprieties	envelope geometry	envelope geometry
4	building volume	interior layout	building volume	interior layout
5	components proprieties	building volume	components proprieties …	components proprieties
6	air conditioning systems	air conditioning systems	air conditioning systems	air conditioning systems
7	artificial lighting systems	artificial lighting systems	artificial lighting systems	artificial lighting systems

The detailing phase survey (Table XL) shows the importance of envelope geometry and components proprieties as the most important decisions. Air conditioning system is a medium concern among recognized architects, third in importance, and it decreases in importance from ESD, 'staff members' and 'pg students'. 'Artificial lighting systems' has similar tendency.

Table XL. Importance of design decisions for the detailing phase.

	PG	Staff members	ESD	Recognized architects
1	envelope geometry	components proprieties	envelope geometry	envelope geometry
2	components proprieties	envelope geometry	components proprieties …	components proprieties
3	interior layout	building orientation	building orientation	air conditioning systems
4	building volume	interior layout	artificial lighting systems	artificial lighting systems
5	building orientation	artificial lighting systems	interior layout	interior layout
6	air conditioning systems	building volume	air conditioning systems	building volume
7	artificial lighting systems	air conditioning systems	building volume	building orientation

Phases of design during which the design is assessed

When the architects were questioned which phases of the design the energy efficiency is assessed, everyone indicated at least one phase. Comparing the results (Fig. 4-2), architects prefer to assess the design mainly during the schematic phase followed by the detailing phase, conceptual phase and conclusion phase.

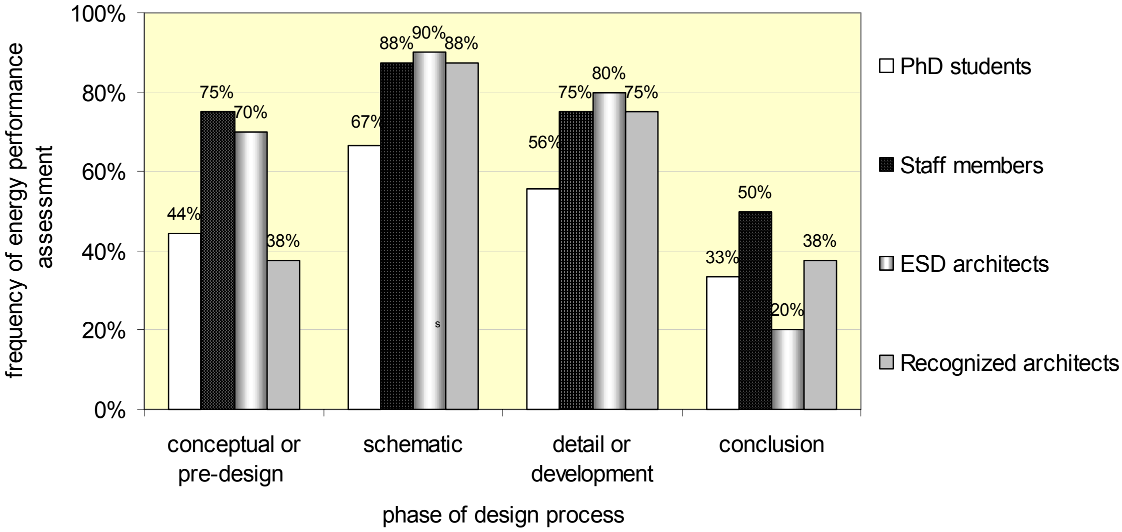

Fig. 4-2. Phases during which architects assess the energy performance of the design.

Climatic information used

The results (Fig. 4-3) evidence the large use of the climate data based on visit to the site. ‘PG students’ prefer the visit to check the wind, ‘staff members’ and ‘recognized architects’ use the visit to check all climatic variables; ‘ESD’ architects emphasize the checking of wind and solar radiation. ‘PG students’ and ‘staff members’ prefer to make use of statistical data with approximately 40% of the preference.

‘PG students’ make a regular use of visit to the site, statistical analysis and hourly annual data. This behaviour is very much predictable, considering their awareness in relation to the availability of data. Maps and monitoring receive last attention, probably due the simplicity and the complexity of both, respectively.

‘Staff members’ rely preferentially on visit to the site to get their climatic information. Statistical analysis comes in second with 40% of the preferences, while hourly annual data and monitoring have 13% of the preferences.

The survey of 'ESD' architects is the most diversified in terms of source of climatic data. Statistical analysis is the most common to provide temperature, whilst solar radiation and wind are preferentially obtained through visit to the site. Sources such as hourly annual data and maps have approximately the same popularity, while monitoring is only mentioned for wind determination.

Besides the visit to the site, maps are the second most common source of climatic data for 'recognized' architects. Statistical analysis has 10% of the preferences, hourly annual data has 5% and monitoring is not mentioned.

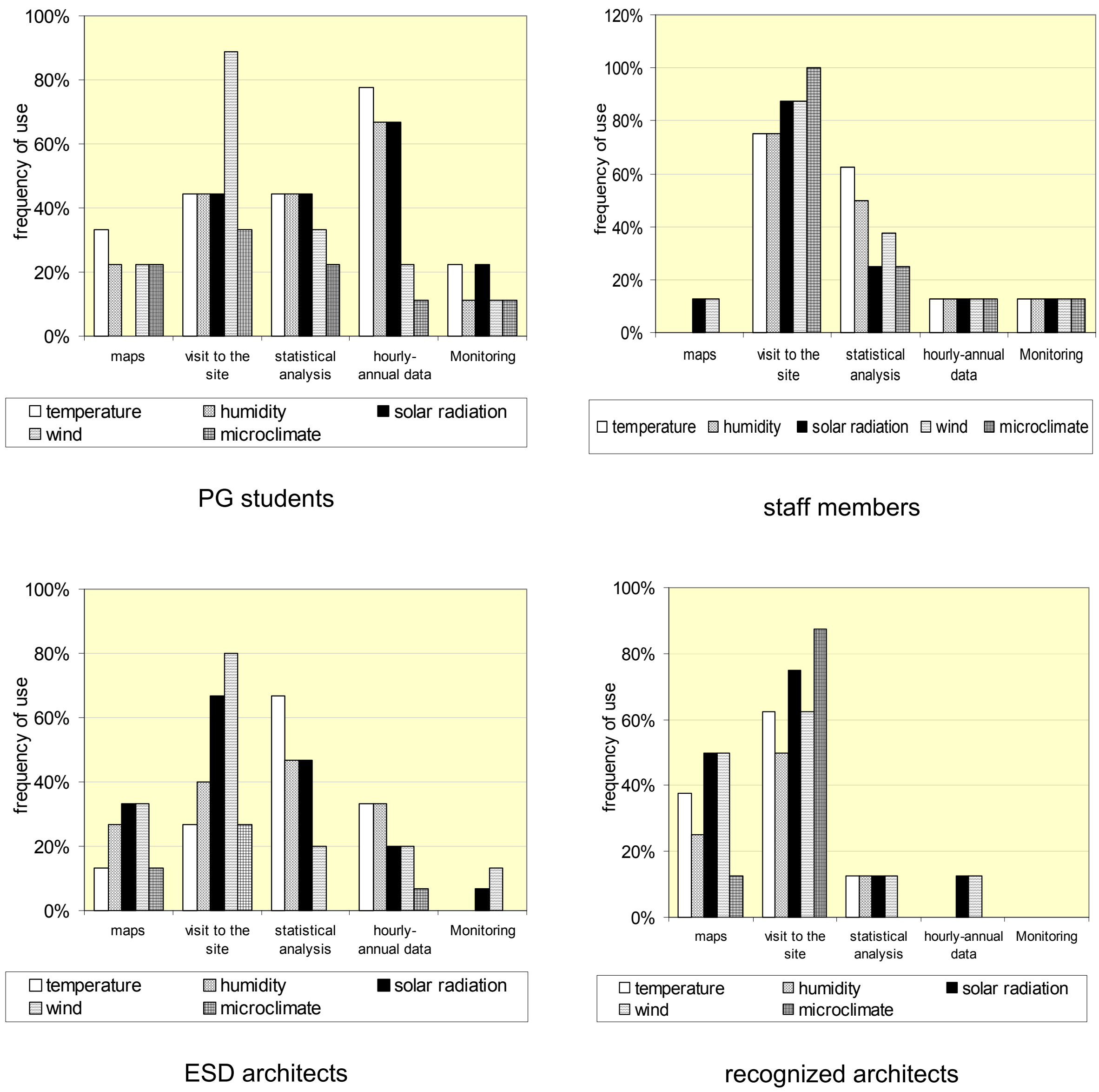

Fig. 4-3. Climatic information and sources.

Use of tools to support design decision

Not intentionally, this is the trickiest group of questions because some of the tools and methods are not fully suitable for the design of office buildings or for every stage of the design process. Other tools such as the ones based on psychometric analysis are most of the time suitable for only one stage of the design, unless the designer use them as a checklist during the design development. Consequently, it was expected to have the lowest frequency of answers (Fig. 4-4).

Comparing the frequency of answers in general for the pre-design phase, the surveyed were more sensitive to issues like guidelines/rules of thumb and principles and dramatically less sensitive to the software packages issue. Only 21% of the ‘staff members’ opined about the importance of software packages in comparison with 52% of the students, 40% of the ‘ESD’ architects and 54% of the recognized architects.

Comparing the four surveyed groups in terms of importance (rank 1-5) and frequency (percentage of answers) in Fig. 4-4 it is possible to establish some differentiations:

- ‘PG students’ have a similar preference for all the methods and the use of principles and guidelines are the most common (more frequency).
- With the exception of ‘PG students’, the groups have a clear preference for some tools and methods: ‘staff members’ prefer principles and guidelines, the ‘ESD’ architects prefer principles, guidelines and case studies and the ‘recognized architects’ prefer principles, guidelines and softwares packages.
- Unexpectedly, a considerable number of ‘PG students’ and ‘staff members’ use Mahoney for every stage of design and the importance varies from 1 to 4.3 (sic!).
- ‘ESD’ architects demonstrate very low use of methods based on climate analysis and do not differentiate (on average) the use of them for the three stages of design process.
- The lowest response and importance concerning software packages is shown by the ‘staff members’.

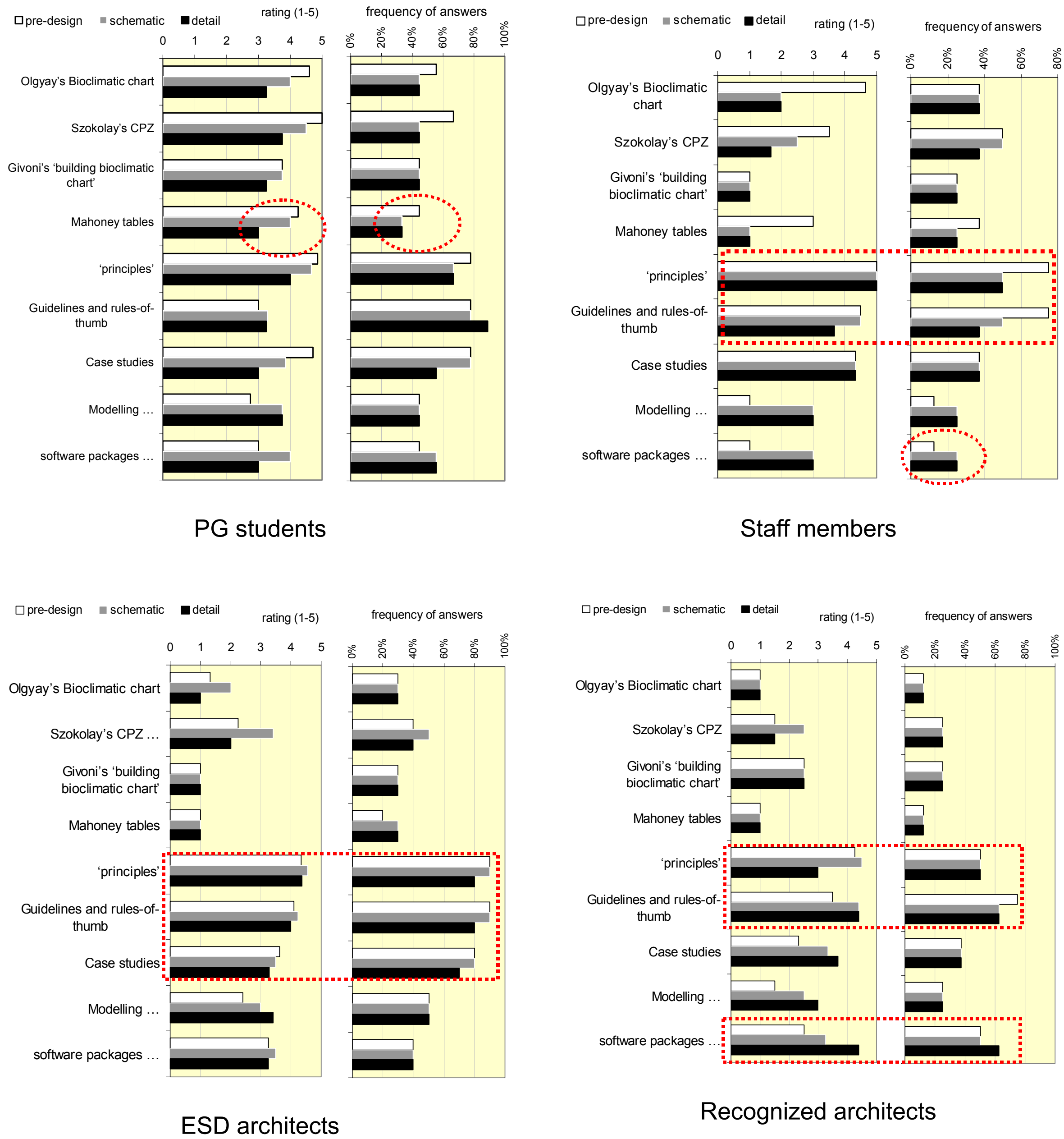

Fig. 4-4. Use of methods to support design decisions and frequencies of answers.

Pre-design

The Table XLI shows that the most frequent answers concern issues such as case studies, guidelines and rules-of-thumb and principles in general. The academic has a tendency to recognize the use of psychometric methods and the recognized architects are the most familiar with use of *software packages*.

The importance of each issue for the pre-design varies among the groups (Table XLI). The 'PG students' prefer the tools that assess the strategies based on the climate. The others prefer the use of *principles* and *guidelines/rules of thumb. Case studies* are also important for 'ESD' architects and slightly less important for 'recognized' architects and 'staff members'. The main difference is the importance of *software packages*, which is the third for 'recognized' architects, 6th for 'ESD' architects and the least for important for 'staff members'. Answers concerning the schematic phase are very similar to preferences with the pre-design (Table XXV).

Table XLI. RESPONSE to the methods and tools to support decisions concerning low energy strategies for the pre-design phase.

	PG	Staff members	ESD	Recognized architects
1	Case studies	Guidelines and rules	'principles'	Guidelines and rules
2	Guidelines and rules	'principles'	Guidelines and rules	'principles'
3	'principles'	Szokolay's CPZ	Case studies	**software packages**
4	Szokolay's CPZ	Olgyay's chart	Modelling	Case studies
5	Olgyay's chart	Case studies	Szokolay's CPZ …	Szokolay's CPZ
6	**software packages**	Mahoney tables	**software packages**	Givoni's 'chart'
7	Givoni's 'chart'	Givoni's 'chart'	Olgyay's chart	Modelling
8	Modelling	Modelling	Givoni's 'chart'	Olgyay's chart
9	Mahoney tables	**software packages …**	Mahoney tables	Mahoney tables

In general, *principles* are the most important method to support the pre-design phase. The academics recognize the importance of exploratory tools based on climate analysis and *case studies* as highly important while the 'ESD' and 'recognized' prefer *guidelines*, *software packages* and *cases studies* (Table XLVII).

Table XLII. IMPORTANCE of methods and tools to support decisions concerning low energy strategies for the pre-design phase.

	PG	Staff members	ESD	Recognized architects
1	Szokolay's CPZ	'principles'	'principles'	'principles'
2	'principles'	Olgyay's chart	Guidelines and rules	Guidelines and rules
3	Case studies	Guidelines and rules	Case studies	**software packages**
4	Olgyay's chart	Case studies	**software packages**	Givoni's 'tic chart'
5	Mahoney tables	Szokolay's CPZ	Modelling	Case studies
6	Givoni's 'chart'	Mahoney tables	Szokolay's CPZ	Szokolay's CPZ
7	**software packages**	Modelling	Olgyay's chart	Modelling
8	Guidelines and rules	**software packages**	Mahoney tables	Mahoney tables
9	Modelling	Givoni's 'c chart'	Givoni's 'chart'	Olgyay's chart

Schematic

The tools and methods have similar order of popularity for the four groups (Table XLIII): principles are the most referenced and the climate analysis tools are the least. The importance of the issues varies among the groups. While *principles*, *guidelines* and *case studies* are a common preference, the use of *software packages* varies: it is the second more important tool for the 'recognized' architects, the 4th for 'PG students', 6th for 'ESD' architects and 7th for 'staff members' (Table XLIV).

Table XLIII. RESPONSE to the methods and tools to support decisions concerning low energy strategies for the schematic phase.

	PG	Staff members	ESD	Recognized architects
1	'principles'	'principles'	'principles'	'principles'
2	Szokolay's CPZ	Guidelines and rules	Guidelines and rules	Guidelines and rules
3	Olgyay's chart	Case studies	Case studies	Case studies
4	software packages	Modelling	software packages	software packages
5	Mahoney tables	software packages	Szokolay's CPZ	Modelling
6	Case studies	Szokolay's CPZ	Modelling	Givoni's 'chart'
7	Modelling	Olgyay's chart	Olgyay's chart	Szokolay's CPZ
8	Givoni's 'chart'	Givoni's 'chart'	Mahoney tables	Mahoney tables
9	Guidelines and rules	Mahoney tables	Givoni's 'chart'	Olgyay's chart

Table XLIV. IMPORTANCE of methods and tools to support decisions concerning low energy strategies for the schematic phase.

	PG	Staff members	ESD	Recognized architects
1	Guidelines and rules	'principles'	'principles'	Guidelines and rules
2	Case studies	Szokolay's CPZ	Guidelines and rules	software packages
3	'principles'	Guidelines and rules	Case studies	'principles'
4	software packages	Olgyay's chart	Modelling	Case studies
5	Givoni's 'chart'	Case studies	Szokolay's CPZ	Szokolay's CPZ
6	Modelling	Modelling	software packages	Givoni's 'chart'
7	Olgyay's chart	software packages	Mahoney tables	Modelling
8	Szokolay's CPZ	Givoni's 'chart'	Olgyay's chart	Olgyay's chart
9	Mahoney tables	Mahoney tables	Givoni's 'chart'	Mahoney tables

Detailing

There is a common response for issues such as *principles* and *guidelines*, however the use of *software packages* are the least commented tool by 'staff members', while is the second most used tool among 'recognized' architects (Table XLV). Similar tendency is found for the importance of methods and tools (Table XLVI): *principles*, guidelines and *case studies* are the most important methods to the detailing stage. *Software packages* is the second more important for recognized architects, the 4th for 'PG students', 5th for 'ESD' architects and last for 'staff members', whose classified Szokolay's CPZ in third (at the detailing phase?).

Table XLV. RESPONSE to the methods and tools to support decisions concerning low energy strategies for the detailing phase.

	PG	Staff members	ESD	Recognized architects
1	Guidelines and rules	'principles'	'principles'	Guidelines and rules
2	'principles'	Guidelines and rules	Guidelines and rules	**software packages**
3	Case studies	Szokolay's CPZ	Case studies	'principles'
4	**software packages**	Olgyay's chart	Modelling	Case studies
5	Szokolay's CPZ	Case studies	**software packages**	Szokolay's CPZ
6	Olgyay's chart	Mahoney tables	Szokolay's CPZ …	Givoni's ' chart'
7	Givoni's 'chart'	Givoni's 'chart'	Olgyay's chart	Modelling
8	Modelling …	Modelling …	Givoni's 'chart'	Olgyay's chart
9	Mahoney tables	**software packages …**	Mahoney tables	Mahoney tables

Table XLVI. IMPORTANCE of methods and tools to support decisions concerning low energy strategies for the detailing phase.

	PG	Staff members	ESD	Recognized architects
1	Guidelines and rules	'principles'	'principles'	Guidelines and rules
2	'principles'	Guidelines and rules	Guidelines and rules	**software packages**
3	Case studies	Szokolay's CPZ	Case studies	'principles'
4	**software packages**	Olgyay's chart	Modelling	Case studies
5	Szokolay's CPZ	Case studies	**software packages**	Szokolay's CPZ
6	Olgyay's chart	Mahoney tables	Szokolay's CPZ	Givoni's 'chart'
7	Givoni's 'chart'	Givoni's 'chart'	Olgyay's chart	Modelling
8	Modelling	Modelling	Givoni's 'chart'	Olgyay's chart
9	Mahoney tables	**software packages**	Mahoney tables	Mahoney tables

Use of low energy strategies

The four groups had a high response to the questions concerning the use of low energy strategies during the design process: 86% for 'PG students', 92% for 'staff members', 96% for 'ESD' architects and 98% for 'recognized' architects.

The results of the pre-design phase (Table XLVII) show that the architects are less concerned with strategies related to the building services (dark shadings). Strategies related to the geometry of the building and passive strategies (highlighted with clear shading) are the most important. Building form and position come first in importance for the all groups. The common important passive strategy is natural ventilation while daylighting is a secondary concern. The more interesting discordance of tendencies is the unexpected importance of passive solar strategies credited by the 'staff members', higher even than strategies such as exterior shadings and daylighting.

Table XLVII. IMPORTANCE of design decisions for the pre-design phase.

	PG	Staff members	ESD	Recognized architects
1	*building orientation*	*building orientation*	*building orientation*	*building orientation*
2	natural ventilation	natural ventilation	natural ventilation	*building form*
3	*building form*	*building form*	*building form*	natural ventilation
4	daylighting	landscape …	*exterior shading …*	landscape …
5	landscape …	*facade geometries*	daylighting	daylighting
6	thermal mass effect	passive solar …	thermal mass effect	*exterior shading …*
7	*exterior shading …*	*exterior shading …*	*facade geometries*	*facade geometries*
8	*facade geometries*	daylighting	thermal insulation	artificial ventilation
9	thermal insulation	thermal mass effect	landscape …	passive solar …
10	efficient air cond …	efficient artificial lighting	passive solar …	efficient air cond …
11	efficient artificial lighting	thermal insulation	efficient artificial lighting	efficient artificial lighting
12	passive solar …	efficient air cond …	efficient air cond …	thermal mass effect
13	artificial ventilation	artificial ventilation	artificial ventilation	thermal insulation

The results for the schematic phase evidence the increasing importance of geometric variables. The importance of the air conditioning slightly increases for the 'recognized' architects. Natural ventilation followed by daylighting are the most important passive strategies for the groups.

Table XLVIII. IMPORTANCE of design decisions for the schematic phase.

	PG	Staff members	ESD	Recognized architects
1	natural ventilation	*exterior shading …*	natural ventilation	*building form*
2	*building form*	*building orientation*	*building orientation*	*building orientation*
3	*building orientation*	natural ventilation	*exterior shading …*	natural ventilation
4	daylighting	*facade geometries*	daylighting	daylighting
5	*exterior shading …*	*building form*	*building form*	landscape …
6	*facade geometries*	passive solar …	thermal insulation	*facade geometries*
7	thermal mass effect	landscape …	thermal mass effect	passive solar …
8	landscape …	daylighting	landscape …	*exterior shading …*
9	thermal insulation	thermal mass effect	passive solar …	efficient air cond …
10	efficient air cond …	efficient artificial lighting	*facade geometries*	efficient artificial lighting
11	efficient artificial lighting	thermal insulation	efficient artificial lighting	artificial ventilation
12	passive solar …	efficient air cond …	efficient air cond …	thermal mass effect
13	artificial ventilation	artificial ventilation	artificial ventilation	thermal insulation

Building services strategies increase in importance for the detailing phase, in relation to the previous phases. Air conditioning is the third more important strategy for 'PG' students and the 4th for 'recognized' architects. The 'staff members' definitely recognize form as the most important group of strategies, followed by passive and building services. 'ESD' architects strongly rely on passive strategies.

Table XLIX. IMPORTANCE of design decisions for the detailing phase.

	PG	Staff members	ESD	Recognized architects
1	natural ventilation	*exterior shading …*	*exterior shading …*	*exterior shading …*
2	daylighting	*building orientation*	natural ventilation	daylighting
3	efficient air cond …	*facade geometries*	thermal insulation	*facade geometries*
4	*building form*	natural ventilation	daylighting	efficient air cond …
5	*exterior shading …*	*building form*	*building orientation*	natural ventilation
6	*building orientation*	landscape …	landscape …	efficient artificial lighting
7	*facade geometries*	daylighting	thermal mass effect	thermal insulation
8	efficient artificial lighting	thermal insulation	*facade geometries*	landscape …
9	thermal mass effect	efficient artificial lighting	efficient artificial lighting	artificial ventilation
10	thermal insulation	passive solar …	passive solar …	*building form*
11	landscape …	thermal mass effect	*building form*	*building orientation*
12	artificial ventilation	artificial ventilation	efficient air cond …	thermal mass effect
13	passive solar …	efficient air cond …	artificial ventilation	passive solar …

Comments and conclusion

The results confirm that building efficiency is far more important for architects with expertise than for a group with different levels of expertise, such as the ‘staff members’. Despite the academics’ awareness of the impact of building design on the environment, the low response of the ‘staff members’ and the attributed low importance of the energy performance on their design suggest a conservative approach when compared with other groups.

Design issues

Practitioners have a clear tendency to emphasize the use of intuition and guidelines during the early stages of design, which decrease as the design progress[83] (Fig. 4-5). The rational thinking and rules have the opposite tendency: they increase as the design progress. This tendency is more evident for the ‘recognized’ architects, which may indicate the importance of their experiences. Although such behaviour implies a massive use of assumptions, they not necessarily make use of tests (*hypothesis and test*). Therefore, the item *impact of the design on the occupants* can be considered as a routine strongly based on *intuition* and *assumptions*.

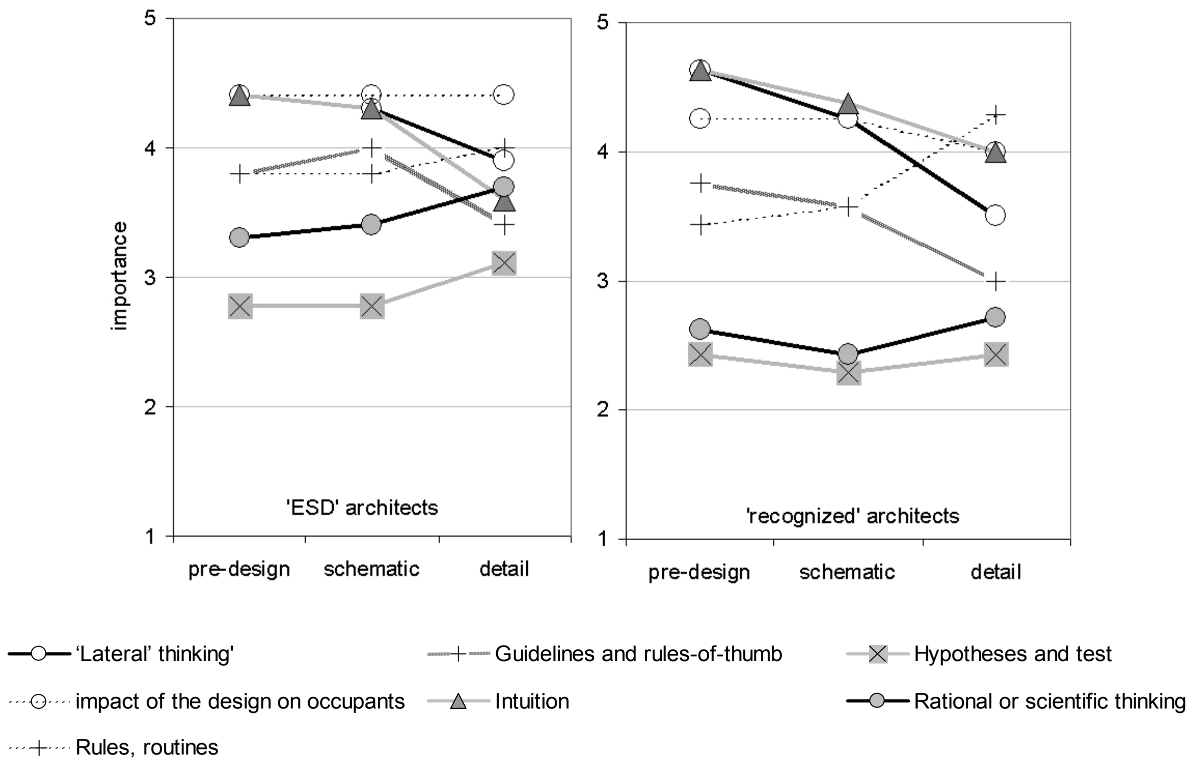

Fig. 4-5. Comparison among issues related with intuition and rational thinking.

[83] Nsofor, C. N. (1993). Daylight availability and design in Nigeria. St. Lucia, Qld.: 300. found similar tendency in his survey of methods to predict use of daylight.

Diagrams and charts are the least preferred methods to support design decisions. This tendency occurs among the four groups and during all three design phases. This result is a strong argument to reject the use of energy tools, considering that the graphics and charts are the most useful resource available in software packages to understand the behaviour of the designs or to explore the potential of climate (such as the CPZ). The uses of *guidelines/rules-of-thumb*, which could be directly or indirectly produced by energy tools, are not very important for the architects. With few exceptions, neither the use of *rational thinking* or *tests of hypothesis* are classified as priority methods, although they become slightly more important during the design development.

Design decisions

The results confirmed the order of importance: it starts with a form inserted in a site, followed by the internal arrangement, geometry of the envelope, properties of the components, design of the air conditioning and lastly, the artificial lighting system.

In the 'Design issues questionnaire', *integration with other professionals* was one of the methods with more variation on importance during the design phases: it had the second last preference of 'staff members' during the pre-design and the second preference of 'recognized' architects during the detailing phase. Probably this tendency is related with the order that design decisions are taken. Other professionals are required probably for tasks that push the architects' expertise to the limit, such as the sizing of exterior shadings, definition of materials for thermal insulation, design of air conditioning and artificial lighting. Indeed, one respondent (a recognized architect) consults engineers instead of consulting methods or energy tools. For example, the item air conditioning systems had the lowest response of answers because it requires an expertise outside the scope of architects. Consequently, the mechanical engineer is one of the most required professional, mainly in the detailing phase to define the hardware instead of improving building performance.

Phases of design assessment

Although the intention was to find out the stage when energy tools would be used[84], the results lead to a different interpretation due to two reasons:

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[84] It was based on the assumption that the energy efficiency performance of a design could be only possible to be obtained by energy simulation.

- a significant number of architects state that they assess the ‘design’ during the pre-design stage, when it does not even exist;
- despite the massive frequency of ‘energy assessment’ during the design phases, almost nobody would use a energy tool (discussed in page 173).

Therefore, it is suspected that a design is assessed when the designer analyses his/her design: if intuition is the basis of design decisions, intuition will be the ‘tool’ to assess the design. Anyway, the results indicate that architects are more concerned with the energy performance of the design during the schematic phase, followed by detailing, conceptual and conclusion phases. As discussed in page 171, the meaning of design assessment is not the same as the action of modelling the building and simulation by a software package.

Climate data

The *visit to the site* is the more common source of data, which is compatible with a design method strongly based on intuition (however, a one-off trip would be meaningless). Excepting the ‘PG students’ group, the use of *hourly data* and *monitoring* has the lowest preference among the practitioners, which is consistent, considering that the *hourly data* is to be used with energy tools. Even quantitative data such as *statistical data* is less popular than the *visit to the site*. There is no doubt that statistical data represent more in terms of information, however only 20% of ‘staff members’ and ‘recognized’ architects make use of them.

Use of tools

No method had 100% response and, in some cases, the surveyed did not even recognize what the methods were about. In general, when practitioners did not opine about tools based on quantification or charts, they suggested doubtful understanding of them. The response of ‘PG students’ was 52% for these specific tools, which indicates a reasonable understanding of their use. On the other hand, the qualitative methods such as use of *principles*, *guidelines and case studies* received the best responses and the highest score for importance.

Case studies are far more available in specific literature for architects than any other method of ESD or design for low energy (discussed in subchapter Case studies, page 40). The method is the most used in the technological subjects in the curse of architecture/UQ. However, the use of *earlier design* has a middle preference and the use of *pictorial precedents* is one of the least important (confessed) for most of the phase and groups of architects. The only exception is the ‘PG students’ who declared a middle preference for the use of *pictorial precedents* during the pre-design phase.

The most discouraging result concerns the low use of a software package. Hien, Poh et al. (2000) found similar behaviour among architects from Singapore: only 1.6% of the architectural offices surveyed used an energy tool to assess energy performance. The authors conclude that the main reason for the limited use of energy tools is the inherent system limitations, the structure of existing building delivery process and the prescriptive nature of the building legislation. The authors go further and suggest a series of 'elimination of limitations' (Fig. 4-6).

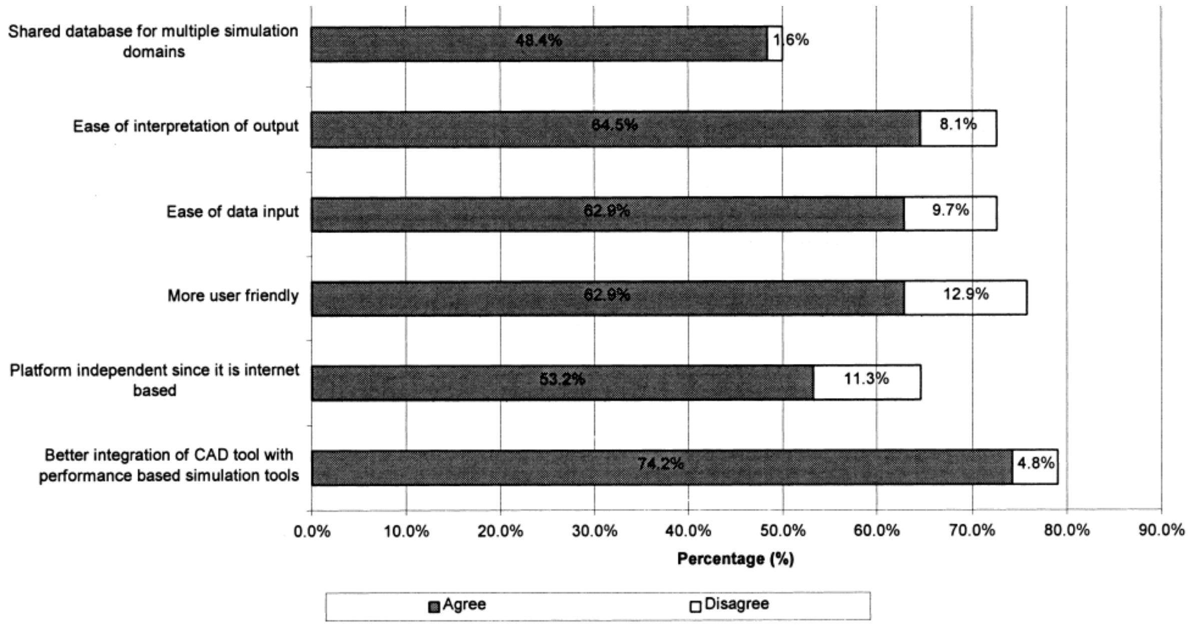

Fig. 4-6. Elimination of the limitations of current simulation tools (Hien, Poh et al. 2000).

However, the problem seems to be far more complex than the improvement of interfaces and platforms of energy tools, which theoretically could attract users from the architectural field. The results from the survey is indicating the preference for methods that emphasize a qualitative approach rather than quantitative. *Intuition*, *feelings*, *experience*, *guidelines* and *principles* have the preference. Energy tools are the last preference of architects. The low response to the issue demonstrates that architects, in general, do not have an opinion about it. On average, the importance attributed to the subject is also low. However, there are two strong arguments in favor of energy tools: the parametric analysis of this thesis and the isolated analysis of the 'recognized' architects, which indicates software packages as the second most important method. Consequently, it is reasonable to suppose that 'staff members' and 'ESD' architects have little knowledge about it.

The misunderstanding of the energy tools application is evidenced in the cited list: 35% of the surveyed referenced one software packaged such as BERS (which is for house assessment), ARCHIPAK (climate analysis and house assessment) and others that assess the sun diagram or sun angles and shadings such as AutoCAD and ArchiCAD. Although these tools are very much welcome to the process, none of them are appropriate to estimate the energy consumption of office buildings. Actually, this is evidence that very few architects had any experience with software packages for such purposes, despite the large number of alternatives available.

Considering that the subject of the thesis is polemic, it supposes that some respondents may have disagreed with the questionnaire and consequently did not answer it. The only expression of the discontent was expressed by one of the most important of architects in Australia and with a large number of buildings in many parts of the world. I'm very thankful for his contribution and his clear exposition of his practice:

'The obvious tools available to any architect are:

- *accurate sun charts of all locations on the globe that have been readily available and in use for more than 50 years;*
- *books on the work of renowned architects are all to be seen in good libraries, specially as applied in warm countries*

How one applies the factual data from these obvious and many other well-known sources is a matter of many faceted architectural design skills – which is the only thing that really matters, rather than trying to categorise the design process into meaningless quasi-scientific steps.'

On the other hand, Michael Leo observes[85]: '*In the conceptual design phase when the architect has a beautiful image (usually colored) in their mind, a paradigm-shift from 2-B penciled doodles to 3D CAD models makes software-based energy assessment possible in the phase where it is most influential. Global environmental issues make this paradigm-shift an urgent issue*'. In this case, the paradigm-shift happens in terms of input.

Low energy strategies

28% of the respondents considers the importance of strategies similar or sometimes identically. On average, the order of design decisions matches the order of architecture design decision and building services (subchapter 'Importance of design decisions related to architecture and building services', page 169). The exception is that during the pre-design and

[85] Extracted from his survey, with his authorization.

schematic phases, 'recognized' architects classify the decision of building services more important than components proprieties such as thermal mass and insulation.

Curiously, the decision for natural ventilation is one of the most important decisions during the pre-design and schematic phases, however artificial ventilation is one of the least preferred.

The design decisions are synchronized with the low energy strategies. For example, natural ventilation and building orientation have similar emphasis during the schematic phase; exterior shading, daylighting, façade geometries and natural ventilation are assessed with similar emphasis during the detailing phase (tendency more observed in 'ESD' and 'recognized' architects groups).

Other comments

After the analysis of the survey, there were suggestions to include cost as an influential factor to decide for the adoption of low energy strategies. Other issues were raised, such as how architects assess the design (previously discussed in page 182), the understanding of energy tools and the most important, the use of computers during the design process.

Enthusiastic testimonies of CAD/ CAM application to the design process are given by Frank Gehry's Bilbao Guggenheim (Fig. 4-9). Definitely, the architect became one of the most expressive professional that make use of virtual reality: '*digital modelling was the heart of the design, fabrication and on site assembly process … and the complex, non-repeating forms were made feasible through clever application of advanced CAD/CAM production capabilities*' (Mitchel 2002).

Even in a condition where the computer may rule, the contribution of the computer to the design concept is questionable. A detailed analysis of the Gehry's interview (Gehry, Forster et al. 1999) and conversations (Friedman, Sorkin et al. 1999) shows a history of achievement in previous experiences that led to the most challenging design, the Guggenheim Museum. Steele (2001) affirms that the merit of CATIA software was the ability to translate Gehry's graphic and cardboard collage design gestures and its capacity to document complicated shapes in a way that did not baffle or intimidate contractors. The sketches of Guggenheim Museum (Fig. 4-7) suggest a development that happened in a very orthodox way, paper and sketching, which preceded the modelling:

'*There are gestures in my sketches. How do you get them built? I was able to build them with the computer, with material I would never have tried before. You'll see the relationship to my sketches in Bilbao'* (Friedman, Sorkin et al. 1999).

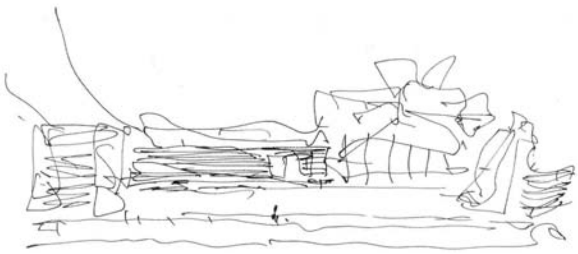

Fig. 4-7. Sketch of Guggenheim Museum Bilbao (Gehry, Forster et al. 1999)

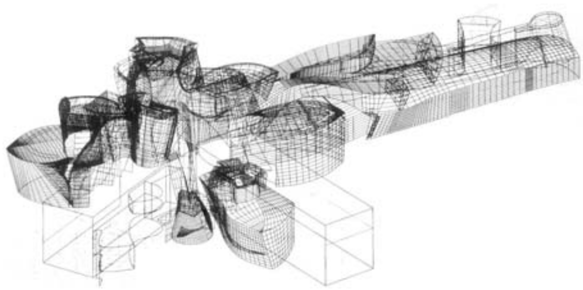

Fig. 4-8. Wire model of Guggenheim Museum Bilbao (Friedman, Sorkin et al. 1999)

Fig. 4-9. Overview of Guggenheim Museum Bilbao (Gehry, Forster et al. 1999)

Fig. 4-10. Overview of Guggenheim Museum Bilbao (Gehry, Forster et al. 1999)

On the other hand, Murcutt keeps collecting awards[86] without any interference of the digital world (AJ 2002). His impressive designs prove that computers are not an obligatory condition for such achievements (Drew 2001). Commitments seems to be more important:

'Glenn Murcutt occupies a unique place in today's architectural firmament. In an age obsessed with celebrity, the glitz of our 'starchitects,' backed by large staffs and copious public relations support, dominate the headlines …. As a total contrast, our laureate works in

[86] Pritzker Award (2002), RAIA Gold Medal (1992), Alvar Aalto Medal, the Thomas Jefferson Medal and the Richard Neutra Award.

a one-person office on the other side of the world from much of the architectural attention, yet has a waiting list of clients, so intent is he to give each project his personal best. He is an innovative architectural technician who is capable of turning his sensitivity to the environment and to locality into forthright, totally honest, non-showy works of art.' Pritzker Prize jury chairman J. Carter Brown (ArchitectureWeek 2002).

4.2 Case Studies

4.2.1 UQ- 4th year students

During the subject ‘Architectural Technologies’, the 4th year students of the Department of Architecture at UQ were required to design buildings using notions of energy efficiency learnt during the course. The students were allowed to work in groups or as individuals. A group of students came to consult me with an already formulated design, which was in the detailing stage. Apparently, the main concern of the group was to prove that their assumptions were right. The project was a winery plant: production and office areas, in Cape Town (South Africa). The design would be submitted in a design competition (Fig. 4-11 and Fig. 4-12).

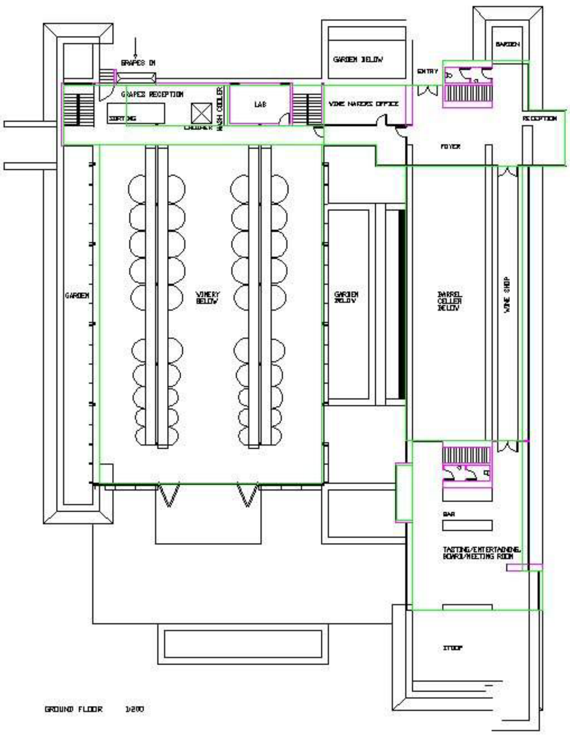

Fig. 4-11. Winery: plan view.

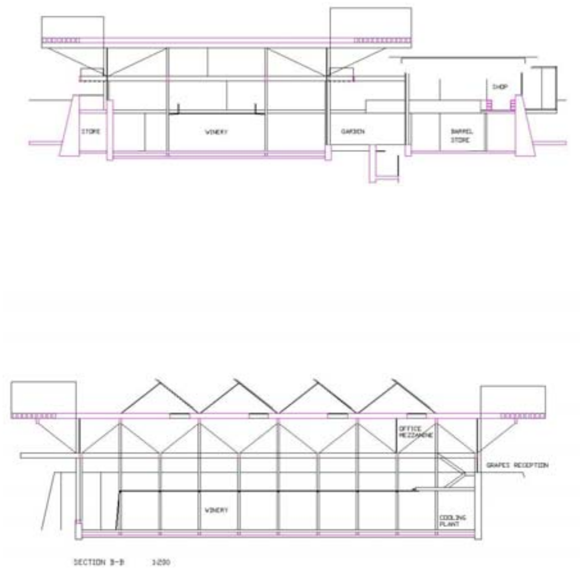

Fig. 4-12. Winery: sections.

Due the advanced stage of design development, my most reasonable contribution consisted of energy performance assessment and comparison with alternatives. The analyses emphasized the positive aspects of the design such as exterior shading and use of daylight. Considering that there was no benchmark or energy target for such design, the results were enough to convince the students that they reached an efficient design and they could go ahead with the detailing process.

Despite the simple contribution, the task consumed more time than expected. Although the design was reasonably detailed in terms of geometry, the modelling demanded more information than what the students had at that stage, such as building components, assumptions of schedules and building services. These variables were decided during meetings, without reasonable review of alternatives or deep analyses. Actually, it seems that the whole process was strongly based on guesses. For example, nobody had done any study of the climate, although one of the students had lived for some period in the Cape Town. There was no indication that a true analysis of bioclimatic principles or low energy strategy would have influenced the design decisions. Apparently, the students relied on a major strategy of energy saving: an underground duct, which would cool the external air, supplying it to the building areas. The students did believe that such strategy would provide an air temperature compatible with comfort and with the wine-making process, although they never came with an analysis or a case study to support the hypothesis. Actually, the modelling of the duct would demand more information than available, such as characteristics of the ground (for estimation of ground temperature) and the generation of heat and mass inside the building. Unfortunately the underground duct is highly susceptible to the formation of fungus and bacteria developments[87].

Other students demonstrated interest for energy simulation, however asking for final checking of their design rather than to support any further design decisions.

4.2.2 ESD practice

A local architect offered an opportunity to examine a design process. The project was a small office building located near Brisbane, which would be a model of sustainable design. A team was invited: an architect, a builder/architect and two energy consultants (including myself), partially sponsored by EPA[88].

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[87] Such strategy was adopted in the late 70's in a 30 000 m² office building in Florianópolis/ Brazil (same climate as Brisbane). The system was turned off after few months of operation because of the decreasing of air quality. More details of the building are available in Pedrini (1997).

[88] The Environmental Protection Agency (EPA) is a department of the Queensland Government. More information is available at http://www.epa.qld.gov.au/environment/about/.

Briefing

Located in an open area (Fig. 4-13), the 152 m² building involved more concerns than just energy consumption. Firstly, the designers understood that the client's intention was to use this project to promote Ecologically Sustainable Development (ESD), to avoid buildings fully relying on active systems.

Fig. 4-13. Building construction site.

Secondly, the designers decided for a type of construction based on the lightweight engineered-timber system 'Guitar Buildings'[89]. In an internal report to the team, Michael Leo stated:

'*The Guitar Buildings thermosiphon, if effective, would remain so for the lifetime of the building. In contrast none of the manufacturers of fiberglass, wool, polystyrene/polyurethane and cellulose batts/blankets guarantee to retain their stated "R" rating for ANY time period. The ESD performance over building lifetime issue here deserves investigation*.'

The walls were designed as a double skin with an air cavity that would remove the heat conducted through the outer skin using air movement caused by a stack effect.

Thirdly, an intricate space-strategy was the construction of a fernery along to the building (Fig. 4-14). Leo's intention was to create a shelterbelt between the building and the large exposed field to the south, decreasing the outside air temperature through natural evaporative cooling inside the fernery, before supplying it to the building.

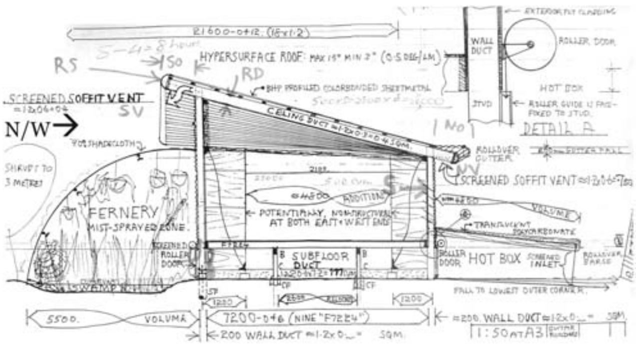

Fig. 4-14. Sketch: fernery section (© M. Leo Guitar Building 2000).

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[89] Guitar Buildings is business name of Michael Leo, B. Arch UQ 1974. QBSA Licd Buider 14924.

The system would require a wall duct system with damper controls under the building and louvers in the interior wall, which is controlled by the occupants, as required for comfort.

Fourthly, a ‘hot box/solar trap’ would be designed to heat the air in the cool season, at ground level. The pre-conditioned air would pass through dampers into the perimeter of a sub-floor plenum. Fifthly, the external building skin would be a translucent polycarbonate, instead of plywood, for unidentified reasons.

Process

Based on the sketch and on the briefing, I conducted the initial analysis. Using the comprehensive list of climate files from Archipak, the climate of Amberley[90] and Brisbane were compared to decide a climate to use in further analysis in VisualDOE. Used as briefing information, the results of CPZ indicated suitable strategies.

Although the building was rather small for an office type, the predictability of thermal performance was beyond the capacity of the consultants and their tools due the complexity of air movement. The air movement caused by stack effect would be strongly dependent on the cooling effect of the fernery and differences of temperature in wall cavities, rooms, roof void and outside. The fernery cooling effect was the first unknown: it was too complex to model, there were no direct references and nobody really knew what vegetation was intended. Furthermore, the driving forces would be also strongly affected by pressures difference caused by the wind. Recorded wind data would be crucial to estimate the wind pressure on the building and it was not available. Had it been solved, a CFD package such as TAS (Fig. 4-15) or IES4 (Fig. 4-16) should be the most appropriate tool for a modelling. It could provide a detailed analysis of the air flowing through the fernery, up through the walls into the building, plus air flow around the building and pressure zones. Temperatures could be assessed in terms of isotherms, instead of average temperatures for zones, such as VisualDOE does.

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[90] Amberley is the closest weather station of the building site.

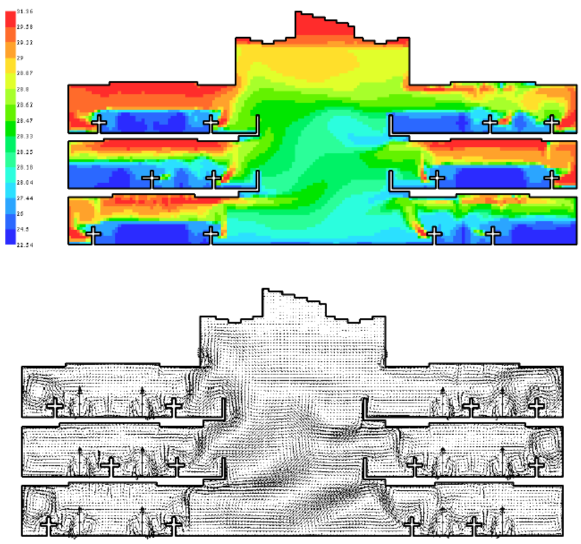

Fig. 4-15. Temperature gradients and air flow (TAS software), in a building section[91].

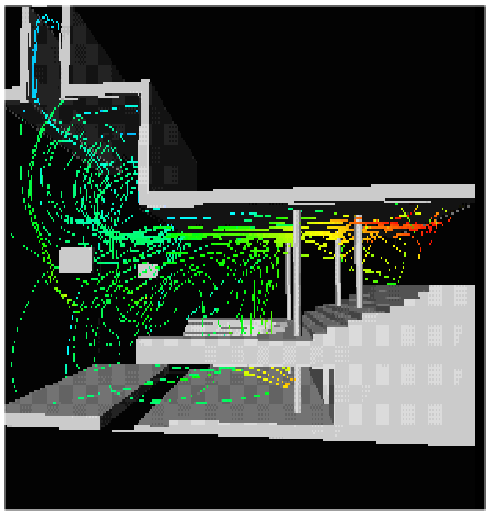

Fig. 4-16. Air flow combined with air temperature (IES4 software), in a perspective view inside the building[92].

As the fernery design and the wind data remained unknown, the most reasonable approach was to assess the design using the most appropriate software available to the consultants, VisualDOE. Due the uncertainties of the strategies and limitations of modelling, the analysis was carried out considering two basic modes of operation: free running (passive) and hybrid (active/passive). Then, air conditioning became a backup mode on occasions when passive strategies were inadequate.

The hybrid model employed passive strategies to reduce the size and the energy consumption of active systems, using "green" strategies. The evaluation process started with a simple model with no ventilation cavity; testing insulation in wall, roof and ground. Further models tested ventilation in cavities with double skin plywood, and also insulation options. A heavy thermal mass was also simulated. The results defined a composition with an improved envelope. Later analyses examined strategies such as daylighting, indirect evaporative pre-cooling, and air conditioning with window/wall units. The last and most complex model was a window wall unit incorporating user intervention by turning the ceiling fans on when the inside temperature reaches 25°C, then turning the air conditioning on and closing the windows when the temperature reaches 29°C.

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[91] http://ourworld.compuserve.com/homepages/edsl

[92] http://www.ies4d.com/products/4D+DetailedPerformanceAssessmentTools/microflo/microflo.htm

After reporting the results to the team, a second analysis was done as a consequence of changes in the original sketch. Apparently, the majority of the changes were more a consequence of the client's demands than the first analysis. Then, an assessment was carried out with more detailed information about occupancy and thermophysical proprieties of building components.

Some months later, a third assessment was requested. Slight changes in the design, more detailed information and a major concern with the energy performance led to a new set of simulations. Special attention was paid to the Energy Star Rating Scheme (Exergy Group. 1999; SEDA 2001)

Observations and conclusions

The consultancy was carried out from February to July of 2001 and the tasks consumed at least four times the expected due many reasons. Significant waste of time could have been avoided if the team members and the client had conducted the design process interactively. For example, the first set of simulations was discarded due the discrepancies between the model used and the updated brief.

The first conceptual plan (Fig. 4-17) shows that design decisions such as geometry, building components and low energy strategies were done by Guitar Building before a proper discussion concerning low energy strategies. As discussed in the subchapter 'Architect's behaviour', page 75, such procedure is very common.

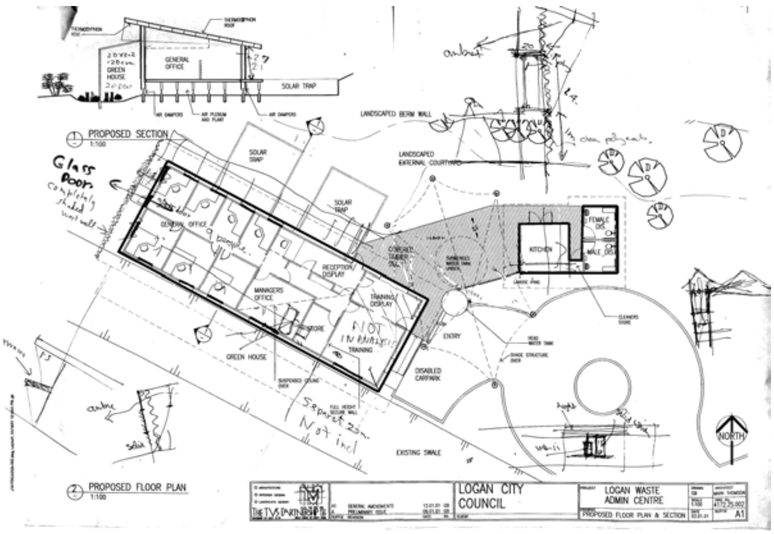

Fig. 4-17. Logan building detailed project.

A remarkable characteristic of this case was the use of lateral thinking to conceive the strategies. The mind behind the most important features is a consciously 'lateral thinker', who makes use of this technique in his practice. Considering that his clever solutions led to a design quite different from the usual bioclimatic recommendations, his decisions had to be strongly based in previous experiences[93], intuitions and guesses. His personal design process may also be understood as a heuristic method.

From the beginning to the end, the four members of the 'team' never really confronted points of view or discussed anything as a group, and discordances were clear. The client's preferences were obscure for part of the team, most of the time. Some design alternatives were simulated three times, aiming to show the disadvantage of some specific features such as the use of translucent polycarbonate as external wall cladding, and offering alternatives based on conventional strategies such the use of insulation, thermal mass, shading etc. There is a belief that the polycarbonate skin preferred by the architect was a dominant idea (or 'primary generator', (Lawson 1997), although refuted in the energy analysis. Actually, understanding the physical processes should be the basis of an initial discussion, before a full energy analysis. Although the first report emphasized the dependence of outputs on thermal loads and their sources (Fig. 4-18 and Fig. 4-19), they were totally ignored.

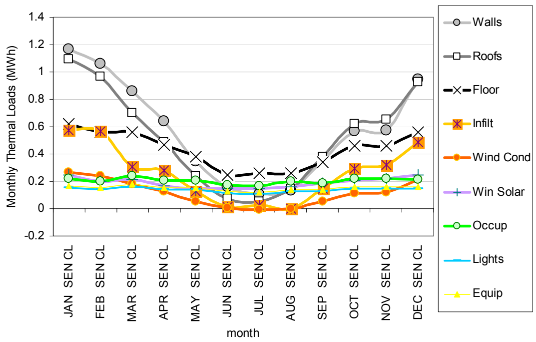

Fig. 4-18. Monthly heating loads.

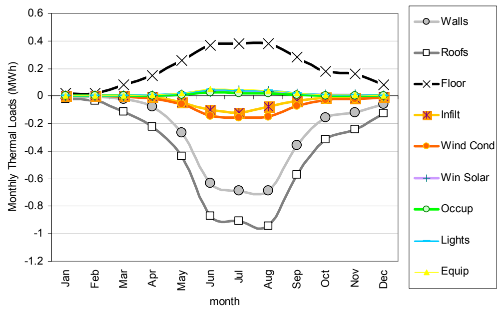

Fig. 4-19. Monthly cooling loads.

The three thermal performance reports never produced the expected feedback or even led to discussion by the whole team, except the system designer. While the report went through the quantification of thermal loads by source and energy consumption by end-use, the only clear question by the architect was '*can I claim five stars for this building*?'. In theory, the reasons for such low level feedback can be:

- delay of the reports relative to the architectural design decisions;
- lack of understanding due the use of technical language;

[93] Such as childhood experience of comfortable conditions in Queensland farmhouse ferneries in the 1950's.

- some members were involved in other projects, leading to a lack of time to appreciate the reports;
- the strategies assessed were not aesthetically interesting;
- the team should be looking for simple, short and straight answers to support their prior decisions.

Working in such a team evidenced the ambiguity and frustration when members do not share similar goals, do not have the same level of commitment or just do not have enough time to dedicate to the task.

This case confirms some previous experiences of the author. The architect usually demands a support that the consultant usually cannot provide promptly. In this specific case, the analyses seemed to come out too late to influence the design decisions. In general, even simple questions such as '*what is the best overhang size for a window?*' involves a series of additional questions by the consultant, who will have to model the geometries, occupants behaviour, etc. This case exemplifies this issue. Sometimes the assumptions by the consultant were not appropriate, sometimes the design moved faster than the analysis. A possible way to avoid such difficulties would be for the consultant to prepare comprehensive design guidelines, perhaps examining a series of pre-constructed models (creating a data-base, such as in the LTV), based on which specific questions could be quickly answered.

Now constructed, Fig. 4-20 and Fig. 4-21, the building is being assessed and it has been already celebrated as a '*smart tip for ESD*' (EPA 2002; QMB Magazine 2002). It may take some time to fully reach all the potentialities of such avant-garde ideas. Considering the unsatisfactory utilization of the thermal performance consultants, all merit achieved must be attributed to the persistence of the '*lateral thinker*'.

Fig. 4-20. Building construction phase.

Fig. 4-21. As built (QMB Magazine 2002)

4.2.3 Design Competition

Dr.Yeang provided a unique opportunity for a design case study. The architect accepted collaboration for a design competition for a building complex in Beijing, China. Due to problems with the energy tool, the analysis was not carried on as planned. However the experience provided enough feedback, mainly related to the first stage of design.

Briefing and process

The project manager explained the brief from the competition's organizer during the first meeting. The project consisted of 100 000 m² shared by commercial, residential and hotel purposes. Based on economic parameters and criteria of viability, the number of towers and the number of levels and area of each were defined. At this stage, the project manager asked for suggestions that could be helpful to the designer to draw the first sketches, which would be further discussed with Dr Yeang in a week's time[94].

One week later, a second meeting exposed the difficulties that the designer had to conceive the first sketches. After some weeks, with the definition of the sketch (Fig. 4-22), the project manager requested a set of simulations with the following characteristics:

- WWR (window wall ratio):
    - 50% for South Elevations;
    - 20%, with wind breaker screen to keep out cold winds on North Elevations, from windows/balconies;
    - horizontal exterior projections: South Elevation, to keep out high altitude summer sun;
    - vertical exterior projections: West & East Elevation.
- type of glazing: double glazing, clear glass on Northern wall;
- U-value and optical transmittance: allow high solar heat penetration through Southern wall during winter and mid-seasons;
- daylighting: maximum daylighting into interior spaces;
- ventilation:

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[94] Unfortunately, that week was programmed to attend visits to buildings in Kuala Lumpur and to attend a conference at Malaya University of Malaysia.

- natural ventilation of public spaces (i.e. Public Plaza, lift lobbies and sky gardens) during summer;
- partial natural ventilation during mid seasons;
- heating during winter.

At that time, a new software was used: the VisualDOE 3.0. The design was modeled as required and it took some days to run the first models. Surprisingly, a series of errors in the code were identified: most of them related to the new graphic interface. Despite the notable support of Eley Inc., new errors were identified in the following weeks. Even after the deadline of the design competition, the software was not reliable. Eventually, the promised support could not be provided.

Fig. 4-22. Sketches.

The design wan the 2001 Winning Entry, Beijing World Science & Trade Centre, Beijing Municipal Institute of city Planning Design, China. (Richards 2001), Fig. 4-23.

Fig. 4-23. Beijing World Science & Trade Centre (Richards 2001)

Observation and conclusions

Despite the failures to support the architects along their design path development, this case study may reveal the process behind Yeang's recognized designs celebrated in many publications (Yeang 1987; Hamzah and Yeang 1994; Yeang 1995; Yeang 1996; Yeang and Hamzah & Yeang. 1998; Jones and Yeang 1999; Powell 1999; Tzonis, Lefaivre et al. 1999; Yeang 1999; Yeang 1999). Because the architects were working with a climate not fully known, probably they behaved as they did when working in warm climates in previous cases.

Every meeting and e-mail was characterized by clear, straight and pertinent questions, which shows a unique experience in terms of interaction. They knew what they were looking for: basic information to take to a briefing. Although these recommendations could be hypothetically adopted without discussion, it is more reasonable to assume that they would proceed with an analysis/ synthesis method to achieve a visually impressive design (as they typically do). During a meeting with the designer assigned to do the first sketches, he demonstrated extreme discomfort to develop a design concept without a proper bioclimatic briefing.

In a second approach, the architects demanded an evaluation of a partially detailed design. The evaluation concerned architectural variables and low energy strategies strongly related to the envelope. Apparently, this design was flexible enough to allow changes. In this case, they were testing a hypothesis that could lead to further design decisions.

These characteristics of the design process reflect rational attitudes, accessible to anyone. It does not demand experience or complex apparatus. Actually, it is compatible with the technology of the last 20 years: parametric analysis and model simulation. For example, the briefing analysis could be supported by a comprehensive database such as the one developed for the LTV method, however using Beijing climate. The first sketches could also be assessed with LTV and after some detailing, many software packages such as VisualDOE could be used for the analysis.

4.3 Parametric analysis

4.3.1 Process

The subchapter 'Building architectural variables' (page 103) provided the variants for the first matrix, which were modeled with approximately 35 000 permutations[95], limited to only one type of fabric. The processes of modelling, running, extracting the results and insertion in a graphic interface using Microsoft Access software took approximately one month of intensive work. However, the first analyses evidenced suspicious results, which led to a series of tests. After checking the models in VisualDOE and the DOE-2.1E, it was concluded that the results were dramatically affected by some error during the conversion from SI to IP: the inputs were in SI and the code in IP. The calculation of solar heat gains was in error, grossly underestimated. The programmers in Eley provided updates for the software in a short time after being notified. Despite the improvements, the whole set of models were discarded and a new set were modeled, but this time in IP, to avoid potential errors in the 'DOE2.1E engine'. The second set of models was rethought to optimize the whole process, which generated the structure proposed in Fig. 4-25, with approximately 24 000 alternatives. A second type of fabric was added, the LPD and COP were combined in one option for building services (high and low efficient) and the type of ventilation was modeled only for 'active' and 'natural ventilation' modes[96]: The sequence of modelling was also modified after the experience with the first set. The variables with more steps to change in VisualDOE were modeled first: in accordance with Fig. 4-25: the room depth was the first one to vary, followed by the ceiling height and so on. Variables such as glass, openings and fabric were changed in the library instead of in the file. Consequently, changing their characteristics once in the file[97], all alternatives were also automatically changed.

Such improvements in the structure reduced the whole process, from modelling to insertion in the Access's database, to only four days of intensive work. In average, each file with 96

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[95] Each permutation corresponds to one alternative and consequently one model.

[96] The results from the first set of models showed that the results of 'enthalpic control' had the consumption of fans equivalent to the 'active' mode and the consumption of cooling equivalent to the 'natural ventilation' mode. Consequently, the energy consumption by end use were calculated after the simulations.

[97] Each file of second set has 96 alternatives while the first set had 72 alternatives. The maximum available in this version of VisualDOE were 100 alternatives per file.

alternatives took 10-13 minutes to run using a pc with Pentium IV 1.6 MHz processor. At the end, VisualDOE generated approximately four Gbytes of files.

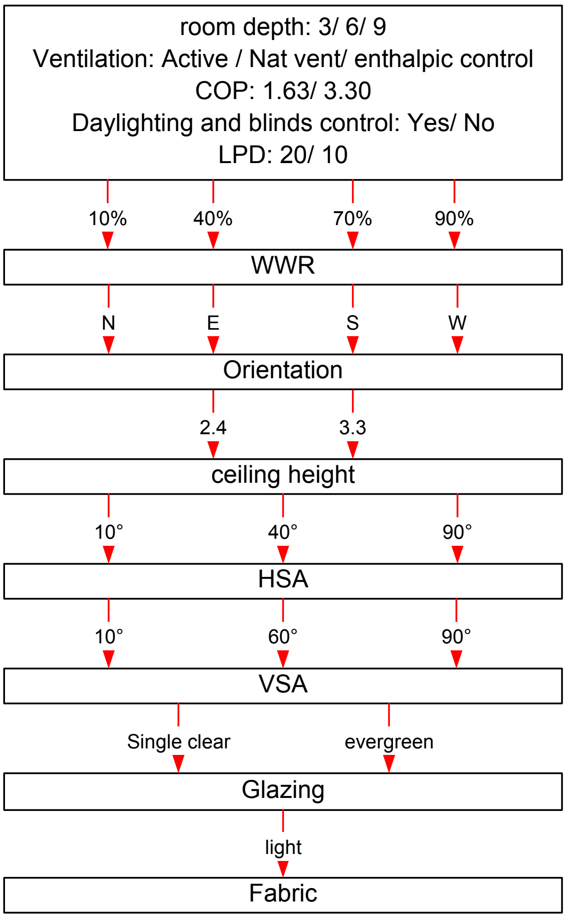

Fig. 4-24. Parameters assessed in the first matrix[98].

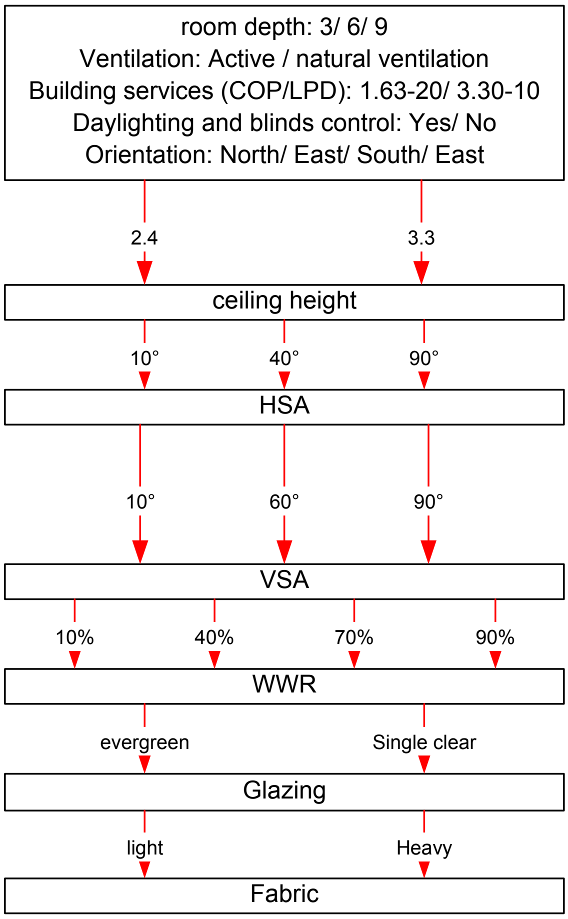

Fig. 4-25. Parameters assessed in the second matrix.

Despite such optimization, the number of alternatives reached the limits of the pc many times when statically analyzed in Excel software. Then, the use of links among cells had to be drastically reduced and many operations had to be done using manual manipulation, which increases the possibilities of mistakes. Probably one alternative more, which would double the numbers of results, would make the process impractical.

Star rating

The use of the Energy Star Rating scale implies a correction on the scale due the differences of the model simulated and the one that generated the rating. While the original scale assumes

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[98] The Fig. 4-24 shows 41 472 permutations, however the total number of runs are 36 865. The reason is that some parameters are not combined with others. For example, there is no VSA or HSA for 0% WWR.

a 50 hours/ week of occupation and an EPD 8 W/m², the models based on ABCB assumes 68 hours/week[99] and EPD 15W/m² for ABCB. The scales are compared in Table L.

Table L. Energy star rating for the parametric analysis.

Stars (whole building)	original annual energy consumption rating (kWh/m²)	annual energy consumption normalized for 68 hours/week (kWh/m²)
1	387	546
2	323	466
3	259	386
4	194	306
5	130	227

[99] Based on hours of occupancy higher than 20% of the peak, as prescribed in Bannister, P. (2001).

4.3.2 Range of energy consumption

The minimum energy consumption for cells with North, East, South and West orientation are very close (Fig. 4-26) and they share characteristics such as efficient building services, use of daylight and natural air ventilation. North cells reach 125 kWh/(yr.m²) with a light fabric, 3 m deep, high ceiling, clear glazing, WWR 70%, VSA 60° and HSA ±40°. East cells reach 132 kWh/(yr.m²) with heavy fabric, 6 m deep, high ceiling, green glazing, WWR70%, VSA 10° and HSA ±10°. South cells reach 130 kWh/(yr.m²) with light fabric, 3 m deep, low ceiling, clear glazing, WWR 40%, VSA 90° and HSA ±40°. West cells reach 132 kWh/(yr.m²) with light fabric, 9 m deep, high ceiling, clear glazing, WWR 90%, VSA 10% and HSA ±10%.

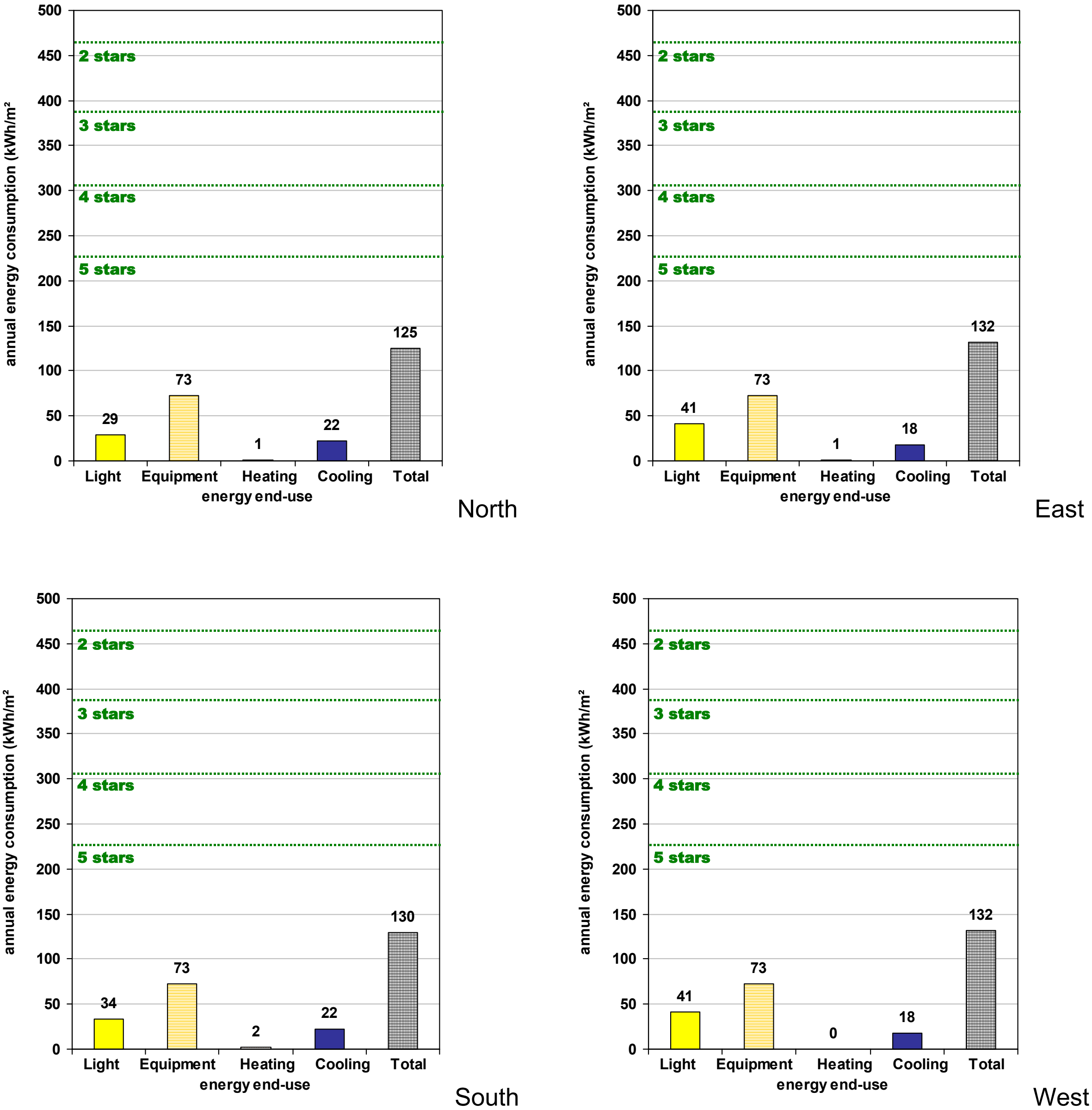

Fig. 4-26. Minimum energy consumption for cells with different orientation.

The maximum energy consumption for cells oriented for North is 444 kWh/(yr.m²), for East is 388 kWh/(yr.m²), for South is 296 kWh/(yr.m²) and West is 494 kWh/(yr.m²) (Fig. 4-27). The four orientations share the same characteristics: heavy fabric[100], 3 m deep, high ceiling height, clear glazing, WWR 90%, VSA 90°, HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting or outside ventilation.

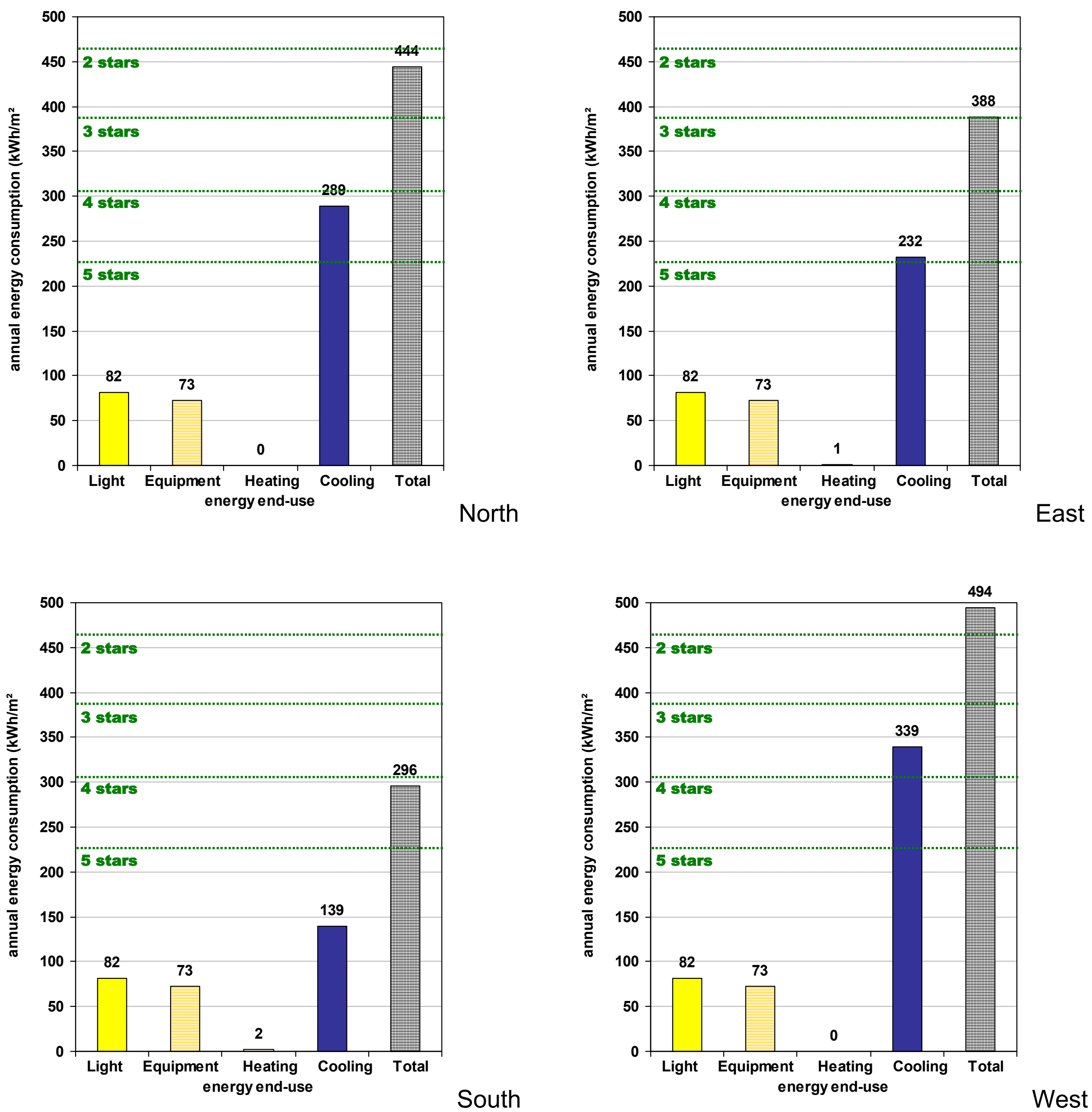

Fig. 4-27. Maximum energy consumption for cells with different orientation.

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[100] The exception is the South cell, which have the maximum consumption with light fabric. The heavy fabric has 296 kWh/(yr.m²).

4.3.3 Maximum changes in energy consumption: report

The intention of this long report is to quantify the maximum changes in energy consumption due the influence of the variables. The influence is determined by comparing cells with identical configuration that differ in only one variable. The difference of such variation is expressed as the ratio of the difference to the higher value. If A>B, the ratio is (A-B)/A and vice-versa.

The whole report is also helpful to illustrate the complex interaction of the variables. Considering that some results may seem ambiguous, it seems interesting to discuss briefly some aspects of these combinations. Fig. 4-28 illustrates the balance between light and cooling consumption, when daylighting is used as a strategy. Increasing VSA from 10° to 60° reduces total energy consumption because the reduction of light consumption is higher than the increase of cooling.

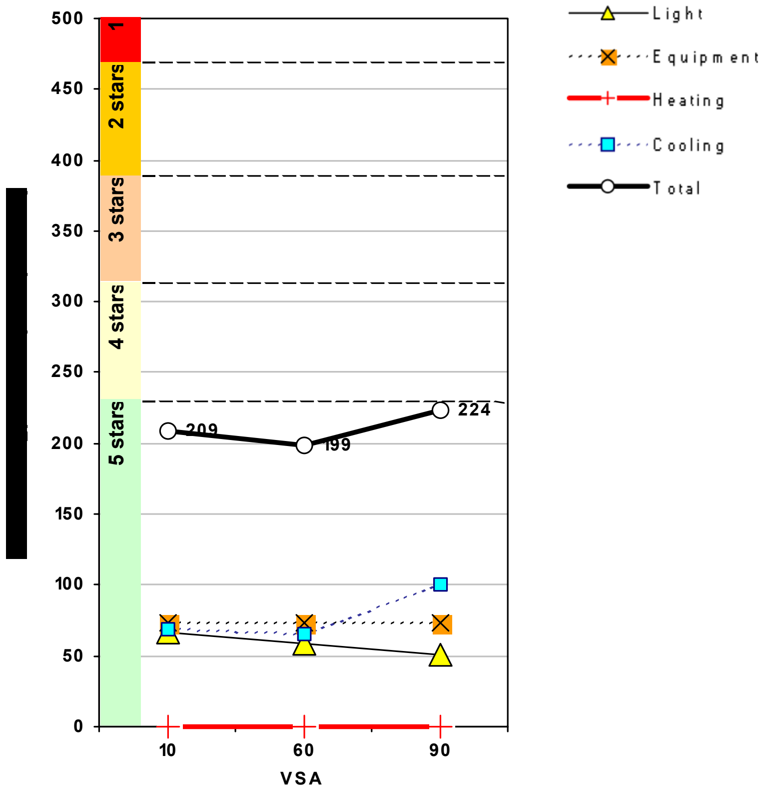


Fig. 4-28. Balance between cooling and light consumption (light).

On the other hand, increasing VSA from 60° to 90° (i.e. no shading) increases the total energy consumption because the increase of cooling is higher than the reduction of light.

Orientation

South 200 kWh/(yr.m²) (87%) less than West.

Cell characteristics: with heavy fabric, 3 m deep, high ceiling, clear glazing, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and active ventilation.

South 148 kWh/(yr.m²) (33%) less than North.

Cell characteristics: with heavy fabric, 3 m deep, high ceiling, clear glazing, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

East 110 kWh/(yr.m²) (47%) less than West.

Cell characteristics: with heavy fabric, 3 m deep, high ceiling, clear glazing, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and active ventilation.

South 92 kWh/(yr.m²) (24%) less than East.

Cell characteristics: with heavy fabric, 3 m deep, high ceiling, clear glazing, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

North 69 kWh/(yr.m²) (21%) less than West.

Cell characteristics: with heavy fabric, 3 m deep, high ceiling, clear glazing, WWR 90%, VSA 90° (i.e. no shading) and HSA ±40°, low efficiency building services, use of daylighting and active ventilation.

East 56 kWh/(yr.m²) (13%) less than North.

Cell characteristics: with heavy fabric, 3 m deep, low ceiling, clear glazing, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

North 37 kWh/(yr.m²) (17%) less than East.

Cell characteristics: with heavy fabric, 3 m deep, low ceiling, clear glazing, WWR 70%, VSA 60° and HSA ±40°, low efficiency building services, use of daylighting and enthalpic control.

North 23 kWh/(yr.m²) (11%) less than South.

Cell characteristics: with heavy fabric, 3 m deep, high ceiling, clear glazing, WWR 70%, VSA 60° and HSA ±40°, low efficiency building services, use of daylighting and enthalpic control.

West 17 kWh/(yr.m²) (7%) less than North.

Cell characteristics: with heavy fabric, 3 m deep, low ceiling, clear glazing, WWR 40%, VSA 10° and HSA ±40°, low efficiency building services, use of daylighting and active ventilation.

West 15 kWh/(yr.m²) less (7%) than East.

Cell characteristics: heavy fabric, clear glazing, 6 m deep, low ceiling height, WWR 40%, VSA 10° and HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and natural ventilation.

West 14 kWh/(yr.m²) (97%) less than South.

Cell characteristics: heavy fabric, clear glazing, 6 m deep, low ceiling, WWR 40%, VSA 10° and HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and natural ventilation.

East 7 kWh/(yr.m²) (3%) less than South.

Cell characteristics: with heavy fabric, 3 m deep, high ceiling, clear glazing, WWR 40%, VSA 10° and HSA ±40°, low efficiency building services, use of daylighting and natural ventilation.

Increase of ceiling height (and window geometry)

North **reduces** 19 kWh/(yr.m²) (7%).

Cell characteristics: light fabric, clear glazing, 6 m deep, WWR 40%, VSA 90° (i.e. no shading) and HSA ±10°, low efficiency building services, no use of daylighting and with active ventilation.

increases 12% or 35 kWh/(yr.m²).

Cell characteristics: light fabric, clear glazing, 3 m deep, WWR 40%, VSA 10° and HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting and with active ventilation.

East **reduces** 23 kWh/(yr.m²) (10%).

Cell characteristics: heavy fabric, clear glazing, 6 m deep, WWR 70%, VSA 60° and HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and with natural ventilation.

increases 28 kWh/(yr.m²) (10%).

Cell characteristics: light fabric, clear glazing, 3 m deep, WWR 70%, VSA 60° and HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting and with enthalpic control.

South **reduces** 13 kWh/(yr.m²) (6%).

Cell characteristics: heavy fabric, clear glazing, 3 m deep, WWR 70%, VSA 10° and HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and with natural ventilation.

increases 11 kWh/(yr.m²) (5%).

Cell characteristics: light fabric, clear glazing, 3 m deep, WWR 40%, VSA 90° (i.e. no shading) and HSA ±40°, low efficiency building services, no use of daylighting and with enthalpic control.

West **reduces** 18 kWh/(yr.m²) (6%).

Cell characteristics: light fabric, clear glazing, 3 m deep, WWR 40%, VSA 90° (i.e. no shading) and HSA ±10°, low efficiency building services, no use of daylighting and with active ventilation.

increases 52 kWh/(yr.m²) (17%)

Cell characteristics: heavy fabric, clear glazing, 3 m deep, WWR 40%, VSA 10° and HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting and with active ventilation.

Increase of room depth

North From 3 to 6 m **reduces** 99 kWh/(yr.m²) (23%).

Cell characteristics: heavy fabric, clear glazing, high ceiling, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and enthalpic control.

From 3 to 6 m **increases** 20 kWh/(yr.m²) (10%).

Cell characteristics: light fabric, clear glazing, high ceiling, WWR 70%, VSA 60° and HSA ±40°, efficient building services, no use of daylighting and natural ventilation.

From 3 to 9 m **reduces** 136 kWh/(yr.m²) (32%).

Cell characteristics: heavy fabric, clear glazing, high ceiling, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), efficient building services, no use of daylighting and active control.

From 3 to 9 m **increases** 125 kWh/(yr.m²) (39%).

Cell characteristics: heavy fabric, clear glazing, low ceiling, WWR 70%, VSA 60° and HSA ±40°, low efficiency services, use of daylighting and enthalpic control.

From 6 to 9 m **reduces** 37 kWh/(yr.m²) (11%).

Cell characteristics: heavy fabric, clear glazing, high ceiling, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), efficient building services, no use of daylighting and active control.

From 6 to 9 m **increases** 114 kWh/(yr.m²) (36%).

Cell characteristics: heavy fabric, clear glazing, low ceiling, WWR 70%, VSA 60° and HSA ±90° (i.e. no shading), low efficiency services, use of daylighting and enthalpic control.

East From 3 to 6 m **reduces** 47 kWh/(yr.m²) (19%).

Cell characteristics: heavy fabric, clear glazing, high ceiling, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

From 3 to 6 m **increases** 14 kWh/(yr.m²) (9%).

Cell characteristics: light fabric, clear glazing, high ceiling, WWR 70%, VSA 60° and HSA ±90° (i.e. no shading), efficient building services, no use of daylighting and natural ventilation.

From 3 to 9 m **reduces** 64 kWh/(yr.m²) (26%).

Cell characteristics: heavy fabric, clear glazing, high ceiling, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), efficient building services, no use of daylighting and active ventilation.

From 3 to 9 m **increases** 12 kWh/(yr.m²) (6%).

Cell characteristics: light fabric, clear glazing, low ceiling, WWR 70%, VSA 60° and HSA ±90° (i.e. no shading), low efficiency services, use of daylighting and natural ventilation.

From 6 to 9 m **reduces** 17 kWh/(yr.m²) (9%).

Cell characteristics: heavy fabric, clear glazing, high ceiling, WWR 90%, VSA 90° (i.e. no shading) (i.e. no shading) and HSA ±90° (i.e. no shading), with low efficiency building services, no use of daylighting and active ventilation.

From 6 to 9 m **increases** 10 kWh/(yr.m²) (5%).

Cell characteristics: heavy fabric, clear glazing, high ceiling, WWR 70%, VSA 60° and HSA ±90° (i.e. no shading), low efficiency services, use of daylighting and active ventilation.

South From 3 to 6 m **reduces** 26 kWh/(yr.m²) (13%).

Cell characteristics: light fabric, clear glazing, high ceiling, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), efficient building services, no use of daylighting and active ventilation.

From 3 to 6 m **increases** 20 kWh/(yr.m²) (10%).

Cell characteristics: heavy fabric, clear glazing, low ceiling, WWR 40%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), efficient building services, use of daylighting and natural ventilation.

From 3 to 9 m **reduces** 35 kWh/(yr.m²) (22%).

Cell characteristics: light fabric, clear glazing, high ceiling, WWR 90%, VSA 10° and HSA ±90° (i.e. no shading), efficient building services, no use of daylighting and active ventilation.

From 3 to 9 m **increases** 17 kWh/(yr.m²) (9%).

Cell characteristics: heavy fabric, clear glazing, low ceiling, WWR 40%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency services, use of daylighting and with enthalpic control.

From 6 to 9 m **reduces** 38 kWh/(yr.m²) (24%).

Cell characteristics: heavy fabric, clear glazing, high ceiling, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), efficient building services, no use of daylighting and enthalpic control.

From 6 to 9 m **increases** 10 kWh/(yr.m²) (5%).

Cell characteristics: heavy fabric, clear glazing, high ceiling, WWR 70%, VSA 60° and HSA ±90° (i.e. no shading), low efficiency services, use of daylighting and with natural ventilation.

West From 3 to 6 m **reduces** 71 kWh/(yr.m²) (25%).

Cell characteristics: light fabric, clear glazing, high ceiling, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), efficient building services, no use of daylighting and active ventilation.

From 3 to 6 m **increases** 8 kWh/(yr.m²) (5%).

Cell characteristics: light fabric, clear glazing, low ceiling, WWR 40%, VSA 10° and HSA ±90° (i.e. no shading), efficient building services, no use of daylighting and natural ventilation.

From 3 to 9 m **reduces** 146 kWh/(yr.m²) (34%).

Cell characteristics: heavy fabric, clear glazing, high ceiling, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and active ventilation.

From 3 to 9 m **increases** 11 kWh/(yr.m²) (5%).

Cell characteristics: heavy fabric, clear glazing, low ceiling, WWR 40%, VSA 10° and HSA ±10°, low efficiency services, no use of daylighting and with enthalpic control.

From 6 to 9 m **reduces** 40 kWh/(yr.m²) (12%).

Cell characteristics: heavy fabric, clear glazing, high ceiling, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and active ventilation.

From 6 to 9 m **increases** 9 kWh/(yr.m²) (4%).

Cell characteristics: heavy fabric, clear glazing, high ceiling, WWR 40%, VSA 10° and HSA ±90° (i.e. no shading), low efficiency services, use of daylighting and with natural ventilation.

Increase of WWR

North From 10 to 40% **reduces** 26 kWh/(yr.m²) (12%).

Cell characteristics: light fabric, clear glazing, 3 m deep, high ceiling, VSA 60° and HSA ± 90°, low efficiency building services, use of daylighting and natural ventilation.

From 10 to 40% **increases** 49 kWh/(yr.m²) (23%).

Cells characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, VSA 90° (i.e. no shading) and HSA ± 90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

From 10 to 70% **reduces** 30 kWh/(yr.m²) (14%).

Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, VSA 60° and HSA ± 40°, low efficiency building services, use of daylighting and natural ventilation.

From 10 to 70% **increases** 93 kWh/(yr.m²) (36%).

Cells characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, VSA 90° (i.e. no shading) and HSA ± 90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

From 10 to 90% **reduces** 26 kWh/(yr.m²) (12%).

Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, VSA 90° (i.e. no shading) and HSA ± 90° (i.e. no shading), efficient building services, use of daylighting and natural ventilation.

From 10 to 90% **increases** 114 kWh/(yr.m²) (41%).

Cells characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, VSA 90° (i.e. no shading) and HSA ± 90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

East From 10 to 40% **reduces** 19 kWh/(yr.m²) (8%).

Cell characteristics: light fabric, clear glazing, 3 m deep, high ceiling, VSA 10° and HSA ± 10°, low efficiency building services, use of daylighting and active ventilation.

From 10 to 40% m **increases** 115 kWh/(yr.m²) (32%).

Cells characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, VSA 90° (i.e. no shading) and HSA ± 90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

From 10 to 70% **reduces** 21 kWh/(yr.m²) (10%).

Cell characteristics: light fabric, clear glazing, 3 m deep, high ceiling, VSA 10° and HSA ± 10°, low efficiency building services, use of daylighting and active ventilation.

From 10 to 70% **increases** 115 kWh/(yr.m²) (38%).

Cells characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, VSA 90° (i.e. no shading) and HSA ± 90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

From 10 to 90% **reduces** 16 kWh/(yr.m²) (7%).

Cell characteristics: light fabric, clear glazing, 3 m deep, high ceiling, VSA 10° and HSA ± 10°, low efficiency building services, use of daylighting and active ventilation.

From 10 to 90% **increases** 51 kWh/(yr.m²) (14%).

Cells characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, VSA 90° (i.e. no shading) and HSA ± 90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

South From 10 to 40% **reduces** 28 kWh/(yr.m²) (13%).

Cells characteristics: heavy fabric, clear glazing, 3 m deep, low ceiling, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and natural ventilation.

From 10 to 40% m **increases** 54 kWh/(yr.m²) (19%).

Cells characteristics: light fabric, clear glazing, 3 m deep, high ceiling, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

From 10 to 70% **reduces** 24 kWh/(yr.m²) (11%).

Cells characteristics: heavy fabric, clear glazing, 3 m deep, low ceiling, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and natural ventilation.

From 10 to 70% **increases** 54 kWh/(yr.m²) (19%).

Cells characteristics: light fabric, clear glazing, 3 m deep, high ceiling, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

From 10 to 90% **reduces** 24 kWh/(yr.m²) (11%).

Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, VSA 90° (i.e. no shading) and HSA ±40°, low efficiency building services, use of daylighting and active ventilation.

From 10 to 90% **increases** 65 kWh/(yr.m²) (22%).

Cells characteristics: light fabric, clear glazing, 3 m deep, high ceiling, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

West From 10 to 40% **reduces** 26 kWh/(yr.m²) (12%).

Cell characteristics: light fabric, clear glazing, 3 m deep, high ceiling, VSA 60° and HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and natural ventilation.

From 10 to 40% **increases** 49 kWh/(yr.m²) (23%).

Cells characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), efficient building services, no use of daylighting and active ventilation.

From 10 to 70% reduces 30 kWh/(yr.m²) (14%).

Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, VSA 60° and HSA ±40°, efficient building services, use of daylighting and natural ventilation.

From 10 to 70% **increases** 93 kWh/(yr.m²) (36%).

Cells characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), efficient building services, no use of daylighting and active ventilation.

From 10 to 90% **reduces** 26 kWh/(yr.m²) (12%).

Cell characteristics: light fabric, clear glazing, 3 m deep, high ceiling, VSA 60° and HSA ±40°, low efficiency building services, use of daylighting and active ventilation.

From 10 to 90% **increases** 114 kWh/(yr.m²) (41%).

Cells characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), efficient building services, no use of daylighting and active ventilation.

Increase of VSA

North From 10° to 60° **reduces** 29 kWh/(yr.m²) (14%).

Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, WWR 70%, HSA ±40°, low efficiency building services, use of daylighting and natural ventilation.

From 10° to 60° **increases** 36 kWh/(yr.m²) (12%).

Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, WWR 70%, HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and active ventilation.

From 10° to 90° **reduces** 21 kWh/(yr.m²) (10%).

Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, WWR 40%, HSA ±40°, low efficiency building services, use of daylighting and natural ventilation.

From 10° to 90° **increases** 93 kWh/(yr.m²) (30%).

Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, WWR 70%, HSA ±90° (i.e. no shading), efficient building services, use of daylighting and enthalpic control.

East From 10° to 60° **reduces** 10 kWh/(yr.m²) (5%).

Cell characteristics: heavy fabric, clear glazing, 6 m deep, high ceiling, WWR 70%, HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and natural ventilation (previously discussed in Fig. 4-28, page 206).

From 10° to 60° **increases** 25 kWh/(yr.m²) (9%).

Cell characteristics: light fabric, clear glazing, 3 m deep, high ceiling, WWR 70%, HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

From 10° to 90° **reduces** 11 kWh/(yr.m²) (5%).

Cell characteristics: heavy fabric, clear glazing, 9 m deep, high ceiling, WWR 40%, HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and natural ventilation.

From 10° to 90° **increases** 59kWh/(yr.m²) (26%).

Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, WWR 70%, HSA ±90° (i.e. no shading), efficient building services, no use of daylighting and active ventilation.

South From 10° to 60° **reduces** 13 kWh/(yr.m²) (6%).

Cell characteristics: heavy fabric, clear glazing, 6 m deep, high ceiling, WWR 70%, HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and natural ventilation.

From 10° to 60° **increases** 12 kWh/(yr.m²) (5%).

Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, WWR 40%, HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting and enthalpic control.

From 10° to 90° **reduces** 26 kWh/(yr.m²) (13%).

Cell characteristics: heavy fabric, clear glazing, 9 m deep, high ceiling, WWR 40%, HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and natural ventilation.

From 10° to 90° **increases** 28 kWh/(yr.m²) (10%).

Cell characteristics: light fabric, clear glazing, 9 m deep, high ceiling, WWR 70%, HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting and enthalpic control.

West From 10° to 60° reduces 3 kWh/(yr.m²) (51%).

Cell characteristics: heavy fabric, clear glazing, 9 m deep, high ceiling, WWR 10%, HSA ± 10°, low efficiency building services, use of daylighting and natural ventilation.

From 10° to 60° increases 54 kWh/(yr.m²) (18%).

Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, WWR 70%, HSA ± 40°, low efficiency building services, no use of daylighting and active ventilation.

From 10° to 90° does not reduce energy consumption, however it remains the same.

Cell characteristics: light fabric, clear glazing, 6 m deep, low ceiling, WWR 40%, HSA ± 90° (i.e. no shading), low efficiency building services, use of daylighting and natural ventilation.

From 10° to 90° increases 115 kWh/(yr.m²) (32%).

Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, WWR 70%, HSA ± 40°, low efficiency building services, no use of daylighting and active ventilation.

Increase of HSA

North From $\pm 10°$ to $\pm 40°$ **reduces** 11 kWh/(yr.m²) (6%).
Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, WWR 70%, VSA 40°, low efficiency building services, use of daylighting and natural ventilation.

From $\pm 10°$ to $\pm 40°$ **increases** 21 kWh/(yr.m²) (8%).
Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, WWR 40%, VSA 90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

From $\pm 10°$ to $\pm 90°$ **reduces** 8 kWh/(yr.m²) (4%).
Cell characteristics: heavy fabric, clear glazing, 6 m deep, high ceiling, WWR 40%, VSA 60°, low efficiency building services, use of daylighting and natural ventilation.

From $\pm 10°$ to $\pm 90°$ **increases** 109 kWh/(yr.m²) (33%).
Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, WWR 70%, VSA 60°, low efficiency building services, use of daylighting and active ventilation.

East From $\pm 10°$ to $\pm 40°$ **reduces** 2 kWh/(yr.m²) (1%).
Cell characteristics: light fabric, clear glazing, 3 m deep, high ceiling, WWR 70%, VSA 60°, low efficiency building services, use of daylighting and natural ventilation.

From $\pm 10°$ to $\pm 40°$ **increases** 20 kWh/(yr.m²) (8%).
Cell characteristics: light fabric, clear glazing, 3 m deep, high ceiling, WWR 70%, VSA 60°, low efficiency building services, no use of daylighting and active ventilation.

From $\pm 10°$ to $\pm 90°$ **reduces** 11 kWh/(yr.m²) (5%).
Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, WWR 70%, VSA 90° (i.e. no shading), low efficiency building services, no use of daylighting and natural ventilation.

From $\pm 10°$ to $\pm 90°$ **increases** 72 kWh/(yr.m²) (23%).
Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, WWR 70%, VSA 90° (i.e. no shading), low efficiency building services, no use of daylighting and natural ventilation.

South From $\pm 10°$ to $\pm 40°$ **reduces** 5 kWh/(yr.m²) (3%).
Cell characteristics: light fabric, clear glazing, 3 m deep, high ceiling, WWR 40%, VSA 90° (i.e. no shading), low efficiency building services, use of daylighting and natural ventilation.

From $\pm 10°$ to $\pm 40°$ **increases** 15 kWh/(yr.m²) (6%).
Cell characteristics: light fabric, clear glazing, 3 m deep, high ceiling, WWR 70%, VSA 90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

From $\pm 10°$ to $\pm 90°$ **reduces** 14 kWh/(yr.m²) (7%).
Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, WWR 70%, VSA 60°, low efficiency building services, use of daylighting and natural ventilation.

From $\pm 10°$ to $\pm 90°$ **increases** 62 kWh/(yr.m²) (22%).
Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, WWR 70%, VSA 90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

West From $\pm 10°$ to $\pm 40°$ **reduces** 11 kWh/(yr.m²) (5%).

Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, WWR 40%, VSA 60°, low efficiency building services, use of daylighting and natural ventilation.

From $\pm 10°$ to $\pm 40°$ **increases** 33 kWh/(yr.m²) (13%).

Cell characteristics: light fabric, clear glazing, 3 m deep, high ceiling, WWR 70%, VSA 60°, low efficiency building services, no use of daylighting and natural ventilation.

From $\pm 10°$ to $\pm 90°$ **reduces** 6 kWh/(yr.m²) (3%).

Cell characteristics: heavy fabric, clear glazing, 6 m deep, high ceiling, WWR 40%, VSA 10°, low efficiency building services, use of daylighting and natural ventilation.

From $\pm 10°$ to $\pm 90°$ **increases** 116 kWh/(yr.m²) (31%).

Cell characteristics: heavy fabric, clear glazing, 3 m deep, high ceiling, WWR 70%, VSA 60°, low efficiency building services, no use of daylighting and active ventilation.

Fabric

North Light cell consumes 15 kWh/(yr.m²) (5%) less than heavy.

Cell characteristics: with 3 m deep, high ceiling, clear glazing, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and natural ventilation.

Heavy cell consumes 19 kWh/(yr.m²) (7%) less than light.

Cell characteristics: with 3 m deep, high ceiling, clear glazing, WWR 10%, VSA 60° and HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

East Light cell consumes 12 kWh/(yr.m²) (5%) less than heavy.

Cell characteristics: with 3 m deep, high ceiling, clear glazing, WWR 90%, VSA 10° and HSA ±40°, low efficiency building services, no use of daylighting and active ventilation.

Heavy cell consumes 14 kWh/(yr.m²) (6%) less than light.

Cell characteristics: with 6 m deep, high ceiling, clear glazing, WWR 70%, VSA 60° and HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and enthalpic control.

South Light cell consumes 12 kWh/(yr.m²) (6%) less than heavy.

Cell characteristics: with 3 m deep, low ceiling, clear glazing, WWR 40%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and natural ventilation.

Heavy cell consumes 4% or 8 kWh/(yr.m²) less than light.

Cell characteristics: with 6 m deep, high ceiling, clear glazing, WWR 70%, VSA 60° and HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and natural ventilation.

West Light cell consumes 28 kWh/(yr.m²) (11%) less than heavy.

Cell characteristics: with 3 m deep, low ceiling, green glazing, WWR 90%, VSA 10° and HSA ±40°, low efficiency building services, use of daylighting and active ventilation.

Heavy cell consumes 10 kWh/(yr.m²) (6%) less than light.

Cell characteristics: with 3 m deep, high ceiling, green glazing, WWR 10%, VSA 60° and HSA ±90° (i.e. no shading), efficient building services, no use of daylighting and enthalpic control.

Ventilation

North Natural ventilation consumes 64 kWh/(yr.m²) (32%) less than active ventilation.

Cell characteristics: heavy fabric, 3 m deep, high ceiling, clear glazing, WWR 70%, VSA 90° (i.e. no shading) and HSA ±40°, efficient building services and no use of daylighting.

Enthalpic controls consume 46 kWh/(yr.m²) (22%) less consumption than active ventilation.

Cell characteristics: heavy fabric, 3 m deep, high ceiling, clear glazing, WWR 70%, VSA 60° and HSA ±90° (i.e. no shading), efficient building services and no use of daylighting.

East Natural ventilation consumes 73 kWh/(yr.m²) (30%) less than active ventilation.

Cell characteristics: light fabric, 3 m deep, high ceiling, clear glazing, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), efficient building services and no use of daylighting.

Enthalpic controls consume 37 kWh/(yr.m²) (20%) less than active ventilation.

Cell characteristics: heavy fabric, 3 m deep, high ceiling, clear glazing, WWR 70%, VSA 60° and HSA ±90° (i.e. no shading), efficient building services and no use of daylighting.

South Natural ventilation consumes 53 kWh/(yr.m²) (28%) less than active ventilation.

Cell characteristics: light fabric, 3 m deep, high ceiling, clear glazing, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), efficient building services and no use of daylighting.

Enthalpic controls consume 38 kWh/(yr.m²) (24%) less than active ventilation.

Cell characteristics: heavy fabric, 9 m deep, high ceiling, clear glazing, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), efficient building services and no use of daylighting.

West Natural ventilation consumes 102 kWh/(yr.m²) (33%) less than active ventilation.

Cell characteristics: light fabric, 3 m deep, high ceiling, clear glazing, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), efficient building services and no use of daylighting.

Enthalpic controls consume 44 kWh/(yr.m²) (18%) less than active ventilation.

Cell characteristics: heavy fabric, 9 m deep, high ceiling, clear glazing, WWR 70%, VSA 60° and HSA ±90° (i.e. no shading), efficient building services and no use of daylighting.

Glazing

North Green glazing consumes 160 kWh/(yr.m²) (36%) less than clear.

Cell characteristics: with heavy fabric, 3 m deep, high ceiling, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

Clear glazing consumes 19 kWh/(yr.m²) (10%) less than green.

Cell characteristics: with heavy fabric, 3 m deep, high ceiling, WWR 70%, VSA 60° and HSA ±40°, low efficiency building services, use of daylighting and natural ventilation.

East Green glazing consumes 127 kWh/(yr.m²) (33%) less than clear.

Cell characteristics: with heavy fabric, 3 m deep, high ceiling, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

Clear glazing consumes 13 kWh/(yr.m²) (6%) less than green.

Cell characteristics: with heavy fabric, 3 m deep, high ceiling, WWR 70%, VSA 60° and HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and natural ventilation.

South Green glazing consumes 62 kWh/(yr.m²) (21%) less than clear.

Cell characteristics: with light fabric, 3 m deep, high ceiling, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

Clear glazing consumes 25 kWh/(yr.m²) (12%) less than green.

Cell characteristics: with light fabric, 3 m deep, low ceiling, WWR 40%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, use of daylighting and natural ventilation.

West Green glazing consumes 193 kWh/(yr.m²) (39%) less than clear.

Cell characteristics: with light fabric, 3 m deep, high ceiling, WWR 90%, VSA 90° (i.e. no shading) and HSA ±90° (i.e. no shading), low efficiency building services, no use of daylighting and active ventilation.

Clear glazing consumes 10 kWh/(yr.m²) (3%) less than green.

Cell characteristics: with light fabric, 3 m deep, low ceiling, WWR 70%, VSA 10° and HSA ±10°, low efficiency building services, use of daylighting and natural ventilation.

Use of daylight

The proper use of daylight to save energy from artificial lighting system usually has some benefit on the overall building performance, which varies from nothing to a maximum, as it follows:

North Daylighting saves 66 kWh/(yr.m²) (24%).
Cell characteristics: with heavy fabric, 3 m deep, high ceiling, clear glazing, WWR 70%, VSA 60° and HSA $\pm 90°$ (i.e. no shading), low efficiency building services and natural ventilation.

East Daylighting saves 66 kWh/(yr.m²) (25%).
Cell characteristics: with heavy fabric, 3 m deep, high ceiling, clear glazing, WWR 70%, VSA 60° and HSA $\pm 90°$ (i.e. no shading), low efficiency building services and natural ventilation.

South Daylighting saves 65 kWh/(yr.m²) (26%).
Cell characteristics: with light fabric, 3 m deep, high ceiling, clear glazing, WWR 70%, VSA 90° (i.e. no shading) and HSA $\pm 90°$ (i.e. no shading), low efficiency building services and natural ventilation.

West Daylighting saves 54 kWh/(yr.m²) (20%).
Cell characteristics: with heavy fabric, 3 m deep, high ceiling, clear glazing, WWR 70%, VSA 10° and HSA $\pm 90°$ (i.e. no shading), low efficiency building services and natural ventilation.

Building services

The efficient building services always improve the energy efficiency of the cells.

North Building services save 170 kWh/(yr.m²) (47%).
Cell characteristics: with heavy fabric, 3 m deep, high ceiling, clear glazing, WWR 70%, VSA 60° and HSA $\pm 90°$ (i.e. no shading), use of daylight and natural ventilation.

East Building services save 150 kWh/(yr.m²) (48%).
Cell characteristics: with heavy fabric, 3 m deep, high ceiling, clear glazing, WWR 70%, VSA 90° (i.e. no shading) and HSA $\pm 90°$ (i.e. no shading), no use of daylight and natural ventilation.

South Building services save 120 kWh/(yr.m²) (47%).
Cell characteristics: with heavy fabric, 3 m deep, high ceiling, clear glazing, WWR 70%, VSA 90° (i.e. no shading) and HSA $\pm 90°$ (i.e. no shading), no use of daylight and natural ventilation.

West Building services save 155 kWh/(yr.m²) (47%).
Cell characteristics: with heavy fabric, 3 m deep, high ceiling, clear glazing, WWR 90%, VSA 60° and HSA $\pm 90°$ (i.e. no shading), no use of daylight and natural ventilation.

4.3.4 Hierarchy

As previously presented, each of the parameters simulated has a maximum variation. It means that the design decision may lead to such impact on the energy performance for areas that matches the cells analysed. For example, the adoption of an efficient building services instead of low efficiency ones in areas orientated to North may lead to a reduction of 47% or energy consumption (Table LI), bringing from 314 to 164 kWh/(yr.m²) or moving the classification from 3 to 5 stars.

Table LI. Order of influence of design decisions.

maximum variation in annual energy use											
North	**%**	$\frac{kWh}{m^2}$	**East**	**%**	$\frac{kWh}{m^2}$	**South**	**%**	$\frac{kWh}{m^2}$	**West**	**%**	$\frac{kWh}{m^2}$
building services	47	-170	building services	48	-150	orientation	87	-200	orientation	87	-200
WWR	41	+114	orientation	47	-110	building services	47	-120	building services	47	-155
room depth	39	+125	WWR	38	+115	ventilation	28	-53	WWR	41	+114
glazing	36	-160	glazing	33	-127	daylight	26	-65	glazing	39	-193
orientation	33	+148	ventilation	30	-73	WWR	22	+65	room depth	34	-146
HSA	33	+109	room depth	26	-64	HSA	22	+62	ventilation	33	-102
ventilation	32	-64	VSA	26	+59	glazing	21	-62	VSA	32	+115
VSA	30	+93	daylight	25	-66	room depth	24	-38	HSA	31	+116
daylight	24	-66	HSA	23	+72	VSA	13	-26	daylight	20	-54
ceiling height	12	+35	ceiling height	10	-23	ceiling height	6	-13	fabric	11	-28
fabric	7	-19	fabric	6	-14	fabric	6	-12	ceiling height	6	-18

4.3.5 Interface

The 36 864 combinations of models were firstly assessed in Microsoft Excel after considerable effort. The only viable alternative to play around with the combination is an interface and the most suitable alternative was to develop an interface in Microsoft Access. The parameters are organized in an order compatible with the architects' preference based on the survey (subchapter'Questionnaire', page 162), as shown in Fig. 4-29.

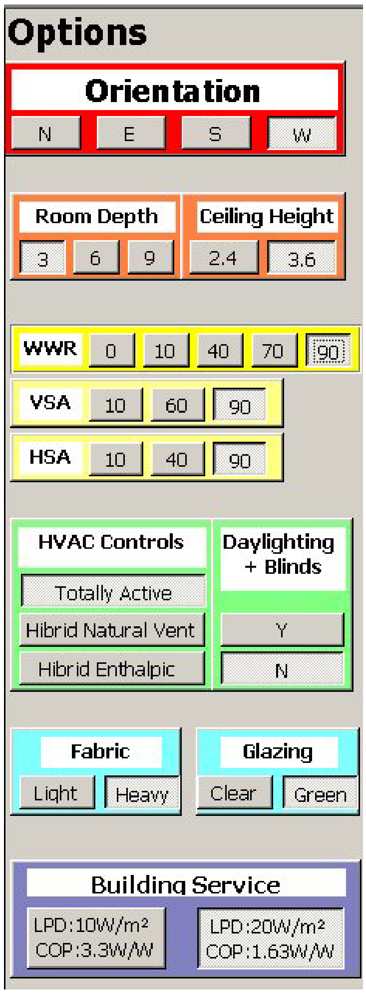
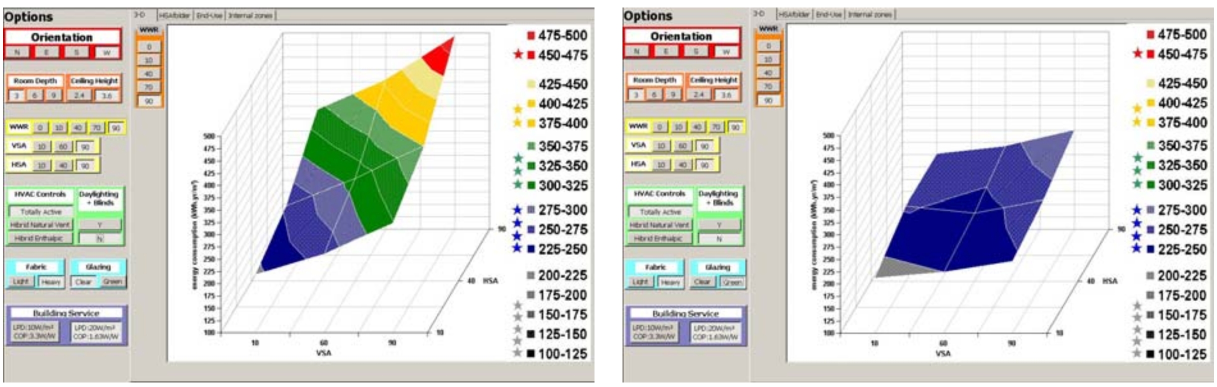


Fig. 4-29. Order of inputs.

So far, the interface has three different types of outputs available in three folders (Fig. 4-30). The intention is to illustrate the effect of vertical and horizontal external shading combination on the energy consumption under different configurations. For example, the chart 'A' concerns a cell with clear glazing and the available shadings may lead to a performance of cells between 1 and 4 stars. On the other hand, the same model with green glazing may lead to cells classified between 4 and 5 stars (B).



A) B)

Fig. 4-30. Study of interrelation of exterior shadings and the impact on total energy consumption.

In the second folder (Fig. 4-31), the influence of VSA and HSA are positioned side-to-side to compare the influence of the two types of shading: horizontal and vertical. In the first charter, VSA is kept constant while the HSA varies in the abscissa. The second chart has a constant HSA while the VSA varies in the abscissa These charts are recommended to assess the balance of daylighting and thermal loads, i.e., the savings of artificial lighting due the use of daylighting and the thermal load by fenestration. For example, the second chart shows that increasing VSA for HSA 40° the energy consumption of lights decreases while the cooling consumption increases, however the optimum corresponds to VSA 60°.

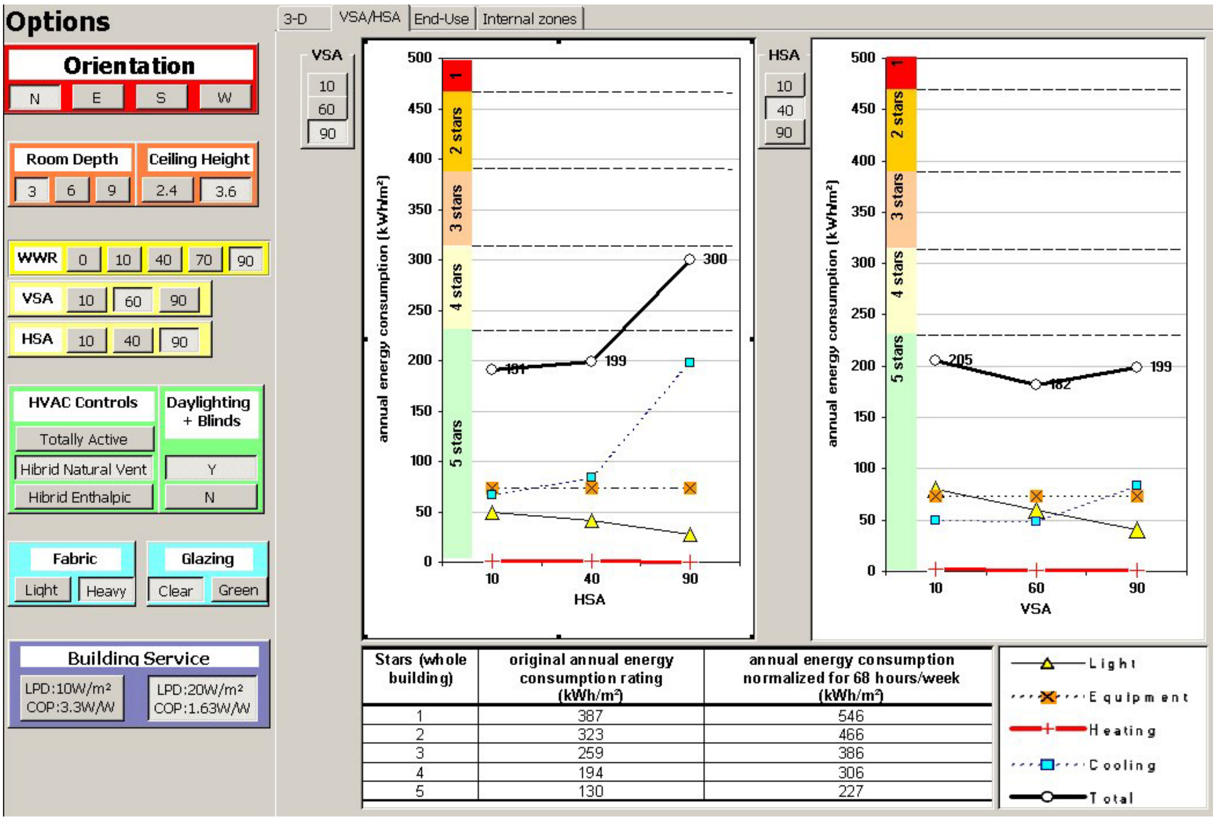


Fig. 4-31. Use of charts to assess the influence of exterior shading.

The third folder has the energy by end-use for the final choice of parameters, in absolute and percentage scales. For example, the chart ‘A’ of Fig. 4-32 shows a case with use of daylighting, which reaches 5 stars while ‘B’ reaches 4 stars, without use of daylighting.

A) B)

Fig. 4-32. Comparison of energy end-uses to assess the influence of using daylighting.

Despite some obstacles inherent to the software and my limited skills, the interface allows anyone to browse the combinations after a short introduction to its operation. This interface is assumed to be a prototype, which is intentionally flexible to vary according to the research development. There is an expectation to convince some partnership to develop the interface to emphasize the use of graphics during the input, replacing the numbers with more intuitive dialogue.

4.3.6 Observations, comments and conclusions

Intermediate orientations

The comparison of energy consumption for façades to North (Fig. 4-33), Northwest (Fig. 4-34), West (Fig. 4-35), Southwest (Fig. 4-36) and South (Fig. 4-37) shows that orientations other than North, East, South and West are not proportional to the interpolation of the data. For example, Northwest is more similar to North than to West. Southwest is more similar to West than to South. Consequently, intermediate orientations deserve more studies and if assessed using this database, the uncertainties must be recognized.

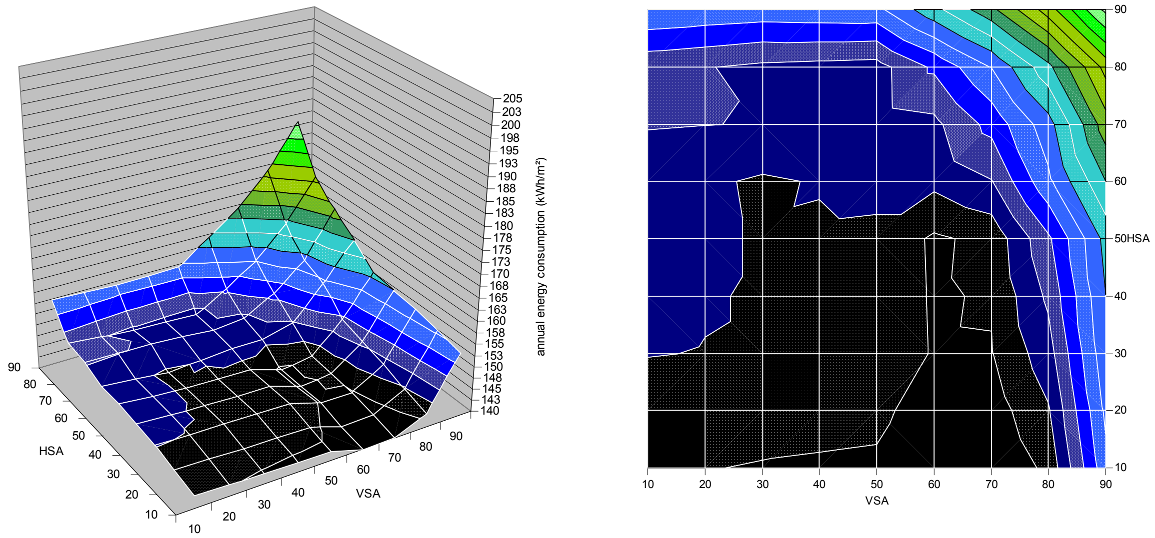


Fig. 4-33. Relation of exterior shading for North.

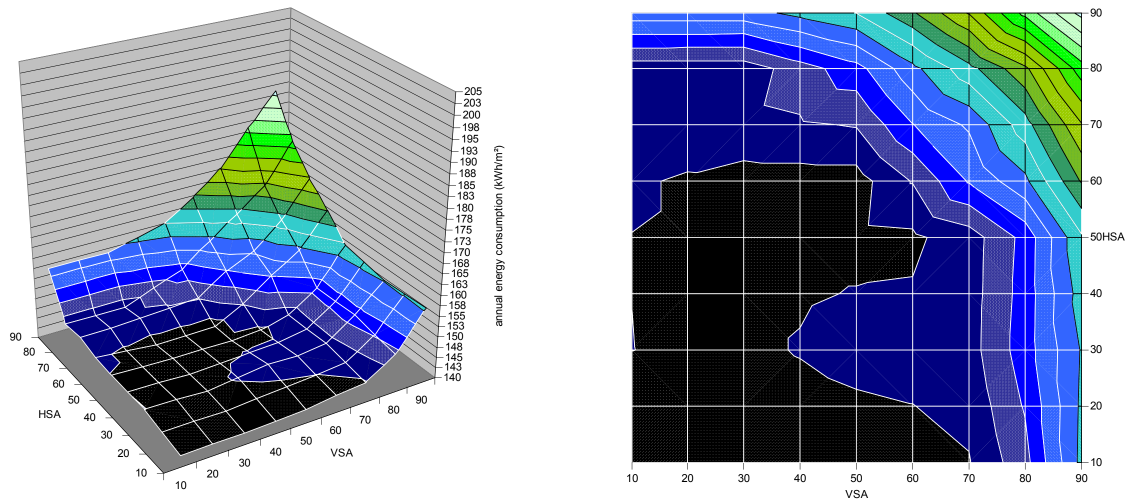


Fig. 4-34. Relation of exterior shading for Northwest.

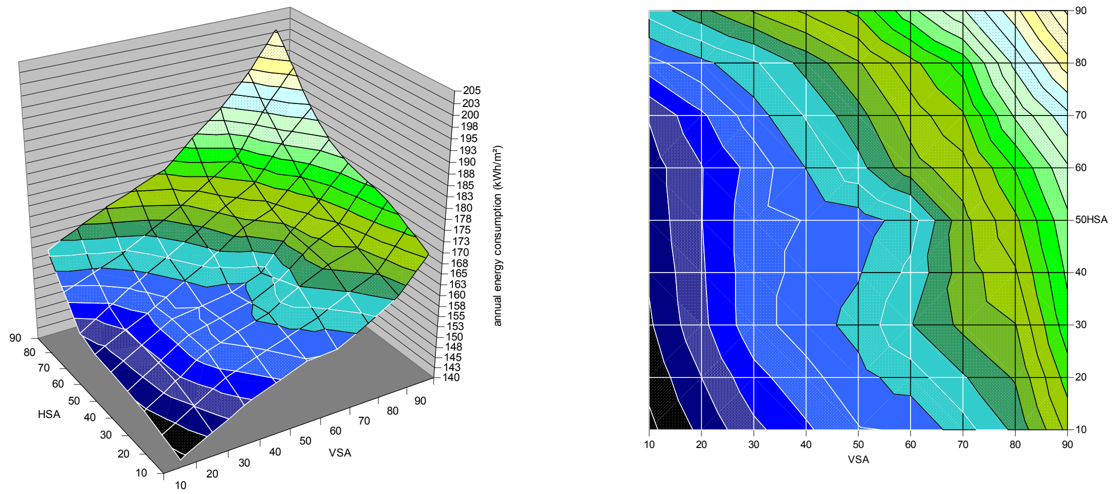


Fig. 4-35. Relation of exterior shading for West.

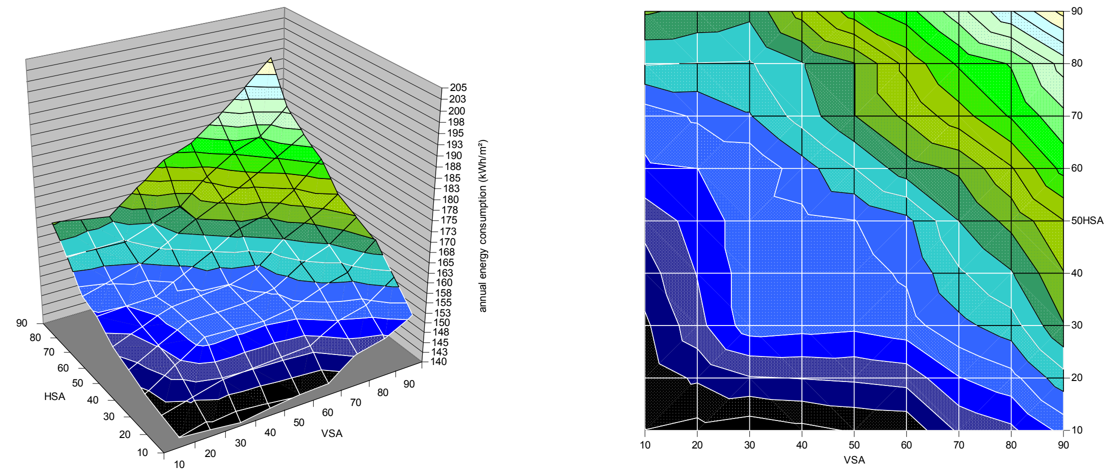


Fig. 4-36. Relation of exterior shading for Southwest.

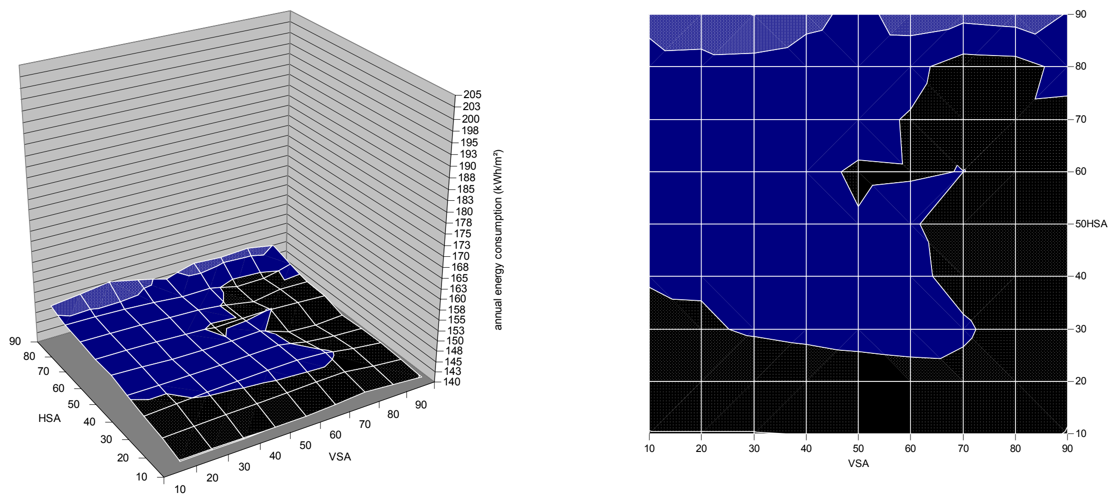


Fig. 4-37. Relation of exterior shading for South.

Different climates

As discussed, the performance of buildings in warm climates is highly sensitive to the balance of thermal and light savings and consequently to the climate characteristics. The influence of climate is easily observed on the relation between VSA and HSA for cells orientated to North with 3m depth and WWR 70% for five different locations. Each climate is plotted in two different charts in Fig. 4-38 to Fig. 4-42: one in perspective 3-D and other in 2-D plan view. Each colour or line of level corresponds to a variation of 5 kWh/(yr.m²).

- For Brisbane, the energy consumption varies from 140 to 180 kWh/(yr.m²) and the angles have a significant influence for VSA above 50° and HSA above 30°. The best combinations are concentrated in one zone (plan tone) and occur with HSA below 50° and VSA below 80°.

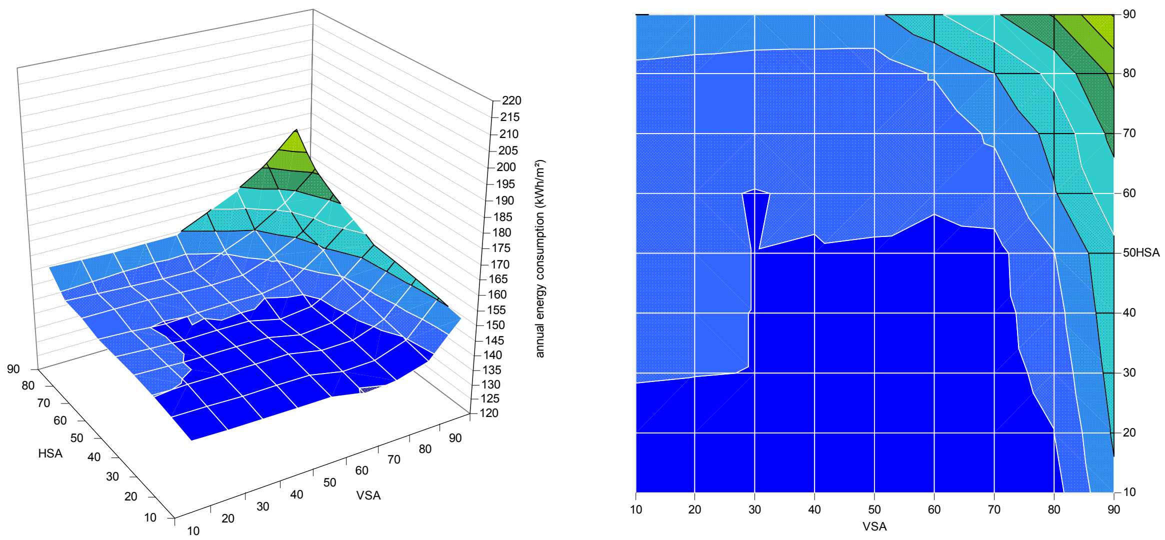


Fig. 4-38. Influence of exterior shading for Brisbane.

- With a variation similar to Brisbane, the energy consumption of Darwin varies from 185 to 226 kWh/(yr.m²). The combination of angles is more critical than for Brisbane. The angles are critical for VSA and HSA above 80° and the best combinations are VSA between 30° and 70° with HSA approximately 70°, for VSA approximately 60° and HSA below 60° and for HSA below 20°.

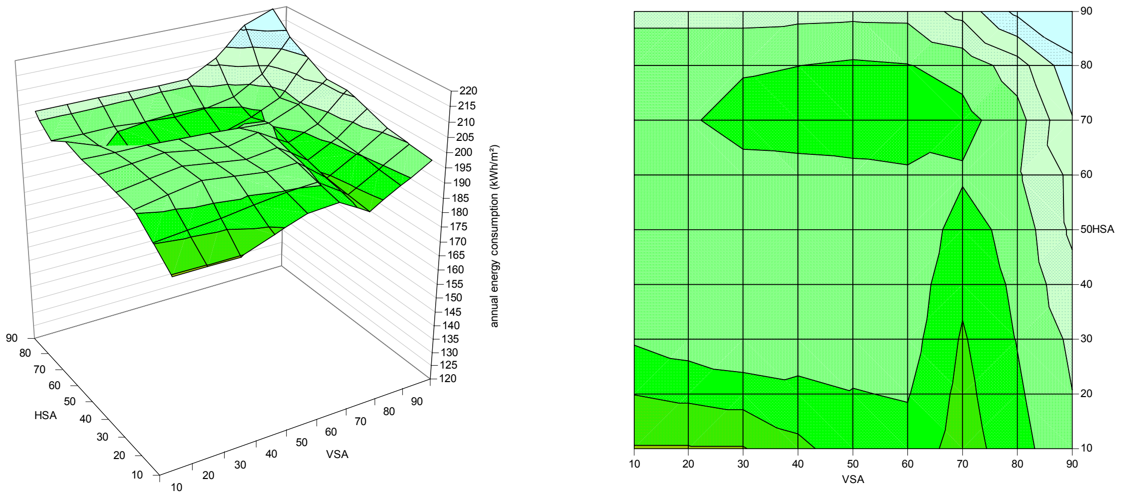


Fig. 4-39. Influence of exterior shading for Darwin.

- For Kuala Lumpur – a climate frequently referenced in Yeang's book – the variation is only 19 kWh/(yr.m²), occurring between 186 and 205 kWh/(yr.m²). The lowest energy consumption occurs for VSA approximately 70° and HSA between 80 and 70° and for HSA below 20° and VSA below 80°. The critical combinations are for no exterior shading (angles close to 90°) and for HSA approximately 30° and VSA below 30°.

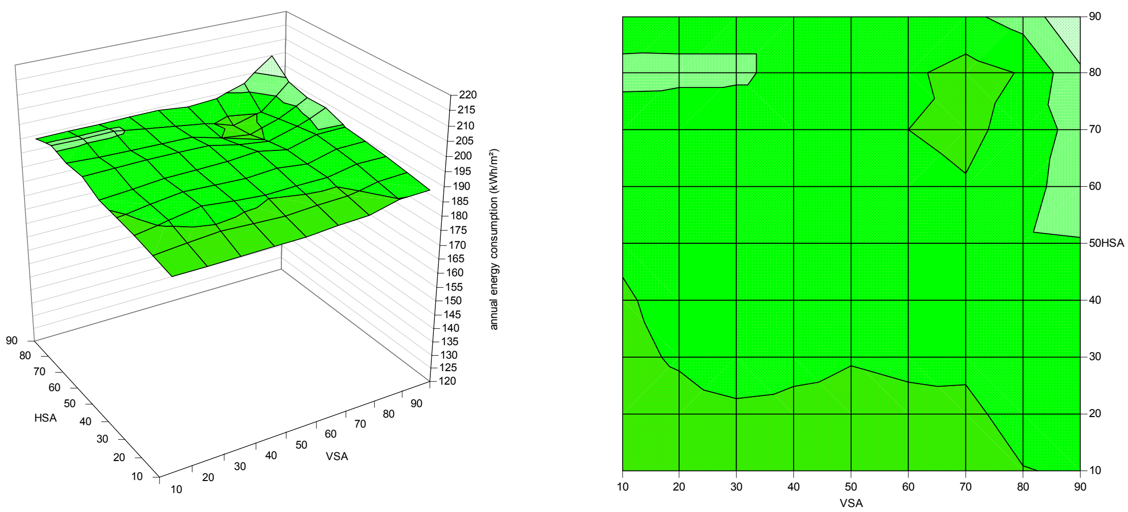


Fig. 4-40. Influence of exterior shading for Kuala Lumpur.

- For Sydney, the range is between 130 and 165 kWh/(yr.m²) and for Melbourne, the range is between 126 and 146 kWh/(yr.m²). The best combinations of exterior shading for both climates are very much different those for Brisbane.

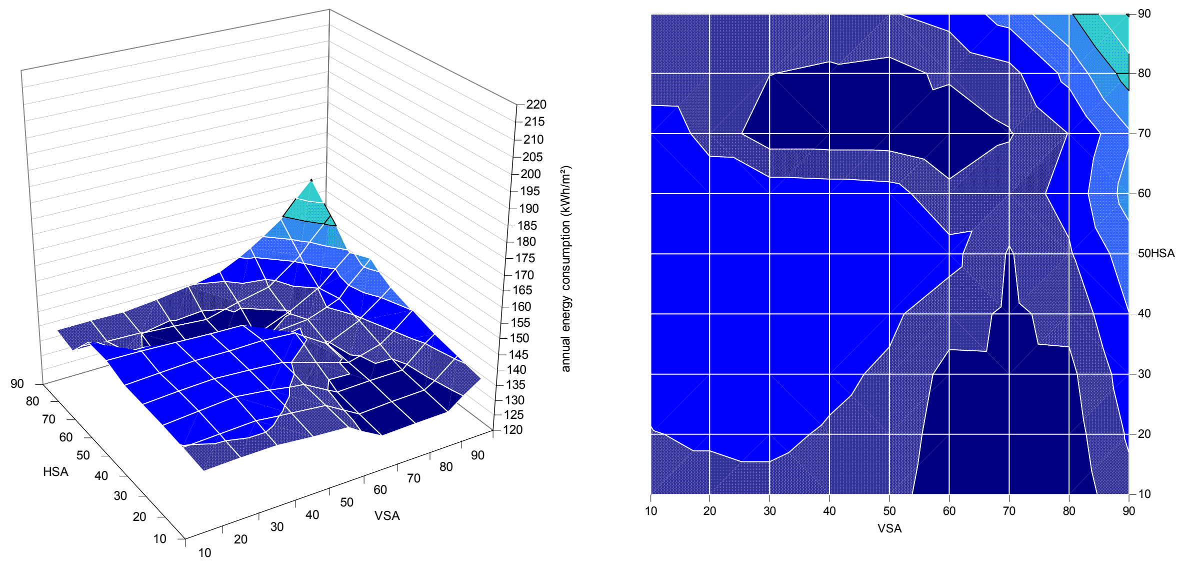


Fig. 4-41. Influence of exterior shading for Sydney.

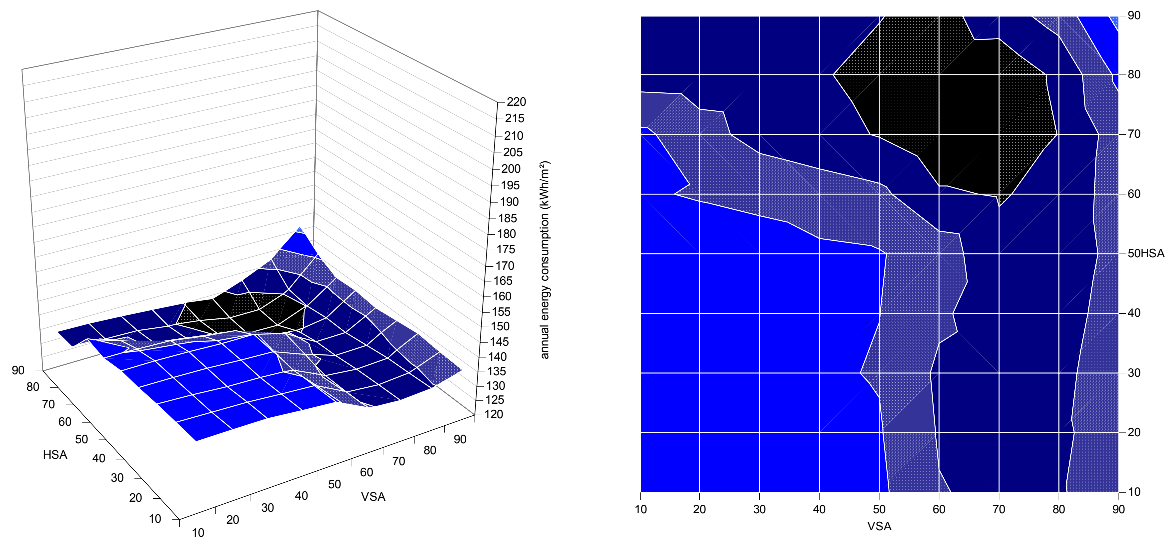


Fig. 4-42. Influence of exterior shading for Melbourne.

Internal zones

The estimate of energy consumption of internal zones is necessary to compare different building volumes with different internal layouts and to classify zones in terms of active or hybrid as discussed in subchapter 'Shape', page 103. Therefore these cells are considered adiabatic, i.e. without thermal transfer through the walls and without solar radiation. The thermal loads are basically internal gains and thermal loads from air renewal and infiltration. The energy consumption for a low efficiency building services and for an efficient building services produced cells with 4 and 5 stars (Fig. 4-43). The results are similar to the cells without windows, which indicates how intense are the exterior thermal loads associated with fenestration.

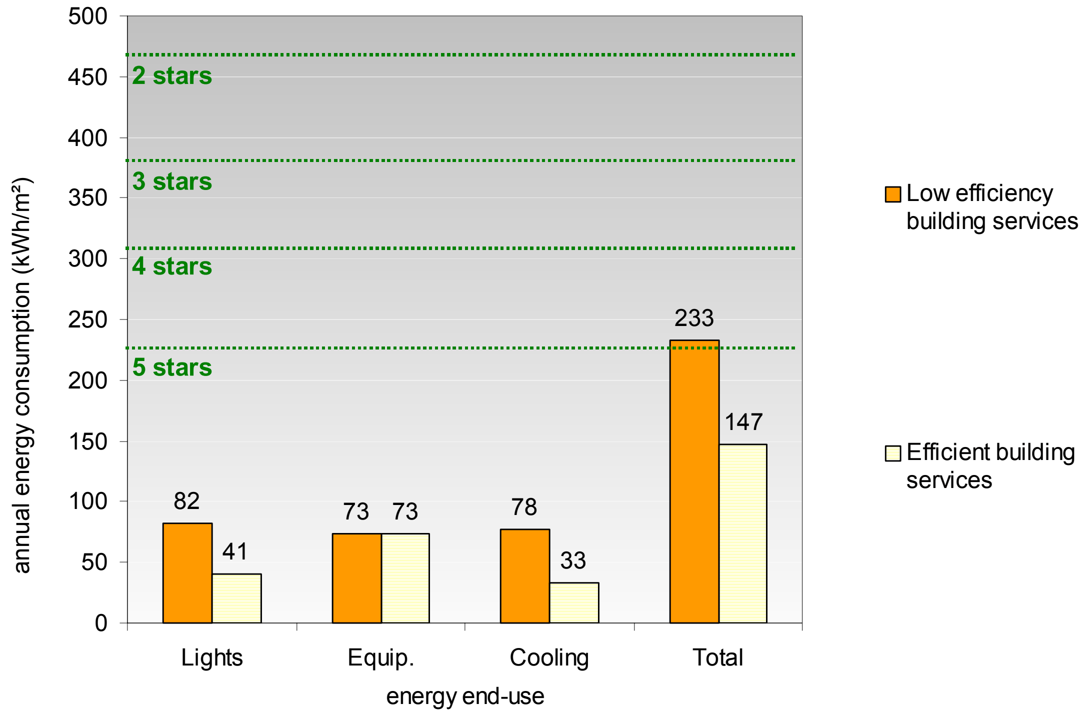


Fig. 4-43. Energy consumption for adiabatic internal cells with two different building services.

Database application

The database/interface is a tool to support the design decisions in the early stages and nothing further. The assessment of complex designs and real buildings involves so many variables and expertise that only few software packages can cope. Furthermore, the assumptions that support the models of the database are also a limitation:

1. Building services dramatically influence the energy performance and every building has its own combination which is certainly different from the parameters adopted in the database formulation. Then, it is a rough approximation to model a real case with the two options of the database: efficient and low efficiency building services.
2. The energy consumption of internal cells may be apparently too optimistic for some experts in building performance. However it is important to recall that the separation from perimeter zones is adiabatic, the model has rational schedules of occupancy and an adaptative model is used for the cooling set point:
    - increasing the weekday occupancy by one hour in the internal cell model increases the energy consumption by 6% of (based on complementary simulations);
    - decreasing the cooling set point to 21°C in the internal cell the energy consumption increases by 9% (based on complementary simulations).
3. Cities with similar climate during some seasons or with apparently slight difference in the climate classification (Fig. 4-44) may have drastically different energy performance (subchapter ‘Different climates’, page 227). Due to the high influence of solar thermal loads, extrapolations of the database to other cities must consider aspects such as latitude and sky characteristics.

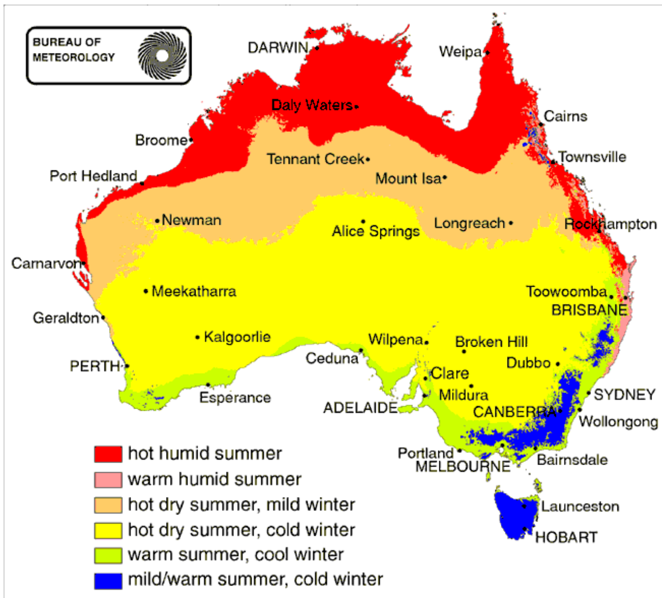


Fig. 4-44. Main climatic zones of Australia (based on temperature and humidity) (Bureau of Meteorology 2000).

Check of principles and guidelines

The ‘worst’ performance of cells greatly varies with orientation, however the ‘best’ performances are very close (Table LII). Consequently, some of the ‘principles’ discussed in subchapter ‘Design principles and guidelines’ (page 39) such as ‘core position’ (Fig. 3-28 and Fig. 3-29) become too simplicistic to deal with such rich subject. Although it helps to avoid bad practice, unfortunately it provides the wrong idea that the design solutions are so restrictive or so predictable.

Table LII. Extreme performances for different orientations.

	North	East	South	West
maximum (kWh/(yr.m²))	444	388	297	494
minimum (kWh/(yr.m²))	125	132	130	132

In general, shading is good if daylighting is not considered as a strategy to save energy. On the contrary, the definition of shading requires careful analysis: increasing HSA can reduce 7% or increase 31% of energy consumption (depends of other variables). It is similar for glass type: replacing clear glazing by green, the savings reach 39%, while the opposite can save 12%.

The architectural variables may cause reduction or increase of energy consumption, as detailed in the subchapter ‘Maximum changes in energy consumption: report’ (page 206). The maximum variations are:

- **ceiling height**: the increase of ceiling height (2.4 to 3.3. m) can save 10% of energy while the reduction (3.3 to 2.7 m) can save 17%;
- **room depth**: increasing the room depth (3 to 9 m), the savings can reach 34% while reducing the room depth (9 to 3m) can save 34%;
- **WWR**: increasing WWR (10 to 70%) the savings can reach 14% while reducing the WWR (90 to 10%) can save 41%;
- **VSA**: increasing VSA (10° to 60°) the savings can reach 14% while reducing VSA (90° to 10°) can save 32%.

The use of structural thermal mass was not assessed in the parametric analysis (the variation of thermal mass concerned only the walls). However, the use of light fabric instead of heavy can save 11% of energy while the opposite can save 7%.

One of the most common guideline or rule-of-thumb for North facades of buildings concerns the VSA for residential buildings, which is often used for non-residential buildings, although is not intended. The 90°-27°=63° VSA is for complete shading of equinox to allow some sun penetration in winter. This may not be needed in offices. The local residential code prescribes a maximum VSA 63° (Brisbane City Plan. 2000). In comparison, the application of the code to a cell with WWR 70% would bring the energy consumption from 181 (no shading) to 159 kWh/(yr.m^2) (Fig. 4-45 and Table LIII), although the minimum energy consumption would be 140 kWh/(yr.m^2) if vertical shading were to be used.

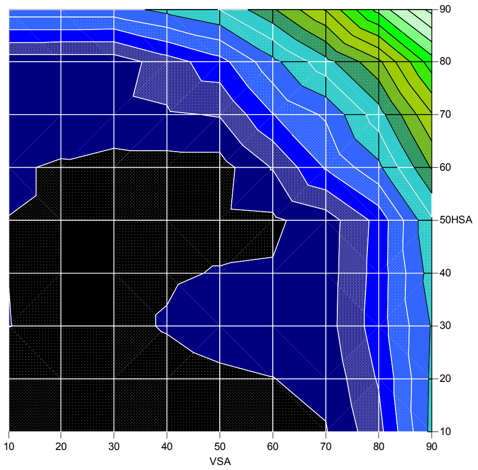


Fig. 4-45. Relation of exterior shading for Northwest.

Table LIII. Total annual energy consumption (kWh/(yr.m²)) for different combinations of VSA and HSA for a cell with WWR 70%.

HSA \ VSA	10°	20°	30°	40°	50°	60°	70°	80°	90°
10°	143	143	142	142	142	*140*	140	143	154
20°	144	144	144	143	143	*141*	141	145	155
30°	145	145	145	145	144	*142*	142	146	157
40°	146	145	145	145	144	*142*	143	148	157
50°	146	145	145	145	144	*142*	143	150	158
60°	146	145	145	145	146	*146*	147	154	163
70°	148	148	147	147	146	*147*	151	156	166
80°	148	148	147	147	146	*150*	155	162	171
90°	155	154	154	154	154	*159*	164	171	181

Using the database/interface, a similar cell with WWR 90% or clear glazing would indicate that absence of exterior shading would produce a zone with 2 stars[101]. Applying the residential code, the performance increased to 3 stars, however combining vertical shading the performance would increase to 4 or 5 stars (Fig. 4-46).

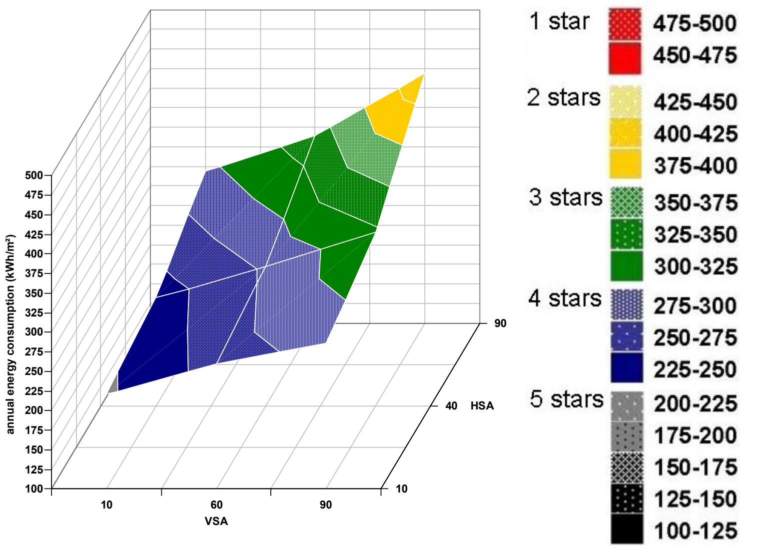


Fig. 4-46. Analysis of VSA 60° from residential codes if extended to office buildings.

[101] As described in the subchapter 'Star rating' (page 202), the relation of energy consumption to classificationis: 546 kWh/m² = 1 star, 466 kWh/m² = 2 stars, 386 kWh/m² = 3 stars, 306 kWh/m² = 4 stars and 227 kWh/m² = 5 stars (excellent building). These values are specific for Brisbane and for the characteristics of the models.

Despite of such influence on clear glazing, the same recommendation (VSA >63°) for Evergreen glazing has much lesser impact (Fig. 4-47). Actually, the choice of the glazing may be more effective than the exterior shading and both combined are even more effective.

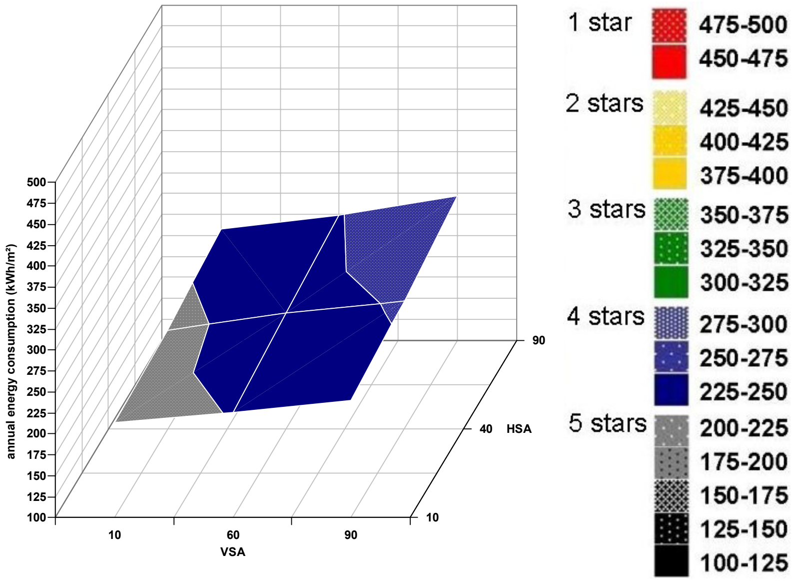


Fig. 4-47. Influence of exterior shading for green glazing.

In conclusion, the guideline is helpful if used in office buildings, it limits the achievements and constraints the solutions.

5 Conclusions

Obstacles to the use of energy tools

Experience with parametric analysis and case studies suggests that energy tools require a particular expertise, not just to operate them, but also to assess the results. Otherwise errors may be introduced into the analysis due to failures in the software ('bugs') and /or users' mistake.

The survey of the group and the cases studies confirm that architects generally use types of knowledge different from those required to operate energy tools[102]. The major preference is for intuition, simple and straight forward methods that can be easily assimilated. Experience drives the design decisions more than other factors. In contrast, the parametric analysis exposes how design decisions influence energy consumption and illustrates that it is impossible to predict the energy efficiency outcome of the interactions of design variables by intuitive methods.

Among the four groups surveyed, 'recognized architects' had demonstrated more awareness of their actions than the other groups and greater coherence of answers. They have the best understanding of the importance of architectural energy decisions and low energy strategies than the other three groups. Their approaches are far more compatible with design assessment. Intuition is still important for all of them, but other methods are also used.

The case studies show that lack of knowledge is an obstacle to the use of quantitative methods. Two case studies were characterized by assumptions based on 'principles' or experiences (both questionable), however when these architects were faced with basic discussions, they neither answered satisfactorily nor did they formulate clear questions. In other cases, the meetings had a didactic purpose. Furthermore, the only clear requirement from the architects was an assessment based on 'thumbs up' or 'thumbs down'. Basically, they showed little inclination to explore the potential of the support. This is contrary to the case study of Dr. Yeang and his team: they conducted the process with understanding (which is not a surprise) because they knew what they wanted. Despite being the author of many 'principles', he and his team posed strategic questions which could only be answered by parametric analyses facilitated by energy tools.

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[102] Similar observations were made during the design competition promoted by the Building Research Energy Conservation Support Unit: 'Architects slated for clichés and sustainable gimmicks' Taylor, D. (2001). "Architects slated for cliches and sustainable 'gimmicks'." Architects' Journal: 18.

The results of 'staff members' survey group matches the literature review, specifically the dichotomy of science & creativity (Szokolay 1980c). They produced the lowest response and interest among the four groups. The average results in each set of questions indicate that they are the last receptive professionals to make use of energy tools, despite the level of indicated commitment 3.5 (of 5). Based on additional observations of the academic environment of UQ, interaction with students, participation in meetings and lectures, the academics' preferences are strongly qualitative. This is apparently the case since 1992, as Dr.Szokolay no longer teaches in the undergraduate course. With very few exceptions such as the LTV method sponsored by Dr.Hyde and used only by him, 'rules-of-thumb' and 'principles' are the methods presented in lecture notes and in recent B.Arch. theses.

The results of case studies and of the survey are compatible with other observations: energy tools are being used during the detailing phase (if at all) by 'energy consultants'. Indeed, 'recognized' architects name the 'integration with other professionals' as the second most important task during the detailing phase. Actually, it is unfair to believe that architects could do such tasks with similar results because it would require a comprehensive understanding: ranging from principles of heat transfer to the operation of building services. However, architects could use 'energy tools' in earlier phases if they were able to simplify the analysis and identify the influential variables. Although some critics may argue that a 'shoe box' is not enough to represent a building, such abstraction is acceptable and may be necessary when the building geometry is not yet defined. The issue is to compare alternatives and test specific ideas. In many cases, the most common alleged obstacles to using energy tools are specific to the detailing phase. The following points are arguable:

- **limited graphic visualization**: in fact, many software packages do have resources of CAD compatible with the level of detail during these stages;
- **lack of easy visualization of output**: in fact, software packages have energy consumption as the major output (other outputs are available based on user's preference), and it is compatible with the simplest codes and energy ratings;
- **user unfriendly**: in fact, VisualDOE is an example of a friendly application, although it requires training (as any software requires) and knowledge, basic enough not be misunderstood as unfriendly;
- **cumbersome data input and time consumed**: in fact, if the user is able to select the important variables, modelling and simulation may only take few minutes (as the models used in the parametric analysis took).

Based on the results and previous experience, the recommendations to make energy tools more suitable for early stages are:

1. Optimise defaults. Many software packages assume automatic values for the models, such as schedules of occupancy, characteristics of air conditioning, properties of building components and others.
2. Regionally standardise defaults. This makes the tools compatible with the region, as done with the selection of characteristics of buildings in Brisbane.
3. Classification of outputs based on local rating. As done with the parametric analysis, which made use of the star rating for Brisbane.
4. The 3D CAD system used should be orientated to sketching. Instead of accuracy, the geometry modelling could emphasize the flexibility of inputs.
5. Automatic parametric analysis. The definition of parameters variation, minimum and maximum could be facilitated through specific features in the softwares. Instead of creating a model for each variation, the software could do this automatically.
6. Low energy strategies listed to guide parametric analysis[103].

Besides the improvement of energy tools, it is necessary to clarify the potential use of them. Architects should be introduced to these methods during their education and academics should offer more tools for those who decide for an environmentally committed design. Furthermore, energy tools are extremely useful for didactic purposes.

The reasons for ignoring energy tools by architects suggest that research in the energy tools and relative methods may be a quixotic[104] [105] [106]enterprise. There is no possible feature in tools that can substitute the lack of knowledge and change attitudes of architects. Although tools may be improved, they will be wasted if professionals ignore basic elements of building

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[103] Energy 10 should be used as a good example for futures developments.

[104] Introduction' s background image: 'Title page of the first illustrated edition Brussels'; Research Methods' background image: 'battle of the Knight and the Windmills'; Results' background image: 'Arthur Boyd Houghton's representation of the Don'. Images in Practice (2002). LECTURE:Don Quixote, The Narrative, Images in Practice. **2002**.;

[105] Literature review's background image: 'Don Quixote', Picasso, P. Don Quixote, Art.com. **2002**.;

[106] Conclusions' background image: Security Awareness Posters (2002). Don Quixote and Sancho Panza, Security Awareness Posters. **2002**.

energy behaviour and scientific methods. Hopefully, a design shift to include scientific approach may be finally triggered by the mandatory codes.

Method for energy consumption assessment during the early stages of design

Based on the literature review, previous experiences with LTV development, relationship with architects[107], survey, cases studies and parametric analysis, the prototype database/interface was developed these major concerns:

1. '*what is required is a design tool that can quickly assess a sketch scheming in terms of energy implications and, more importantly, is transparent and educative so that the designer is aware of the consequences of the design decisions'* (Steemers 1994);
2. '*If the procedure takes more than 10 or 15 minutes then it simply won't be used'* (Mazria 1980);
3. assessment of results from parametric analysis' simulations;
4. to represent the approach that I would provide, as energy consultant, to architects during the briefing and early design stages (such as the case study with Dr. Yeang);
5. offering a tool more accessible to architects than the ones available to quantify of impact of design decisions.

The prototype has the following characteristics:

1. **Compatible with architects' knowledge**. It demands a level of expertise equivalent to what 'principles' or 'rules-of-thumb' required to operate. It summarises the most important architectural design decisions, low energy strategies and types of building services, by reduction to a few comprehensive variables.
2. **Compatible with 'energy consultants'**. The parametric analysis is based on parameters and variables carefully chosen from the most recent and influential publications, thus becoming a reference for further energy consultancy.
3. **Sequencing of design decisions**. The button lay-out is based on the average preference found in the survey. Considering that many architects do not have an order of preference, the prototype is flexible enough to be used in any order.

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[107] Such as discussion of students' thesis, participation of weekly sessions in the RAIA to discuss the Brisbane City Council energy codes, presentations and other meetings.

4. **Outputs**. The results are quantified in annual total and end-use energy consumption per area. Instead of 'thumb-up' or 'thumbs-down', the energy star rating provides an up to date classification to the design.
5. **Fast feedback**. Fundamental questions, such as made by Dr. Yeang's team are solved in seconds.
6. **Didactic mode**. Browsing the database, it is possible to explore how variables are interrelated and consequently to improve the understanding of how energy consumption of buildings is influenced by the design decisions. Consequently, it is expected that architects evolve their own guidelines and 'principles' compatible with their practice and preferences.

The database/interface has limitations such as visualization and integration with other software. However, these constraints also exist on methods such as 'principles' and 'rules-of-thumb'. Consequently, the prototype is not much more incompatible with architects' practice than the most common methods used at present.

Architects' influence

Design decisions about the efficiency of building services are very common in practice. They are compatible with energy assessment in later stages and, most importantly, they can improve the building performance from 183 to 50 kWh/(yr.m²). Considering that each star corresponds to approximately 80 kWh/(yr.m²), there is a potential to be improve as much as three stars with efficient building services. For example, a West cell with 2 stars or 396 kWh/(yr.m²) can be improved to 5 stars or 213 kWh/(yr.m²). Obviously, building services can be used as 'patching' over bad designs. Furthermore, buildings labeled as 'energy efficient' may lead to misunderstanding if the reasons for the 'energy' achievements are not clear. Suspicion emerged during a series of visits to efficient buildings in Brisbane: some of then had efficient building services but questionable envelopes and low energy strategies. If building behaviour is not seriously understood, the reproduction of architectural features may become a serious misapplication of such features of supposed benefit.

Table LI (page 221) in chapter 4 shows that the maximum influence of building services on energy consumption is higher than isolated architectural design decisions (Table LI, page 221), however the combination of architectural variables are more influential: it can save up to 72% of energy consumption or 354 kWh/(yr.m²). Table LIV illustrates that even for South orientation, architectural design decisions can save more energy than the efficiency of air conditioning and artificial lighting.

Table LIV. Architectural variables x building services.

maximum variation											
North	%	kWh/m²	**East**	%	kWh/m²	**South**	%	kWh/m²	**West**	%	kWh/m²
architectural variables	69	306	architectural variables	64	247	architectural variables	53	157	architectural variables	72	354
building services	47	170	building services	48	150	building services	47	120	building services	47	155

Given that architectural variables are so influential, it can be confirmed that qualitative methods are too limited in comparison with methods based on quantification. For example, recommendations for zones with green glass windows are significantly different to those with clear glass. The variation of energy consumption is not linear with variations of VSA and HSA. In other words, it is more complex to define guidelines for these situations than provide a quantitative tool.

5.1 Suggestion of future developments

There are three groups of suggestion with different levels of complexity for further developments.

Prototype development

As previously mentioned, the prototype has a series of constraints that can be avoided to match other architects' preference. Most of them requires expertise from other disciplines such programming and feedback from architects based on the applicability of the method. The opportunities are:

1. replacement of the numerical inputs by graphics aiming at a more intuitive interface, i.e. the windows geometry could be defined through a schematic drawing rather than a numerical window ratio;
2. graphic visualization of the variable combinations, i.e. the facades could be visualized with appropriate exterior shading, window area, ceiling height and type of glass;
3. inclusion of best practices to the database, i.e. complex exterior shading could be available in the database;
4. inclusion of case study in the database for comparisons.

CAD linked to the database

This proposition consists of a simplified CAD for sketch drawing, which would be linked with the database. Then, the prediction of the energy consumption would be updated at each alteration in the geometry. For example, changing the window size, the tool would find in the database a specific case to match that drawn. The logic would be same of a manual plan zoning and classification in hybrid zones and active zones.

Energy tool with emphasis in parametric analysis.

The process of modelling and simulation demanded considerable manual effort. From the creation of thousand of models to the analysis of the results, the management of so many files and information demonstrated highly susceptibility to mistakes. The introduction of specific features for this purpose in energy tools would make parametric analysis faster, more reliable and more accessible. For example, the manual procedure of creating a model for each value (correspondent to the variable in analysis) should be replaced by an option, which would define the intended values of this specific variable, such as extreme values and intervals of variation. Then, the software would automatically create the models and run them, for each of the possible permutations. The results could be reported with base on statistical treatment and represented in charts, similarly to the prototype database/interface.

6 Appendix

6.1 Appendix A. Design process questionnaires.

Indicate what importance you attribute to the following methods during the three main stages of the design process:	pre-design Low Medium High ← →	schematic Low Medium High ← →	detailing Low Medium High ← →
Use of intuition, experience or/and human feel	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Established techniques and proven solutions	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Rules, routines and methods previously tested	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Pictorial precedents (what the building is going to look like), such as in periodicals and books	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Following earlier designs (tested), learning from case studies	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Use of guidelines and rules-of-thumb	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Rational or scientific thinking, based on prior analyses	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
'Lateral' thinking (searching for different ways to solve problems, avoiding dominant and established ideas)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Hypotheses followed by test	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Breaking down problems into smaller parts	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Development of alternative solutions for elimination/ combination	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Diagrams, charts and mathematical models	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Volumetric (3-D) thinking	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Plan (2-D) thinking	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Integration with other consultant professionals	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Considering the 'meaning' of the building itself for the client, architect, occupants and the surrounding environment	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Consideration of the impact of the design on interior conditions (e.g. light and thermal) and its interaction with the occupants	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Dominance of a central idea (an 'organizing principle) that influences the whole design conception	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

Indicate when and what intensity you attribute to the following design decisions	pre-design Low Medium High ← →	schematic Low Medium High ← →	detail Low Medium High ← →
building volume	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
building orientation	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
envelope geometry	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
interior layout	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
components proprieties (elements of construction, such as wall, roof, floor, etc)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
fenestration characteristics such as glazing, overhangs, side fin,	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
artificial lighting systems	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
air conditioning systems	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

6.2 Appendix B. Questionnaire for low energy design process.

What is the importance of the energy performance of your product (design), in relation to the other variables, such as function, aesthetics, context, cost, etc)?	1 2 3 4 5 Low Medium High
If you assess the energy performance of your design (prediction), please indicate at which phase(s)?	
❑ *conceptual or pre-design* ❑ *schematic* ❑ *detailing or development* ❑ *conclusion*	
What climate type(s) are you designing for? ❑ *Hot* ❑ *Warm* ❑ *Temperate* ❑ *Cool temperature*	
What design (yours or some other architect) would you identify as representative of your production? (location of the building or reference in books or articles)	

Mark (☑) the climatic information and sources that you use to support you design decisions

source of data	maps	visit to the site	statistical analysis	hourly-annual data	Monitoring
temperature	❑	❑	❑	❑	❑
humidity	❑	❑	❑	❑	❑
solar radiation	❑	❑	❑	❑	❑
wind	❑	❑	❑	❑	❑
microclimate	❑	❑	❑	❑	❑

If you use some of the following tools, what is their importance in your view ?	**pre-design** Low Medium High	**schematic** Low Medium High	**detail** Low Medium High
Olgyay's Bioclimatic chart	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Szokolay's CPZ or 'psychometric' chart method	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Givoni's 'building bioclimatic chart'	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Mahoney tables	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
'principles'	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Guidelines and rules-of-thumb	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Case studies	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Modelling (wind tunnel, water table, solarscope)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
software packages (indicate):	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

What importance do you attribute to the following strategies?	**pre-design** Low Medium High	**schematic** Low Medium High	**detailing** Low Medium High
building orientation	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
building form	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
facade geometries	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
exterior shading (windows)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
thermal insulation	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
thermal mass effect	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
passive solar heating	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
landscape (microclimate manipulation)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
daylighting	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
natural ventilation	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
artificial ventilation	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
efficient air conditioning	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
efficient artificial lighting	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

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