ENVIRONMENT DESIGN GUIDE

EVALUATING ADVANCED FACADE SYSTEMS FOR COMMERCIAL BUILDINGS

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SUMMARY OF

ACTIONS TOWARDS SUSTAINABLE OUTCOMES

Environmental Issues/Principal Impacts

- In recent times the multiple roles played by the facade in providing natural daylight, enhancing visual and improving thermal performance has come to the fore.
- Integrated design is integral to achieving an energy efficient and sustainable building. Optimising the facade performance is critical to achieving this outcome.
- Using an integrated approach to design active or intelligent buildings offers the potential to redistribute capital costs from the mechanical services into an advanced facade. This would result in lower operating costs over the life of the building.

Basic Strategies

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

- Stakeholders should prioritise project imperatives in a set of key performance indicators.
- Suggested key performance indicators are Annual Energy Performance, Thermal Comfort, Visual Comfort, Life Cycle Cost, Embodied Energy, Maintainability, Reflectivity, Acoustic Performance.
- Develop design while balancing performance levels for each key performance indicator according to agreed priority ranking.
- Once the facade is optimised, other systems can be configured and integrated into the building as a whole.

Cutting EDGe Strategies

- Select type of facade required for project, from static, active and intelligent, and design to this requirement.
- Static facades are fixed. Active facades are controlled, and can be integrated with other systems, i.e., environmental control system to provide natural ventilation. Intelligent facades have self learning capacity.
- Design the facade to integrate active control for thermal and visual comfort performance, ventilation control and acoustic response.
- Ventilation control is critical to mixed mode operation.
- Use state-of-the-art analyses techniques to assist the design team in selecting and optimising a facade. Where appropriate, these studies would be carried out for perimeter areas adjoining the facades.

Synergies and References

- Environmental rating schemes for buildings in Australia and internationally
- Information from the International Energy Agency Tasks – see www.iea.org and www.ecbcs.org
- GEN 57 – *A Guide to Environmental Design and Assessment Tools*
- TEC 10 – *Emerging Technologies in Building Envelopes*
- DES 2 – *Energy Efficiency in Commercial Buildings*
- DES 12 – *Perceived Comfort*
- DES 21 – *An introduction to Building Energy Performance Software*
- PRO 3 – *The Energy Impact of Windows in Building Design*

EVALUATING ADVANCED FACADE SYSTEMS FOR COMMERCIAL BUILDINGS

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1.0 INTRODUCTION

Proponents of energy efficiency and sustainability in the built environment have always understood the importance of the facade as a key element for a building to achieve these aims. In recent times the multiple roles played by the facade in providing natural light, enhancing visual amenity and improving thermal comfort has come to the fore. This is in no small measure due to improvements in technology being achieved at low costs. A number of international and local buildings have demonstrated the effectiveness of a facade to resolve aesthetic priorities against performance requirements. These buildings stand apart from others in part because of the level of detail in the resolution of the facade, and it's integration with the other building systems. Some examples are:

1. **APICORP Offices, DEGW, Al Khobar, Saudi Arabia (Hawkes, Forster & Arup, 2002)**
   A three-level deep plan building in a harsh desert climate. Direct solar gain prevented from facade by elegantly designed sunshades. Controlled daylight ingress through facades and roof.
2. **Eastgate, Pearce Partnership, Harare, Zimbabwe (Hawkes, Forster & Arup, 2002)**
   A nine-level passively cooled commercial building in a warm and sunny climate. Deep overhangs on north and south facades shade the glazing. Air supply at the facade sill via a concrete underfloor plenum. Stack driven exhaust from offices, and atrium venting. Solar hot water system. Daylight linked perimeter lighting.
3. **GSW HQ, Sauerbruch & Hutton, Arup, Berlin, Germany (Wigginton & Harris, 2002)**
   22-storey commercial building, naturally ventilated for 70% of the year. The facade plays a critical role in controlling ventilation. Perimeter lights are controlled by daylight levels.
4. **City Gate, Petzinka Pink und Partner, Dusseldorf, Germany (Wigginton & Harris, 2002)**
   Mixed mode 20-storey commercial building with a double skin, cavity wall facade. Retractable venetian blinds in the cavity provide solar control, BMS control of flaps in facade, atrium vents and manual control of internal windows combine for an effective ventilation strategy.

In a recent study that developed a rating system for sustainable facades, Thomas et al (2004) identified eight key performance indicators for sustainable facades: Annual Energy Performance, Thermal Comfort, Visual Comfort, Life Cycle Cost, Embodied Energy, Maintainability, Acoustic Performance, and Reflectivity. Qualitative descriptors (for example Excellent, Good, Average and Poor) based on quantitative performance ranges for the key performance indicators were developed.

For each project, stakeholders are urged to agree on a qualitative target level for each key performance indicator, as a way of prioritising competing demands. Suggested stakeholder prioritisation using this method for two projects is shown below, with stakeholders nominating minimising greenhouse gas emissions as critical for one project, and minimising life cycle cost for the other.

In this note we will only consider the analysis of a facade design from the standpoint of an integrated approach seeking superior performance in the areas of Thermal and Visual Comfort and Annual Energy Performance. It is assumed that details in other areas of sustainability are addressed elsewhere.

Facades can be static, active or intelligent (Wigginton & Harris, 2002) in their response to the external environment. Static facades have fixed elements, and could be a compromise solution. Commercial buildings with static facades need energy systems to control internal comfort parameters, due to varying diurnal conditions. Temperature, humidity (in critical applications), lighting levels, dilution and removal of pollutants, and fresh air replacement are maintained by energy systems, generally using non-renewable forms of energy. Such facades may be said to exhibit a climate rejecting approach.

Criteria	Priority on minimising greenhouse gas (or annual energy use)	Priority on minimising life cycle cost
Annual energy or CO_2	Excellent	Good
Thermal comfort	Very good	Very good
Visual comfort	Very good	Very good
Life cycle cost	Medium	Excellent
Embodied energy	Medium	Medium
Maintainability	High complexity	Low
Reflectivity	Excellent	Good
Acoustic performance	Acceptable	Acceptable

Table 1. Performance matrix to arrive at a consensus for facade selection priorities

Active facades go one step further and work with, rather than against, the local climate. Elements are actively controlled to accept or reject solar radiation, daylight, and air (ventilation) as required. The environmental control system is integrated with the functioning of the active facade with pre-programmed control algorithms.

Intelligent facades are active facades with self-learning capability. The environmental control system learns from the building's response to different ambient conditions, and adjusts algorithms to better control the building.

2.0 INTEGRATED DESIGN APPROACH

The skin of a building is the first interface between the external and internal environments. It presents a unique opportunity for the design team to impact on comfort parameters, in a way that reduces dependence on other energy consuming systems that provide heat, coolth, airflow, and light. This line of thinking leads to an outside-to-inside design imperative, i.e. an approach wherein the facade system is optimised before all other energy systems, (HVAC, electrical lighting and hydraulic systems) of the building are designed.

While the roof is an important heat flow path in buildings that have a large footprint with respect to their total floor area, it is the vertical facade that can play the major role in control of indoor environmental conditions for multi-storey buildings.

In addition to its impact on energy use, the design of the facade influences visual and thermal comfort and the psychological well-being of the occupants. Comfort can be understood as a function of temperature and humidity levels, indoor air quality, air movement, lighting quality, and acoustic response of a space. A well-lit, comfortable work environment has been linked with increased productivity and reduced absenteeism (refer to EDG note DES 2 Energy Efficiency in Commercial Buildings).

Using an integrated approach to design active or intelligent buildings also offers the potential to redistribute capital costs from mechanical services into an advanced facade. This would result in lower operating energy costs over the life of the building. Such an approach will be strengthened if the life cycle cost for the building was the same as, or lower than that of a conventional building, with the additional advantage of higher internal environmental quality providing some productivity gain.

Notwithstanding the above, when assessed purely in economic terms, it is often difficult to justify the use of innovative/advanced facades given the low energy prices prevalent in Australia. However, projections of increasing energy prices coupled with the increased incidence of extreme temperatures and consequent escalation in peak energy demand can change the economic argument in favour of an advanced building facade.

Attention to the environmental design of the building envelope, and particularly the facade, has received a further impetus with the uptake of Australian building rating tools such as Green Star, NABERS (National Australian Built Environment Rating System), and ABGR (Australian Building Greenhouse Rating) that provide a degree of holistic evaluation of sustainability and energy efficiency. Details of rating tools can be found in BDP *Environment Design Guide* (EDG) note GEN 57 – A Guide to Environmental Rating and Assessment Tools.

3.0 OPTIMISING FACADE PERFORMANCE

In order to achieve a high performance building it is necessary to adopt an integrated design philosophy. The design may be developed through a classic multi-variate optimisation analysis, where the variables are building systems that impact performance in tangible and intangible ways. Optimisation is not linear, but an iterative process which includes reviews at critical points between concept design and building delivery.

The integrated design philosophy requires a number of key performance criteria to be tested and optimised simultaneously. This can only be achieved by dynamic simulation analysis. This section reviews such techniques.

Based on the outside to inside optimisation approach, design options for the facade are evaluated first. The transparent portion of the facade should be optimised to limit solar heat gain while admitting the appropriate amount of visible light. Acoustic, thermal comfort, visual comfort and air quality parameters also need to be reviewed and prioritised. Selected facade options then need to be tested for their relative energy use characteristics. Once the facade is optimised, other systems can be configured and integrated into the building as a whole.

3.1 Facade analysis

The following sections describe state-of-the-art analysis techniques to assist a design team in selecting and optimising a facade. Where appropriate, these studies would be carried out for perimeter areas adjoining the facades.

3.1.1 Shadow animations

These are investigations of shadows cast during sunshine hours on the building, by itself, and by surrounding obstructions, for summer and winter solstices, and for the equinox. The analysis helps to identify critical facade shading requirements to limit solar gain while maintaining adequate daylighting.

These animations show the changing shadows and quickly identify zones that might be particularly uncomfortable for a few hours in the day. This allows the designer to deal with the problem using an array of facade treatments. It also gives the mechanical engineer advance warning of zones that may need special requirements.

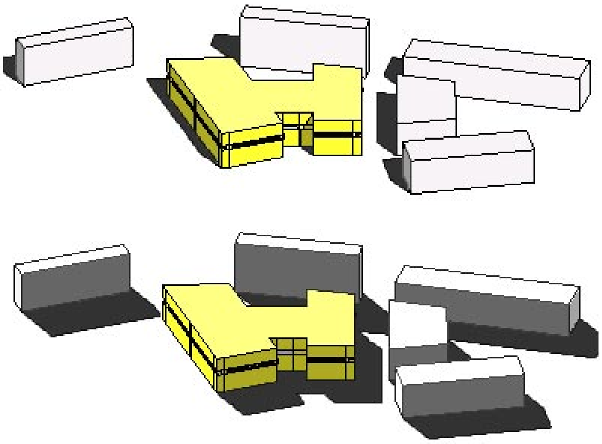

Figure 1. Shows two frames from a shadow animation at 9:00am and 4:00pm

3.1.2 Sun penetration animations

Sun penetration animations are used to understand the travel of sun patches within floor plates that adjoin each facade. In conjunction with the external shadow animations, it gives a complete understanding of the response of a facade to the sun. These animations are particularly useful when testing the impact of light redirecting devices, external and internal shading devices, and hi-lite windows.

Figure 2 is a frame from an animation of a north-facing facade with external overhang, light re-direction device and fritting on the lower panel. The frame shows light patches redirected to the ceiling, the depth of solar penetration on the floor, and the shadow effect of columns.

3.1.3 Blind occlusion analysis

Blind occlusion is a complex analysis, to determine the probability that blinds would need to be used by occupants, to manage issues of glare and thermal comfort. Results are given in the percentage of time, during hours of operation that the blinds need to be deployed, to provide glare free conditions in the space. Alternate facade designs should be tested for lowest blind occlusion statistics, so as to provide occupants with greater access to views.

Note that simplistic blind models will not provide realistic answers. More complex algorithms (Inoue et al, 1988) that account for blind usage based on research into occupant behaviour, and modified by sun penetration in a space should be used.

3.1.4 Daylight autonomy analysis

This is an annual simulation analysis to determine the percentage of time that perimeter areas of the floor plate can be day-lit. The results provide an estimate of potential reduction in electric lighting. Higher daylight autonomy numbers indicate that a well implemented, daylight linked electric lighting system, will provide higher lighting energy savings.

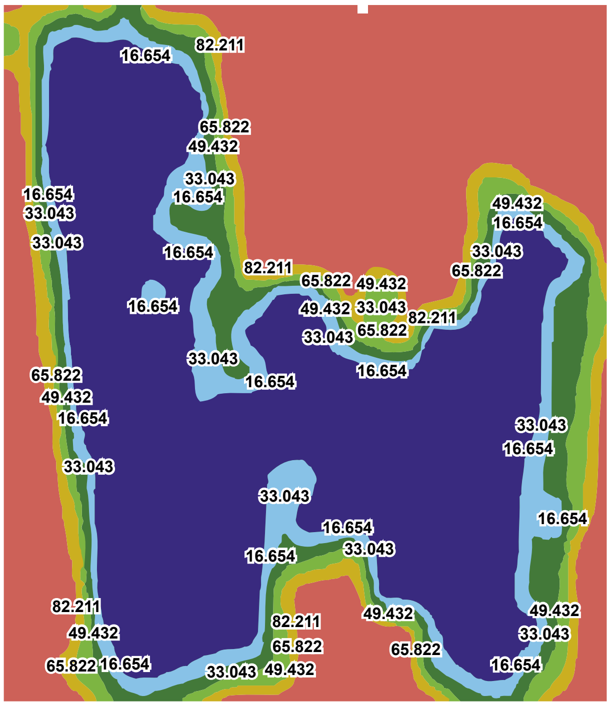

Figure 3. Contour map of the floor plate indicating the percentage of time that daylight can satisfy lighting requirements

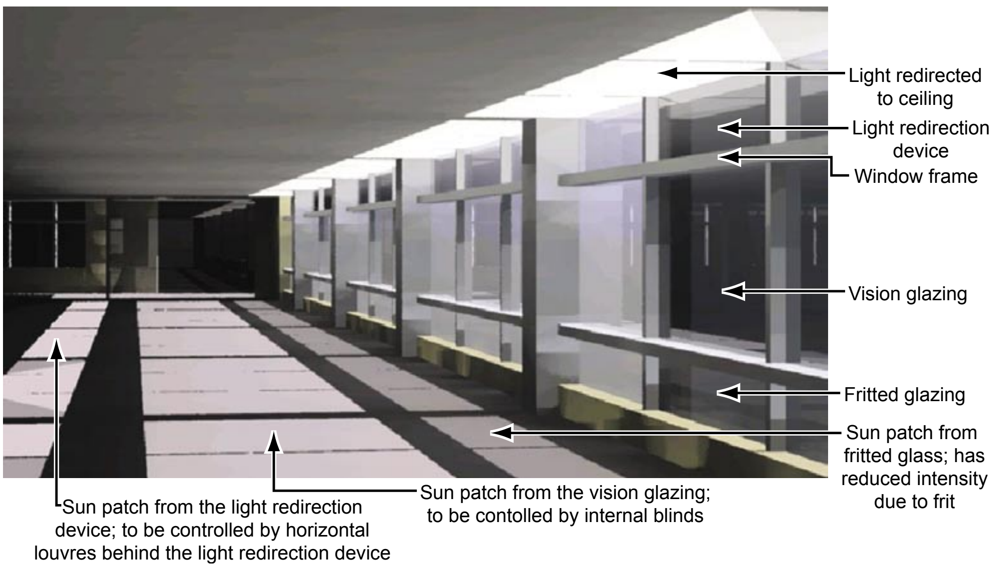

Figure 2. North-facing facade with external overhang (animated view)

Sun penetration, blind and daylight analysis should be carried out using verified lighting simulation software. RADIANCE is the premier software of this type, capable of accurately modelling complex environments, materials and lighting conditions. Shadow analysis should be carried out using verified programs that create visualisations using solar geometry.

3.1.5 Thermal comfort analysis

Thermal comfort, in terms of Predicted Mean Vote (PMV) or Percentage of People Dissatisfied (PPD), should be simulated in the perimeter areas adjoining the facades. Relative performance of alternative facade designs at peak times should be compared. This analysis should account for the impact of solar radiation impinging on the floor plate to obtain an accurate picture of hourly comfort variation.

3.1.6 Ventilation

The facade can be designed to control airflow through the floor plate in mixed mode buildings. A mixed mode building is designed to fall back on HVAC systems to maintain comfortable internal environmental conditions during peak summer and winter times. At other times, the building uses a natural ventilation strategy to maintain comfort. Openable elements in the facade can become critical for the control of comfort in the natural ventilation mode.

It is important to test that minimum airflow requirements are met under all weather conditions. CFD (computational fluid dynamics) analysis should be developed to test proof of concept. A dynamic thermal model that integrates bulk air simulation must be used to generate meaningful annual results under natural ventilation conditions. This will ensure that the impact of thermal storage in the structure and internal heat loads are properly accounted for.

3.1.7 Peak demand and energy use

A dynamic model simulation of a typical floor plate including all facades, and their attached perimeter zones, will provide comparative annual energy use and peak demand information between facade design alternatives. Innovative facades have the potential to mitigate peak cooling and heating requirements when compared with conventional buildings. An integrated design approach will capture this facade optimisation information in specifying smaller HVAC plant, and develop a system configuration to work in conjunction with the facade.

3.1.8 Maintenance and life cycle cost

An assessment of maintenance issues for alternative facade designs should be carried out to list relative merits. For example, the cost incurred for operable shading elements could be offset by an innovative design where overhangs double as access platforms for cleaning.

High performance buildings with longer economic time horizons can be attractive as BOOT (Build Own Operate Transfer) projects. Incorporating issues like facade maintenance in the project life cycle cost analysis can offer the opportunity to present the economic case for a higher performance facade. Clearly, operational and maintenance costs, as well as construction costs must be considered in tandem with capital costs for the best outcome.

3.1.9 Environmental impact of materials

Procurement procedures should be alerted to specifying materials with low environmental impact. Some tools are available to model the environmental and life cycle impact of materials selected on a project. EcoSpecifier (www.ecospecifier.org) can be used to select such materials. New tools like LCA-Design (CRC-CI, 2004) are being developed to test the impact of

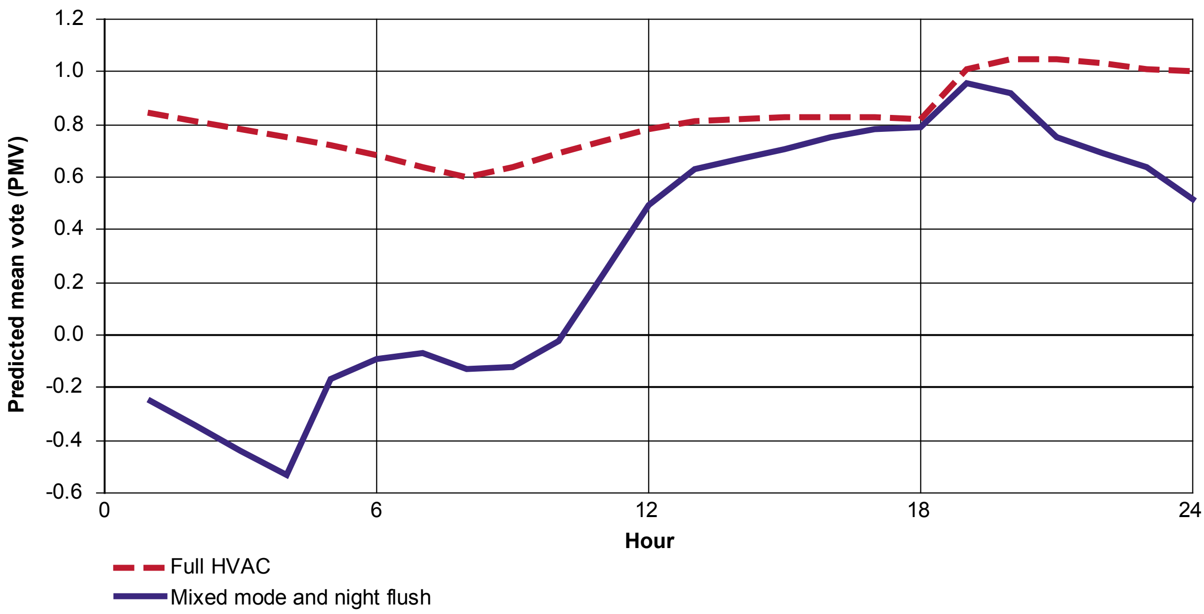

Figure 4. Variation of PMV in an air-conditioned space with and without night flush cooling. Note the effect on PMV in the early morning hours

Item	Value/discussion
Glazing properties (centre-of-glass values)	
Shading coefficient	<0.35; environmentally responsive buildings try to reduce loads through the facade by reducing solar load. Can also be achieved by using smaller, appropriately shaded, glass areas.
U-value	<2.0 W/m²-K; typical double glazed unit performance.
Visible Light Transmittance (Tvis)	30%<Tvis<50%; too much light can be a problem for workspaces with computer screens; this range is considered appropriate for most Australian climates.
External light reflectance	<20%; this value mandated by many councils as limiting value to mitigate disability glare.
Other items	
Opaque wall U-value	<0.5 W/m²-K; low values required to minimise cooling and heating peak demand, i.e. equipment size.
Facade openable area for natural ventilation	≈5% is a good initial value; to be optimised using dynamic simulation; consider flow resistance in the supply and exhaust paths carefully.
PMV in perimeter areas	±1.0 or less during most business hours; however, consider adaptive comfort conditions in naturally ventilated spaces.
Shading devices	External, adjustable shading will keep the sun's energy out, and let daylight in. Overhangs work best only on north orientation! A commercial building with typical internal loads requires cooling even in winter! Design shading to respond to winter situation as well!
Glazing vs shading	High performance glazing without external shading offers clean lines and cheaper maintenance. Adjustable external shading can provide similar performance, but with some increased maintenance.
Internal blinds	Use blinds to improve occupant comfort when direct sunshine penetrates onto floor plate.
Daylight integration	Use light redirection devices on high level windows. Review glare sources. Use light coloured ceilings to spread light away from windows.
Daylight linking	Install lights nearest the windows on a separate control circuit, to be controlled by photoelectric cells.
Mixed mode operation	Consider transitions between HVAC mode and natural ventilation mode operation. How will the control system interact between facade and HVAC systems?

Table 2. Considerations and best practise for selecting an advanced facade

alternative materials on a building's environmental performance. *EDG* note GEN 51 provides practical information on the application of LCA to building components and materials.

4.0 SELECTING BETWEEN ALTERNATIVES

The previous section gives an indication of the number of competing variables that must be considered when optimising the facade. A recommended way forward is to compare facade alternatives against a base case. The base case facade can be an initial design proposal based on project imperatives, and should be evaluated against the key performance indicator matrix in Table 1. The performance of alternative facades can then be evaluated against the base case, and the variables can be ranked and prioritised. Project imperatives can then be tested against the performance of facade alternatives and a selection can be made. Furthermore, the powerful simulation processes described above enable development of customised design responses for varying orientations and functions.

The analyses techniques described use complex mathematics and are based on numerous assumptions. It is imperative that the analyst(s) understand the implications of the underlying assumptions, and use software tools that have been verified against international benchmarks. We are not aware of any single software package that can cover these analyses in any great depth. However, there are a number of software tools that can perform one or more of these investigations.

For a successful outcome from the decision making process, it is imperative that the design team maintain good communication between themselves; and that the architect maintains a coordinating role to achieve the project imperatives. Table 2 provides a basic checklist of items impacting facade performance. It provides best practise values (where appropriate) and a discussion of factors to be considered.

5.0 CONCLUSION

Advanced facade systems offer significant environmental and energy benefits. It is hoped that this note enhances the awareness and understanding of the capabilities of these systems, and provides building designers with a framework to make informed choices for their application.

In summary:

- In addition to providing a visual connection to the outdoors, and acting as a shield against weather, facade systems impact on the heating, cooling and daylight performance of the building.

- Advanced facade systems minimise energy use for cooling and heating in the perimeter areas of a building while maintaining the benefits of comfort and connection with the outdoors.
- Advanced facade systems can play a critical role in the control of natural ventilation to supply fresh air during natural ventilation operation in a mixed mode building.
- Advanced facade systems in combination with innovative daylighting and shading strategies, along with mixed-mode or natural ventilation systems can achieve very low energy use and greenhouse emissions.
- Dynamic simulation modelling is required to predict and optimise the integrated impact of the facade, air conditioning and lighting systems for building design.

REFERENCES AND FURTHER READING

Australian Building Greenhouse Rating, www.abgr.com.au

Australian Green Building Council of Australia, www.gbcaus.org

Examples of dynamic simulation models and bulk air flow model combinations are Apache+MacroFlo, Energy Plus+COMIS, and ESPr and TAS which have in-built models.

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IEA Task-23 has a wealth of work on multi-criteria decision making as applied to optimising solar energy use in buildings; see www.iea-shc.org/task23/.

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