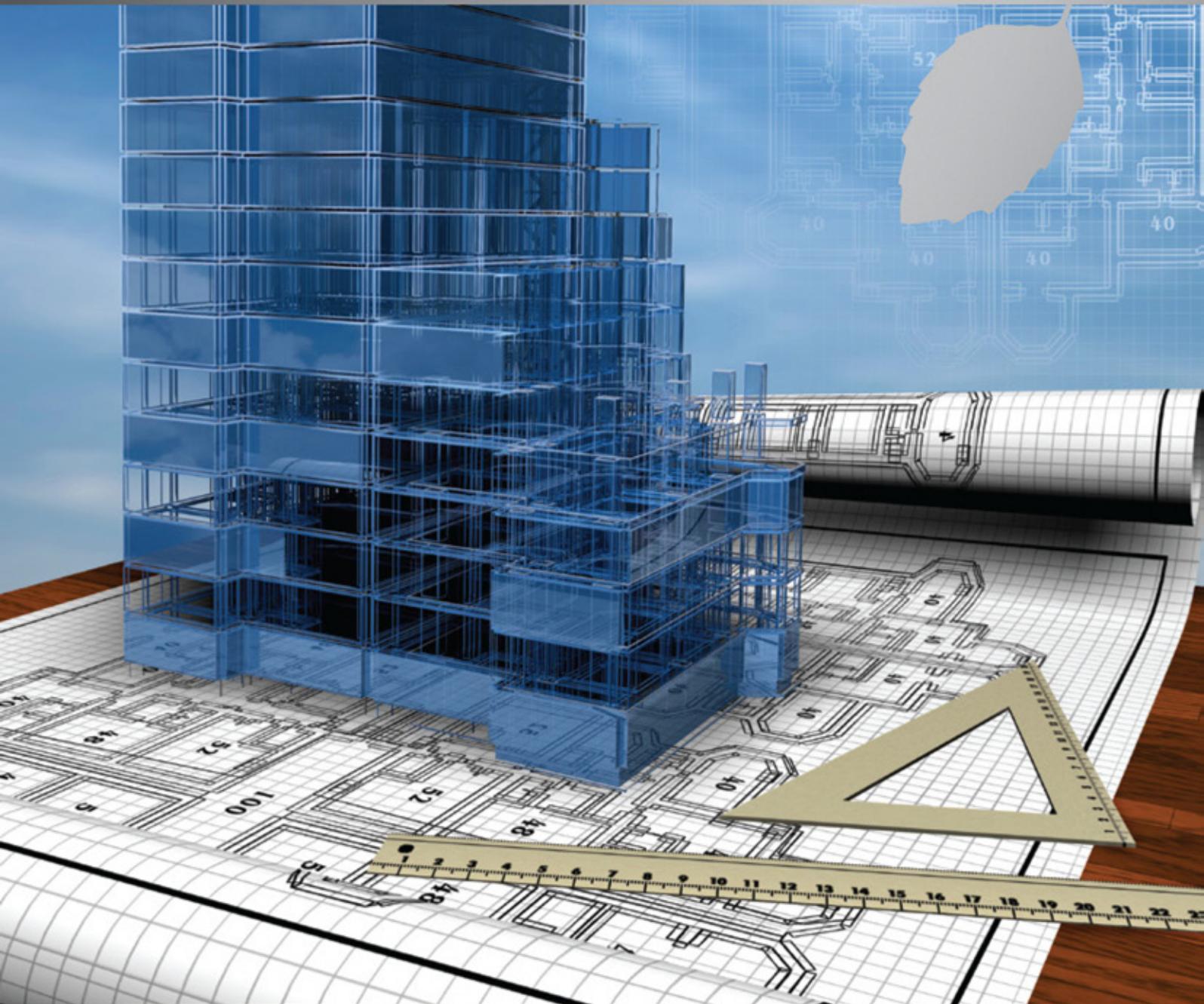


building planning and massing



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INTRODUCTION

Guide for Green Buildings



GLOBAL SUSTAINABLE DEVELOPMENT CHALLENGES

The way the world has used global natural resources in the past has placed a tremendous strain on the environment – depleting our natural resources, polluting the environment, warming the earth, raising sea levels, and endangering our biodiversity. Climate change has become the inevitable result of our past actions.

According to the United Nations, cities consume two thirds of global energy use. 76% of the world's energy-related carbon dioxide (CO₂) are also emitted by cities through transport, industry, and building and construction related activities.

Studies have shown that buildings and construction activities use 40% energy, 30% mineral resources and 20% water of the world's resources. It also accounts for 40% CO₂ emissions, 30% solid wastes and 20% water pollution in the world.

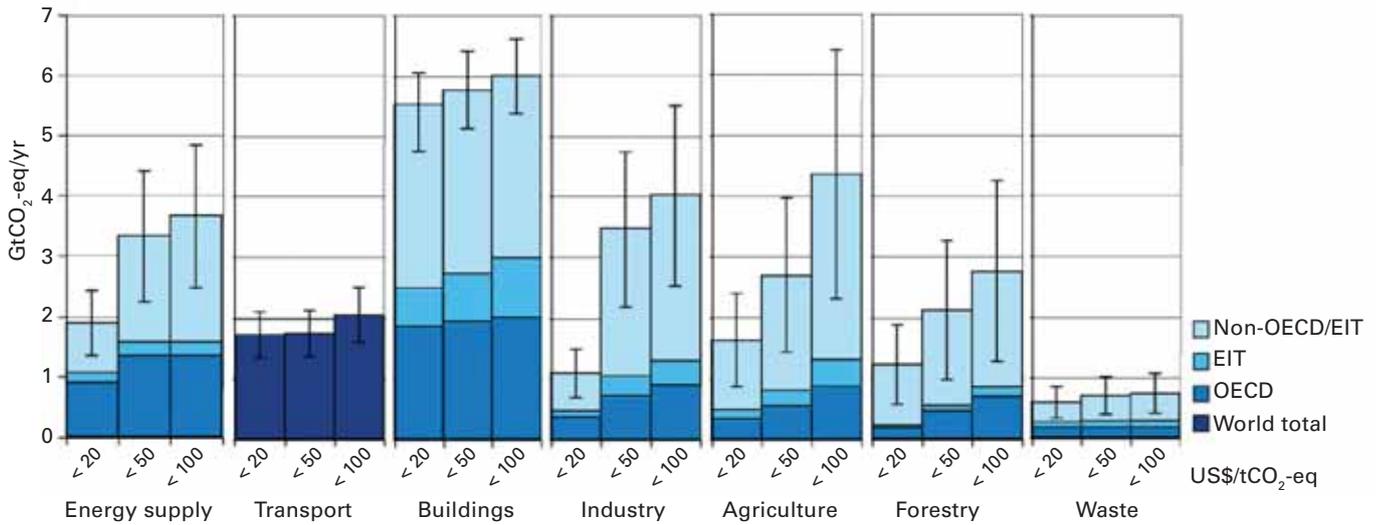
SUSTAINABLE DEVELOPMENT, ESSENTIAL TO SINGAPORE

Sustainable development has always been a key consideration for the development of Singapore. Growing and developing our city state in an efficient, clean and green way by utilising less resources; generating less waste; reducing pollution to the environment; and preserving greenery, waterways and our natural heritage, are the goals of the Sustainable Development Blueprint as set out by the Inter-Ministerial Committee on Sustainable Development (IMCSD). This way, we ensure that Singapore can enjoy both economic growth and a good living environment for ourselves, and for the future generations.

THE ROLE OF BUILDINGS

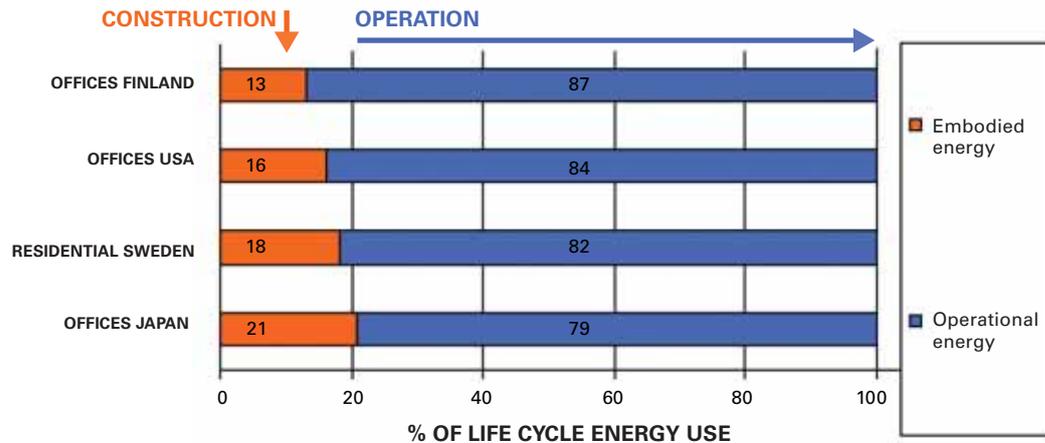
The 4th Assessment Report from the Intergovernmental Panel on Climate Change (IPCC) has shown that buildings have the highest potential to reduce carbon emissions [Figure 1]. This is due to the large consumption of energy within buildings. With the use of the right design and green technologies, a considerable amount of both energy and economic savings can actually be achieved.





[Figure 1] Buildings have the highest potential to reduce carbon emissions (4th Assessment Report, Intergovernmental Panel on Climate Change).

Source: IPCC, 2007: 4th Assessment Report of the IPCC



[Figure 2] Life cycle energy use of buildings.

Source: UNEP-SBCI, 2007

A study conducted by the United Nations Environment Programme – Sustainable Buildings and Climate Initiative (UNEP-SBCI) has also shown that an average of 15% of total energy used occurs in the material production and construction process, while about 85% of total energy used is in the operational phase of the building [Figure 2]. Of these, as high as 50% of the total energy used can be reduced at net zero cost with commercially available technologies.

This is a challenge to the industry and there are many opportunities to develop new solutions, especially in the area of energy efficiency. Our buildings consume about one third of Singapore's total end-use electricity and are the largest electricity consumer after the industrial sector. It is critical to look into practical measures to reduce the impact of our buildings, and make them more resource and energy efficient.

The Green Agenda is not merely a fad. As climate change and resource constraints become more apparent, we must adapt out of necessity and respond to the new drivers and economics of the earth. We are entering an ecological age where the impact of our activities on the earth will drive our actions.

THE GROWING NEED AND TREND FOR GREEN BUILDING DESIGN



In response to broad concerns regarding the environment and climate change, Green Buildings are becoming much more common and are increasingly in demand by building owners and occupiers. As a result, they are featuring more prominently in the portfolios of most building developers, architects and engineering consultants. The current green trends are quickly becoming the new standard. Current developments that do not follow these trends will find themselves becoming obsolete and will need upgrading or replacing, or risk losing value. Green Building Design can future-proof a development.

Especially relevant in resource-scarce Singapore, sustainable development has become a must. Green Building Design has therefore become essential. This is reflected in the statutory requirement for all new developments and existing buildings undergoing major retrofitting works with a Gross Floor Area (GFA) of 2,000 m² and more to achieve a minimum of Green Mark certified standard.

CHALLENGES OF THE TROPICS

Singapore, with an equatorial tropical climate, faces many challenges to building design. In order to achieve comfortable conditions for building users to live, work and play effectively throughout the day, the climatic conditions they experience need to be modified.

A typical day in Singapore can have temperatures ranging from 23°C to 34°C and high humidity of about 84 RH% (relative humidity). Such high temperatures and humidity lead to a need to cool and de-humidify spaces to

create comfortable conditions for occupants. However, the need for such climatic modification of spaces within a building consumes much energy. This has posed a great challenge for the buildings in Singapore to balance our needs with our responsibility to the environment we live in.

BUILDING PLANNING AND MASSING

To create a green building design that can not only minimise the impact on the environment, but also remain practical, economical and comfortable for use, it is important to look into integrated green building design, in which the design team works hand-in-hand throughout the entire process, as well as consider each aspect of a building in an integrative and holistic manner.

Besides this, the focus of this guidebook will also be on the role of passive design features, e.g. aspects of the building form and envelope that will reduce energy consumption, as well as the adoption of energy efficient strategies such as natural ventilation, building greenery and the use of renewable energy. Other volumes in this series of guidebooks will consider other aspects of building design such as building systems and indoor environmental quality.

With this guidebook, we hope that building owners, architects, engineering consultants, and all the parties in a building project can have informed discussions and decisions, and as a team, take the building's design to a higher level of achievement and success, economically and performance-wise.





[Key Points]



Achieving an integrated green building design requires a design approach that draws all project stakeholders to work throughout the project phases to evaluate the design for aesthetics, efficiency, environmental sustainability, cost, maintainability, flexibility, accessibility, functionality, security and safety issues. The process is an ongoing and iterative one having the following key components:

AN INTEGRATED DESIGN APPROACH

A successful integrated design approach always begins with acquiring an early in-depth understanding of how various building systems and the environment relate to, interact with and affect each other in a holistic manner to ultimately contribute to the end performance of the building. This ensures that the performance and cost of one building system or environment is not optimised at the expense of another building system.

AN INTEGRATED TEAM PROCESS

This design approach brings all stakeholders together to look at project objectives, materials, systems and assemblies from many different perspectives. This essentially moves away from traditional planning and design process where specialists work in their respective specialties somewhat isolated from each other and address problems with each other only when they arise. The whole team is encouraged to contribute towards the output design by sharing their experiences, knowledge and expertise. [Table 1] explains the key differences moving from traditional planning and design process to the integrated green building design approach.

ITERATIVE PROCESSES

It is not a one-off design session but continuous processes consisting of reviews and workshops / charrettes until the best solutions, under the project circumstances are identified. Such iterative processes can ultimately lead to downsizing or elimination of systems altogether.

DESIGN ANALYSIS TOOLS

Design analysis tools such as energy modeling, daylight simulations, natural ventilation simulations, etc are commonly performed to assist in evaluating design options. Using such tools does not necessarily mean higher capital investment costs but instead may lead to cost savings when building performance is optimised and design options are scientifically tested.

[Table 1] Key differences moving from traditional planning and design process to integrated green building design approach.

TRADITIONAL PLANNING AND DESIGN APPROACH	INTEGRATED GREEN BUILDING DESIGN APPROACH
Involvement of the project members is limited to their trade and specialisation.	Project members are included right from start of project to draw inputs that will help to shape the design and planning process.
Project gets more intensive as it progresses. Less time is spent at the early stages.	Project starts off intensively with time spent on meetings, charrettes and discussions.
Decisions are made typically by a few stakeholders such as owners, architects and contractors.	Decisions are made by the team. Brainstorming sessions, research and iterative discussions are held amongst as many stakeholders as possible before decisions are made.
A linear process is adopted.	A whole system thinking approach is adopted.
The focus is to reduce up-front capital costs.	The project team aims towards reducing long term operation and maintenance costs by using highly efficient systems.
Systems are considered in isolation and often result in over-designing / over-sizing.	Total building performance is used to assess how each system affects one another to deliver the optimum design.
Project members undertake limited responsibilities.	All team members share equal responsibilities and work together to solve problems.
The linear process ends when construction of the project is completed.	This design approach emphasises on the long term performance of the building and users' satisfaction through commissioning, Post Occupancy Evaluation (POE) surveys and energy audits.



[Decisions by Building Owners and Architects]

Building owners and architects must recognise and understand that an integrated design approach can help them achieve the project goals.

The key decision is for them to define and set these overall project goals. For example, is the building meant as a very low energy building or an open and accessible public space or simply a shell space for production activities with zero tolerance for downtime, etc? When these goals have been clearly defined, the following can then be considered:

- Explain to them the benefits of integrated design and the commitment required from them.
- Be prepared to listen, evaluate and adopt views from different perspectives and from people who do not traditionally 'look after' these issues. Be ready to challenge entrenched mindsets and assumptions.
- Are you prepared to devote time and resources to actively and continuously participate in the whole project life cycle – from design concept stage to schematic design, detailed design, finalised design, construction and maintenance? If not, an owner's representative could be appointed to advocate, clarify and develop the owner's interests. This person may also be a third party consultant.
- Who are the stakeholders of the project? Not just the design and construction team but also the future users, facility managers, community; and non-traditional consultants like commissioning agents, materials consultants, simulation specialists, etc. Identify them early at the start of the project and where possible, appoint them early so that they can be involved right at the start. The stakeholders in a typical construction project are illustrated in [Figure 1].



[Figure 1] Stakeholders typically found in a construction project.

[Getting Started]

With every start of a design process, it is critical for the design team to understand the details of the project so that all inputs are considered in the building design. In an integrated design approach, this is even more critical and stakeholders should come with such similar understanding. A document such as the Project Brief and/or Owner's Project Requirement should be prepared and disseminated to stakeholders for prior understanding. It should contain, but not limited to, the following:

- 1 » What are the project and owner's overall requirements? Some of these requirements may be:
 - What is the primary purpose of the project? Is it a campus for international students or a Grade A office building with high-end retail podium? Is it owner occupied or speculative in nature?
 - Is future expansion envisaged? Must building be designed to allow for flexibility?

- What are the qualities of materials and finishing to be expected? Normal or top-grade?
 - Any budgetary construction and operational costs (in \$/m²)?
 - What is the project duration? Is there a time constraint?
 - Any cultural or historical significance that has to be preserved or communicated?
 - Are there any environmental and sustainability targets? Energy and water consumption targets, level of Green Mark certification, extent of green spaces and naturally ventilated spaces, etc.
 - What are the indoor environmental quality goals? What are the key space usages and their requirements in terms of lighting, ventilation, temperature, controllability, etc.
 - Are there any system and equipment expectations in terms of quality, reliability, flexibility and maintainability? Any preferred suppliers or building systems?
 - Who will be operating and maintaining the building?
 - Are there any objectives that can measure the success of the project?
- 2 » What are the strengths and constraints of the site environment in helping or working against the achievement of these objectives?
- 3 » What is the macro-environment in which the building is being developed? What benefits can this development add on to the environment?

A facilitator may be appointed to lead and champion the integrated green building design process and to ensure that team involvement is always maintained and open communication are in place. The facilitator may be someone experienced in the whole building design process. He may be an independent person or where the project has budget constraints, someone involved in the project such as the architect, owner's representative or ESD consultant.



CASE STUDY

Integrated Design – System Level



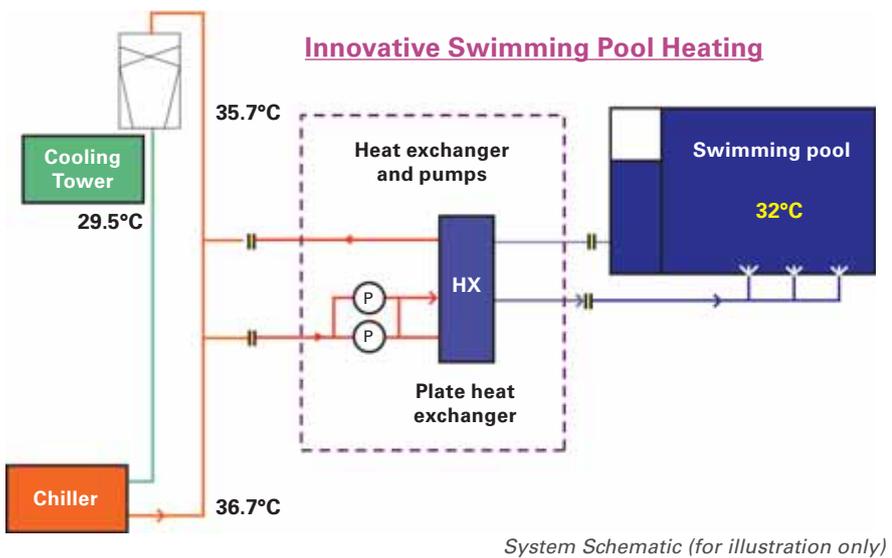
MAPLETREE BUSINESS CITY (MBC), SINGAPORE

NO. 10, 20, 30 PASIR PANJANG ROAD

- o 2 blocks of 14 and 17 storey Business Park
- o 1 block of 18 storey office
- o Landscape deck covers the entire 1st storey and mezzanine floor carpark
- o Green Mark Platinum certification

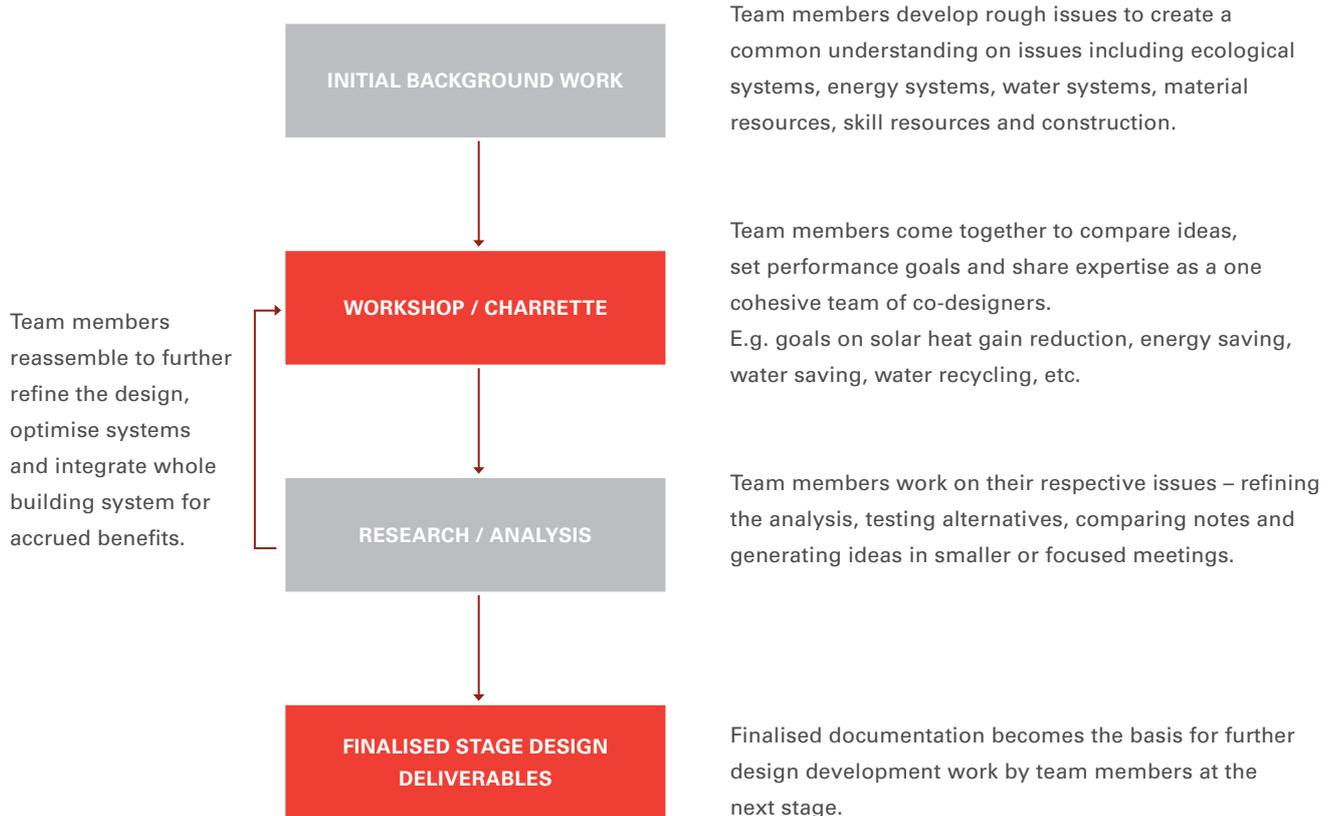
Key initiatives to system integration:

- o Innovative use of condenser waste heat from chiller for swimming pool heating.
- o Part of the design requirement is to keep the swimming pool water heated instead of keeping it at ambient temperature. While conventional design maintains the desired temperature through a gas heater, the designer has innovatively harnessed the waste heat from condenser water to heat the swimming pool water.
- o MBC chilled water plant is designed for low-flow, high temperature difference for chilled water and condenser water loop, resulting in high condenser water leaving temperature of 36.7°C at design condition (instead of 34.5°C).
- o This innovative system seamlessly takes advantage of the low-flow, high temperature properties of condenser water return, hence reducing the condenser water return temperature to the cooling tower.
- o In addition, cooling tower evaporation is reduced due to lower entering temperature. This result in water savings and less make-up water required.



- o MBC's chilled water plant is designed to achieve 0.623 kW/RTon and annual water saving of approximately 44 Olympic-sized swimming pools
- o This integrated system design not only avoids energy consumption due to gas heater, it also reduces cooling tower fan energy since lesser heat is rejected through cooling tower. Lower evaporation rate result in water savings as well.

[Implementing Integrated Green Building Design Approach]



[Figure 2] An integrated green building design approach.

An integrated green building design is iterative and the approach is summarised in [Figure 2]. It should be continuous over the whole design and construction stages of the building with commissioning and post occupancy evaluation of the building being stages where the building is measured against the project and owner's requirements.

PRE-DESIGN

The pre-design activities as described above sets forth the project and owner's goals and clear indicators for measuring the meeting of these goals at various stages of the project life cycle. The pre-design activities usually involve only the owner and/or his representative. In some cases, the architect may be involved in helping him put these in achievable goals. If an architect or owner's representative is involved, extensive consultations should be held with the owner in deriving these goals. Though set, these goals may still be changed as the project progresses though changing these goals may mean abortive works. If the project is engaging a commissioning agent, he should be brought in at this stage to document the owner's project requirements and goals.

CONCEPT DESIGN

After the pre-design activities are completed, graphical illustrations for the project either in whole or in parts will be produced as an initial conceptual idea of the project. The sketches are meant to form a starting point for further discussions, stimulate thoughts, initiate discussions and the means of achieving the end design. A series of integrated design charrettes (in the form of workshops, focused team meetings, brainstorming sessions or community engagement events) will be held during this stage to start the communication process among the project stakeholders. Depending on project size and constraints, some stakeholders may not be appointed at this stage but where possible, as many of them should be involved as early as possible. Stakeholders' insights made at this point can minimise costly changes further along in the process. The following are key events or characteristics to ensure that integrated design approach is practised at this stage:

1 » Appoint a good facilitator:

- The person is usually a member from the owner / developer, architect or environmental design consultant team. He should have a broad overview of the whole building design and must have relevant experiences.
- He is responsible for the design process and provides the vital linkages between various design functions. He is not to produce the building design or parts of it.
- He should develop a firm and systematic platform to make decisions, prevent misunderstandings and deal with issues at task in the right order.
- He should be able to encourage participation and inclusiveness.
- Recognise situations where discussion sessions are needed and to initiate them. He must also encourage the other stakeholders to do so as well.
- Ensure that stakeholders understand the project and owner's requirements.

2 » Gradually develop the design towards meeting the interests and requirements of all participants while also meeting the overall project and owner's goals established during pre-design activities. Encourage stakeholders to research and discuss on topics such as but not limited to the following:

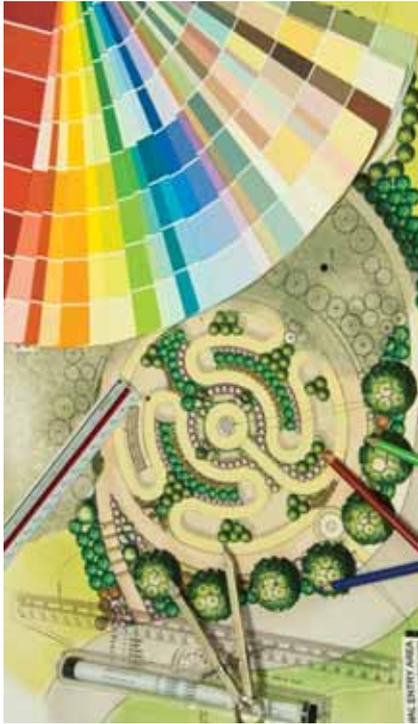
- **Environmental sustainability.** An integrated green labelled building design best addresses the issues of energy use, water use, materials, indoor environmental quality and carbon emissions before the construction of the building. At the design concept stages, usually broad concepts are explored such as orientation to minimise heat gain, building massing to allow for good ventilation, strategies to minimise water use, energy efficiency strategies (e.g. options for renewable energy), materials selection strategies (high recycled content, green labelled, etc), greenery strategies such as ground greenery, skyrise greenery, etc. Simulation tools should be used to explore design schemes promoting good air flow and daylighting.
- **Design for aesthetics.** Develop the building's appearance in collaboration with the owner, users, consultants and the public community. Good architecture is usually associated with qualities such as functional, practical, buildable, visually interesting, able to relate to the environment, etc. Public consultations, design competitions, etc may be avenues to seek feedbacks.
- **Cost.** Determine first costs and life cycle costs of various alternatives. For larger projects, cost managers, specialist suppliers / consultants could be on board at concept design stages to provide value engineering to achieve cost-effective solutions.

- **Flexibility.** If it is expected that the building may undergo numerous changes in use throughout its life; building design, material use, construction methods, building services, etc should be flexible enough to accommodate these changes.
- **Accessibility.** At this stage, considerations for easy access, smooth and comfortable pedestrian access especially for aging and physically challenged people, good connectivity to public transport systems and vehicular flows are key concerns.
- **Functionality.** Functionality usually depends on the building usage. A good design should meet the requirements of the occupants and their activities. It must also be noted that other design objectives mentioned here must be achieved in tandem to meet any change in user demands.

3 » Make use of tools to evaluate options and push the boundaries of green building. At this stage, tools that are more applicable include:

- **Computer simulation.** Examples are fluid dynamics analysis for air flow and natural ventilation analysis at estate level and sun path analysis to determine shading effects.
- **Design charrettes.** Depending on the stage of the project where design charrettes are carried out, the depth and content of discussion may be different. The first session requires all key stakeholders to compare ideas, to set performance goals and to begin forming a cohesive team that function as a consortium of co-designers. Subsequent charrettes require deeper discussion of benefits and opportunities, design refinement and system optimisation. Design charrettes will help build momentum for the project and set it on a course to meet project goals.





DESIGN DEVELOPMENT STAGES

Moving the project from conceptual stages into detailed design stages, schematic designs would have been produced showing general site layout, building shapes, space allocations and rough building specifications that require further development. Indicative budgetary costing should also be derived.

At design development stages, the integrated collaborative process continues but more stakeholders (such as consulting engineers, contractor, specialist suppliers / consultants, facility managers, etc if not already in the team) should be brought into the process to assist with design development for all aspects of the building. The topics to research on, discuss and develop remain largely similar though the scale of consideration would be enlarged. The details would be explored in greater depth to eventually produce architectural and engineering drawings, material / equipment specifications, facility management manuals, control manuals, user guides, etc.

- **Environmental sustainability.** Issues are discussed in greater details and involving more stakeholders. For example, façade glazing design such as selection, sizing, types of glass and accessories, orientation, performance etc, are not solely the responsibility of the architect or façade engineer, but other stakeholders as well. The impact of the glazing design will affect the ACMV sizing / selection (energy), daylight and views, occupant controllability (IEQ), maintenance (water and facility management), building structures (materials), costs, productivity and even the landscape. Such issues concern almost all project stakeholders. If one parameter changes, the exercise should be repeated to ensure efficiency and comfort are maintained. Simulation tools at this stage would be used to study more detailed designs, e.g. location of rooms, doors, windows, etc. Energy modeling can be used to select energy strategies that are most optimal.
- **Design for aesthetics.** Develop further the building's appearance in collaboration with the stakeholders. Concerns from various stakeholders, such as excessive daylighting entering into the spaces or adding screens to conceal building services that are located on the roof, changes have to be considered.
- **Cost.** Refine the project costs to consider additions or omissions following consultations and feedback from stakeholders. For example, additional green areas require larger irrigation demands that can be met by grey water recycling; incremental cost for using a more energy efficient lighting system can be offset by a reduction in electricity bills due to reduced cooling load or fewer number of light fittings.
- **Maintainability.** Building maintainability is not only the responsibility of the maintenance team, but also the responsibility of the design team as a whole, integrating their knowledge and experience, to determine maintainable design and construction solutions. Maintainability is usually discussed together with serviceability, replaceability, operability, cleanability and provision of access for inspections.

- **Flexibility.** Further develop the building design, material use, construction methods, building services, etc for flexibility following greater understanding from various stakeholders. For example, an office block may be added on with another floor, hence building services (water, ACMV, sanitary, etc), structural loading, façades, parking, increased amenities, etc have to be catered for.
- **Accessibility.** Design for aging and physically challenged people. Develop detailed designs to cater to these requirements.
- **Functionality.** Consistently evaluate design, equipment, materials, and technologies to ensure that they are able to meet, if not exceed the minimum requirements.
- **Security and safety.** For instance, schools will have very different security and safety requirements as compared to an aircraft production factory. Hence, the building owner, security consultants, system suppliers should also be engaged in the discussions along with the architects and consultants for fire, structural, electrical and mechanical systems.

At this stage, team members will be involved in smaller focused meetings for specific issues. Simulation tools such as airflow, human traffic study, energy and daylighting modeling will continue to be used towards finalising the overall building design and equipment selection.

CONSTRUCTION STAGES

As the project progresses towards construction phases, more and more stakeholders would be brought in. Sub-contractors, suppliers of equipment and materials who are not already on board should be brought into the integrated design process. Their understanding of the project and owner's requirements and goals should be ensured. Decisions previously made should be clarified with them and contract documents should be reviewed by them to ensure compliance to performance. If alternative solutions or changes are proposed, these require broad consultation with the rest of the project stakeholders again since they may affect the performance parameters of the building. It is hence important that the iterative process of the integrated design approach be carried out so that previous decisions are constructively challenged at the various stages of the project. When an idea emerges, it is developed and tested, and may then be refined or discarded in view of whether it improves on the building performance without excessive impact to other green design goals. Regular meetings will provide avenues for members to evaluate collaboratively the full impact of any changes to design. The construction documents should also be coordinated between relevant trades so that they are properly reviewed, updated and recorded.



BUILDING COMMISSIONING

Once the development is completed and prior to handover and occupancy, commissioning of installed energy related systems must be conducted to verify that they are installed and calibrated to perform according to the project requirements, based on design and construction documents. Commissioning should be coordinated and led by the commissioning agent.

Systems to be commissioned may include but are not limited to:

- o ACMV systems and associated controls
- o Building Management System (BMS)
- o Lighting systems and controls
- o Renewable energy systems
- o Façade system for tightness
- o Water fittings / rainwater harvesting systems / irrigation systems
- o Indoor air quality, daylight and views

Commissioning allows key building systems to be reviewed and at this stage, specialist suppliers, installers, contractors, designers should be present to commission their respective systems to the satisfaction of the owner. Facility managers and representatives from the user groups should also be present during this period to receive training on how the systems should be operated and maintained as intended. Complete documentation relating to the building's performance and green features should also be handed over to the users and facility management team.



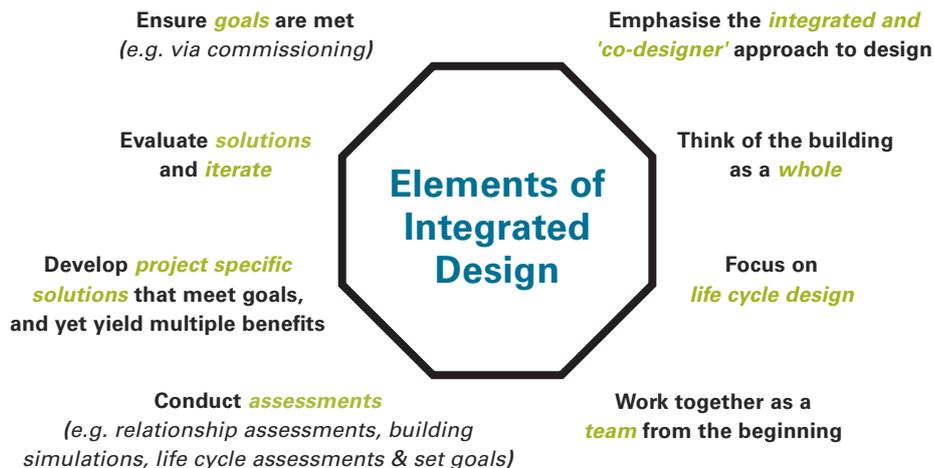
POST OCCUPANCY STAGES

During building operation, POE audits can be conducted to verify that the performance parameters can be maintained in the long term. This is usually done one year after substantial occupancy or when occupancy levels exceed at least 50%. Energy-related systems, space comfort conditions, users' perception, etc can be surveyed and measured to identify shortfalls that need to be rectified.

A building performance evaluation team may be created for ongoing monitoring of the building's performance. They, together with the facility management team and the building owner / users must also allocate sufficient budget for POE audits and regular maintenance and upgrading of the building to uphold its efficiency and performance.

[Putting It All Together]

The integrated green building design approach described above is neither new nor exceptional to many. However, it stresses on 'Three E's' – Everybody engaged, Every issue considered, Early in the project. Throughout the project phases, there should be clear and continuous communication among the stakeholders where ideas can be shared, tested, researched and considered for implementation. Stakeholders involved in the building design and those who will eventually use and maintain the building should interact closely throughout the design process so that they contribute their understanding of how the building and its systems will work for them once they occupy it with those who plan and design the building. The fundamental challenge of the integrated design approach is to understand that all building systems are interdependent. [Figure 3] illustrates the key elements of an integrated green building design approach.



[Figure 3] Key elements of an integrated green building design approach.

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GLOSSARY

CHARRETTE	Any collaborative session in which a group of designers drafts a solution to a design problem.
INTEGRATED GREEN BUILDING DESIGN	A process of design in which multiple disciplines and seemingly unrelated aspects of designs are integrated in a manner that permits synergistic benefits to be realised, to produce a green and more efficient building.
RESEARCH / ANALYSIS	A task or activity in which team members work on their respective issues – simulate the environment by varying design parameters, testing assumptions through appropriate design tools, refining the analysis, testing alternatives, comparing notes and generating ideas.
WORKSHOP / CHARRETTE	A platform for collaborative exchange in which team members come together to compare ideas, set performance goals and share expertise as one cohesive team of co-designers or reassemble to further refine the design, optimise systems and integrate whole building system.

CASE STUDY

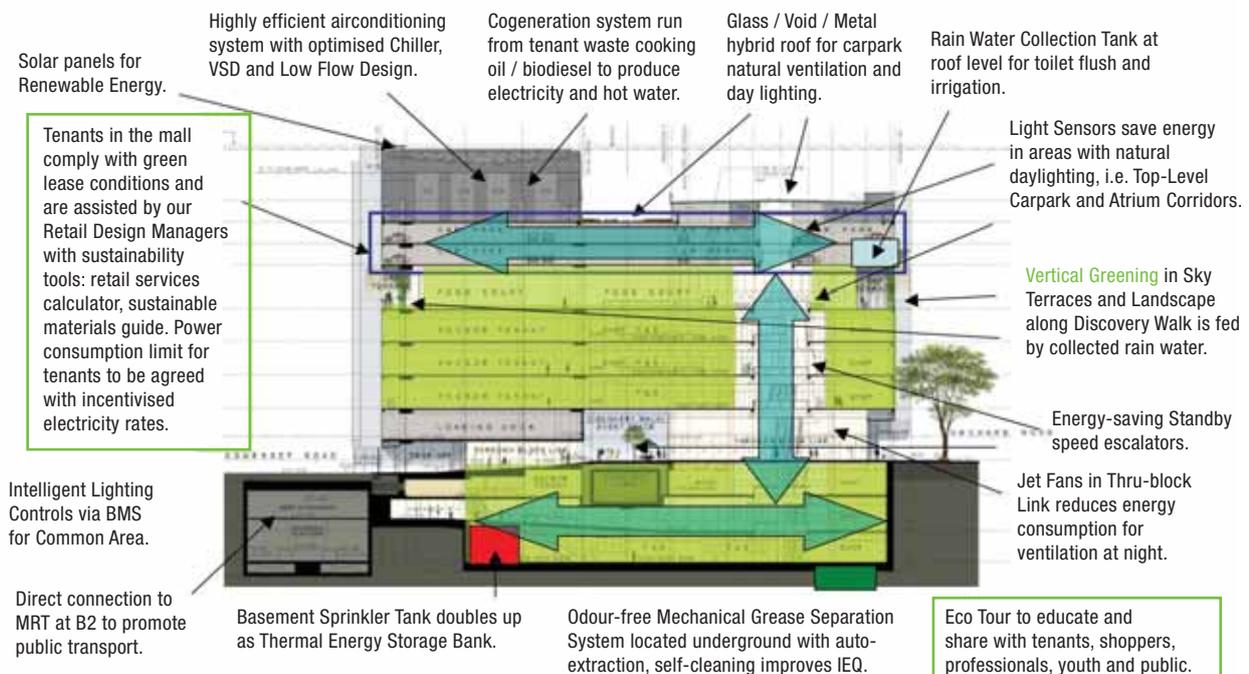
Integrated Design – System Level

313 @ SOMERSET, SINGAPORE
NO. 313 ORCHARD ROAD



- o 8 storey retail mall with approximately 28,000 m² of leasable floor space
- o Sustainable features include integrated design process, co-generation plant, thermal energy storage system using sprinkler tank, photovoltaic panels, rain water harvesting, materials with high recycled content, carbon footprinting, extensive computer simulation studies, green lease and tenancy collaborations.
- o Green Mark Platinum certification

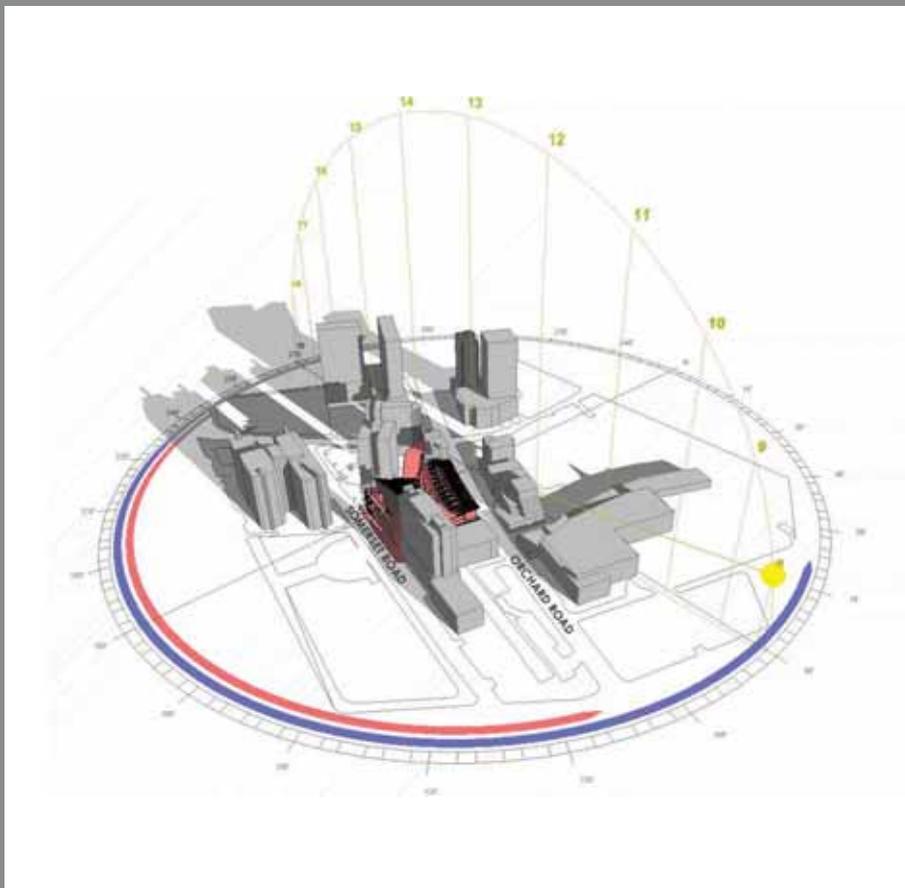
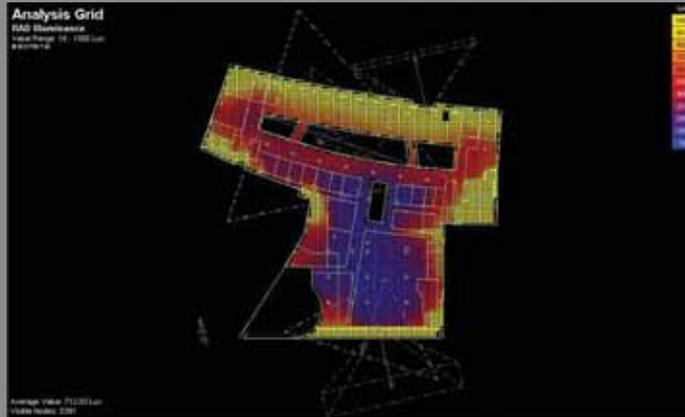
End to End Sustainability: Key Initiatives



Key initiatives to system integration:

- o Participation of all stakeholders from concept design stages. Design charrettes were held at start of project involving owners, mall operators (also representing general public and shoppers), designers, builders, consulting engineers, facility managers, etc.
- o Key concerns of each stakeholder were communicated and discussed at working sessions each lasting 2 days. After each session, stakeholders return to develop design alternatives to be discussed at next session. Computer simulations were carried out to assist development of design. Examples of optimised design as a result of such work sessions include:

- » Carparks were relocated from basement to rooftop. Decision resulted in carpark acting as a thermal barrier for heat insulation, doing away with mechanical ventilation in a basement carpark and cost savings from excavation works.
- » Optimal conditions at Discovery Walkway. Client and architects preferred good daylight and views at Discovery Walkway but the facility management team were concerned about maintainability of glass canopy roof. Consultants recognised potential high heat transmitted through glass canopy. Simulations were carried out based on all concerns to achieve a canopy design that balanced daylight, views, heat and maintenance issues.
- » Façade design. Owners wanted façade to comprise of advertising panels, mall operators were concerned with connectivity to exterior, daylight and view. Engineers were concerned about energy consumption of



advertising panels but welcomed the reduced heat transmission due to increased opaque areas. Collaborative discussions eventually led to a balancing of all concerns resulting in LED façade with intermittent vision glass of low-e double glazed system.

- o This integrated design approach not only allowed stakeholders to share their individual concerns with the team but also allowed for speedy resolution of project constraints and optimal solutions to be reached.

CHAPTER 2

Building Siting, Massing and Orientation



[Key Points]

The initial site planning of a project has significant impact towards achieving a green or high performance building. Things like the siting, massing and orientation of buildings set up the parameters and potential limitations for the later design process. These early stage design decisions are fundamental to optimising passive design, determining the degree of site development and providing green or open space. In terms of passive design, these are the first steps in minimising the building energy demand, providing natural ventilation, daylight, shade, and thermal comfort. The larger green building issues associated with site planning are:

HEAT ISLAND IMPACT

Built-up areas cause local temperatures to rise due to surface absorption and radiation of solar heat, resulting in heat island effects. They affect the thermal comfort of outdoor spaces for occupants by making them less comfortable, and can increase the cooling load and therefore energy demand of a building. The more developed and impervious a site is planned to be, the greater the heat island effects will be. The amount of open and green space, greenery and shade provided as well as material selection and treatment of roof areas are strategies that can help to mitigate these effects.

STORMWATER GENERATION AND RUNOFF

As green field sites are developed, the amount of impervious surfaces increases which leads to less rainwater that can be absorbed on site. This increase in stormwater generation therefore increases the runoff into drains and receiving water bodies. This can harm water quality since water runoff from impervious surfaces typically contains high levels of particulates (Total Suspended Solid (TSS)) in addition to a range of contaminants including oils, metals, fuels, and phosphorous. Additionally, increased runoff stresses existing drainage capacities. Many strategies can be utilised to first reduce site disturbance and stormwater generation, and then to control, attenuate and treat the stormwater prior to discharging it off site.

TRANSPORTATION IMPACT

Vehicle emissions are also associated with green buildings as new projects require vehicular infrastructure for occupants, deliveries and operations. Emissions contribute to climate change, smog, acid rain and other air quality problems. Additionally, areas to accommodate vehicles (parking areas, roads, loading areas, etc) typically add impervious surfaces on site which contribute to heat island effects and storm water runoff. Locating projects close to public transport infrastructure (i.e. bus stops and MRT stations) and designing for alternate forms of transport (i.e. walking, cycling, electric vehicles and charging points) help to mitigate these negative environmental impacts.



PASSIVE DESIGN

Optimising passive design is the first step towards reducing the energy demand of a building or project. Initial site planning establishes the orientation, massing and location of the components and uses of a project, all of which impact and set the parameters for passive design strategies. Some of the primary issues to consider are:

SOLAR HEAT GAIN

Solar heat gains (via direct solar radiation) increase the cooling load of a project and hence energy use. In naturally ventilated spaces, solar heat gains heat up spaces such that they typically become thermally uncomfortable to occupants. The first

step in minimising solar heat gains is to optimise the orientation and massing of a project specific to its location. Certain orientations (east and west for example) provide more exposure to the sun and therefore greater heat gains. This varies according to the location of a project so the sun path needs to be looked at for different locations (e.g. for a project in Singapore versus Bangkok) and at different times of the year. Likewise, the massing of a project could provide shade to itself or other blocks to further mitigate solar heat gains.

NATURAL VENTILATION

Maximising the amount of space to be naturally ventilated is another strategy towards reducing energy demand

on a project since natural ventilation requires little energy use as compared to air-conditioning. Establishing and understanding prevailing wind directions and how they work on your specific site will affect massing and orientation decisions.

DAYLIGHT

While minimising solar heat gains is important, it is also important to take advantage of and harness natural daylight for spaces. This reduces the need for artificial lighting which requires significant amounts of energy. Bringing in daylight via window openings at appropriate heights, skylights and/or atrium spaces are all effective strategies that will affect massing and orientation decisions.

[Decisions by Building Owners and Architects]



For owners and architects, the most important decisions in initial planning involve designing and developing a solution that meets both architect's intent and owner's aspirations. The key decision is in prioritising design issues during the planning phase and understanding site constraints. For instance, the specific site boundary could limit massing options, or the preferred form or massing of the building may work against passive design principles. Still, despite site constraints, establishing good passive design strategies at the onset of the planning phase, puts the project on the right path towards achieving sustainability. Some questions to ask include:

- How much of the site area should the building and overall development footprint occupy and how much open or green space should be provided?
- Is all or part of the building to be natural ventilated?
- Where is the main entrance to the site? Where are building entrances and primary routes of circulation (vehicular and pedestrian)?
- Is daylighting of spaces or providing shade a priority? Or both?
- What is the energy efficiency or Green Mark target, or sustainability objectives to be achieved?

[Getting Started]

Information that may facilitate the start of the site planning include:

What is around your site? It is important to take into account the surrounding context since this can impact wind, daylight, shade, noise and many other factors.

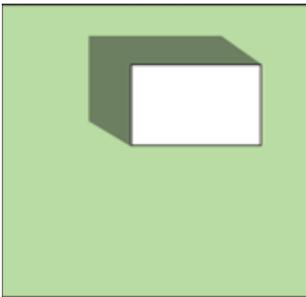
- How close and tall are the buildings around your site? This can leave areas of the site in shade / shadow and can block or change prevailing wind conditions.
- What is the topography of the areas around your site? Built-up density, valley or hilltop conditions affect the sun exposure and wind conditions differently.
- Where are the best view corridors from your site?

- Are there any major or busy roads nearby? This potential noise source can impact the siting of the building(s).

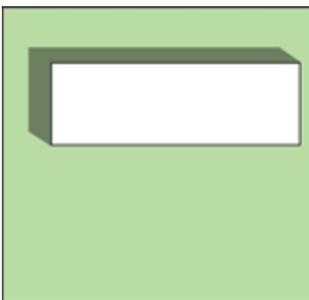
Identify external site transport infrastructure like roads, bus stops, MRT stations, bicycle paths and other pedestrian connections. This is important to help in planning entrances to the site and building(s) and overall circulation (pedestrian and vehicular) for the project.

What are the future plans around the site? The site next door may be currently empty, but it is good to consider if it is likely to be developed in the future or if older projects nearby may undergo major renovation or be rebuilt. Additionally, it is important to consider if public transportation will be brought to or near to the site, or if any public parks are being planned, and other similar considerations.

4,200 m² SITE AREA – 15 STOREY BUILDING



3,700 m² SITE AREA – 8 STOREY BUILDING



[Figure 1] Buildings with same GFA but different footprint.

[Strategies]

Strategies to address the green building issues associated with initial site planning include:

DEVELOPMENT AND BUILDING FOOTPRINT

Minimising the development footprint (building footprint, roadway, walkway, parking areas, or other hardscape) of a project has impacts on heat island effects, stormwater generation, and green and open space. The overall intent for a green building is to minimise its impact on its site, surrounding environment and resources which is why minimising impervious surfaces and maximising green and open space are key initial steps towards meeting that goal. While this can be challenging in high density urban areas, like Singapore, it is still important to take these issues into consideration and maximise their potential.

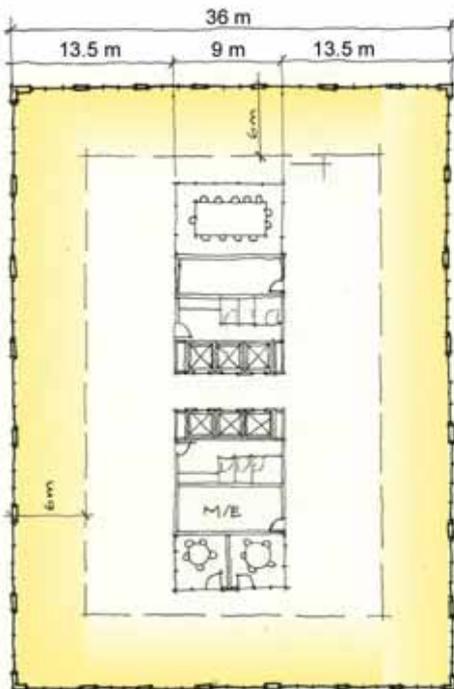
Strategies to minimise the development footprint include:

- Design a taller building with a smaller footprint, rather than a shorter building with a larger footprint (given the GFA is the same in both cases) [Figure 1].

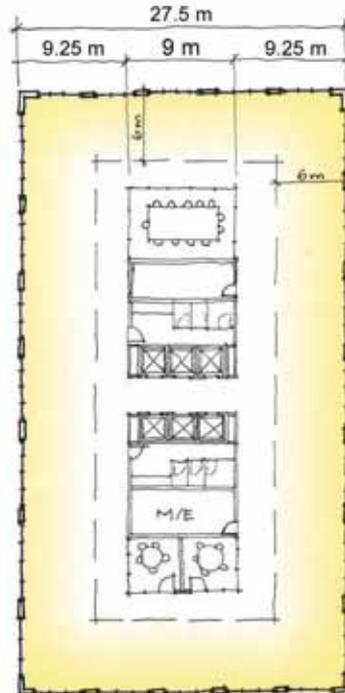
- o Provide the minimum number of parking spaces required by code and encourage alternative or mass transportation. This will reduce the area required for parking and roadway which usually are impervious surfaces.
- o Place vehicular parking underground or in a multi-storey parking garage. Underground parking garages need to be evaluated in terms of cost and benefit since mechanical or conditioned ventilation is then required which adds energy demand. However, this strategy does minimise site area required for parking and therefore reduce heat island impacts. Above ground parking garages can be naturally ventilated while still minimising site area required as compared to a surface parking lot.
- o Minimise road areas on site. Good site planning can keep internal roadways and other associated accesses (i.e. loading or services) to a minimum.

[Massing and Site Planning]

FLOOR PLATE > 27.5 m = MORE ARTIFICIAL LIGHTING



FLOOR PLATE < 27.5 m = LESS ARTIFICIAL LIGHTING

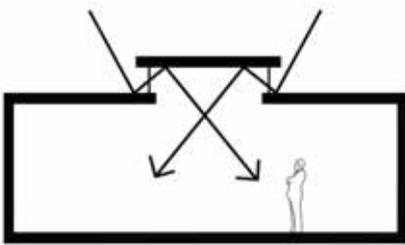


FOR DAYLIGHT

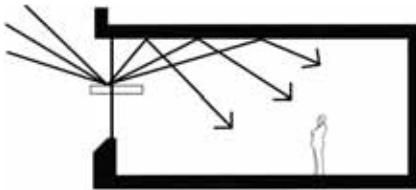
- o Plan for daylight by minimising floor plate depth, especially in office buildings. The deeper the floor plate, the harder it is to bring natural daylight into spaces therefore increasing the dependence on artificial lighting. Floor plates in excess of 27.5 m will have difficulty achieving effective daylighting to spaces (refer to [Figure 2] on the left).

[Figure 2] Effects of floor plates on artificial lighting requirement.

CLERESTORY FOR DAYLIGHTING
(NORTH / SOUTH FACING IS BEST)



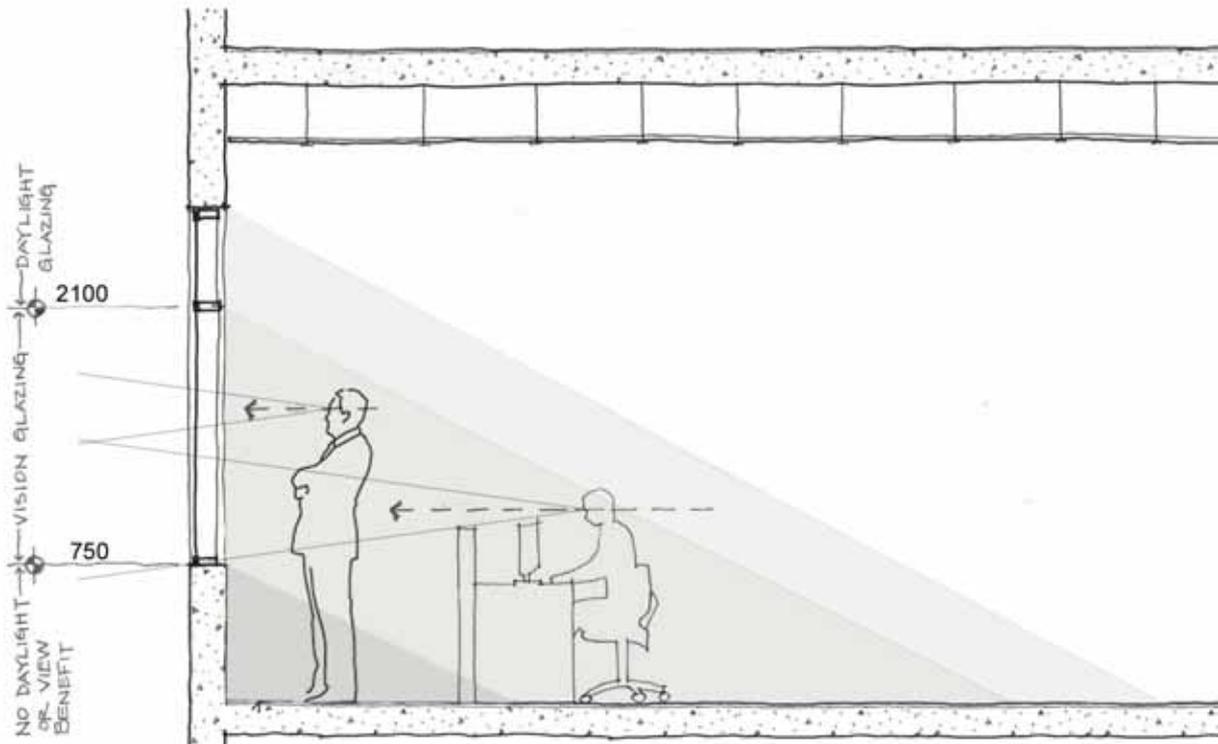
HOW LIGHT SHELVES WORK



[Figure 3] Methods to bring in natural daylight.

If the floor plate is deep, consider [Figure 3]:

- o Adding clerestory lighting or atrium spaces through the building to bring more natural light in. In general, clerestory lighting (indirect light) is better than providing skylights since glare and solar heat gains are reduced.
- o Adding light shelves to bring daylight further into spaces, up to 8 m. Mirror ducts and sun pipes are also effective at bringing daylight into spaces.
- o Plan for daylight by adjusting floor-to-floor heights. Consider slightly larger floor-to-floor heights and providing glazing above 2,100 mm. This enables natural light to penetrate deeper into spaces. Daylight glazing is most effective above 2,100 mm [Figure 4]. However, one has to be careful not to introduce glare into the space.
- o Optimise views. Providing glazing from floor to ceiling is not the most effective way to provide views as it will also bring in more solar radiation. Vision glazing is typically applied between 750 mm and 2,100 mm to accommodate sitting and standing occupants [Figure 4]. Areas below 750 mm therefore do not require glazing for either daylight or vision purposes. This can save in material cost and also reduce the amount of solar radiation entering into the space through the glass.

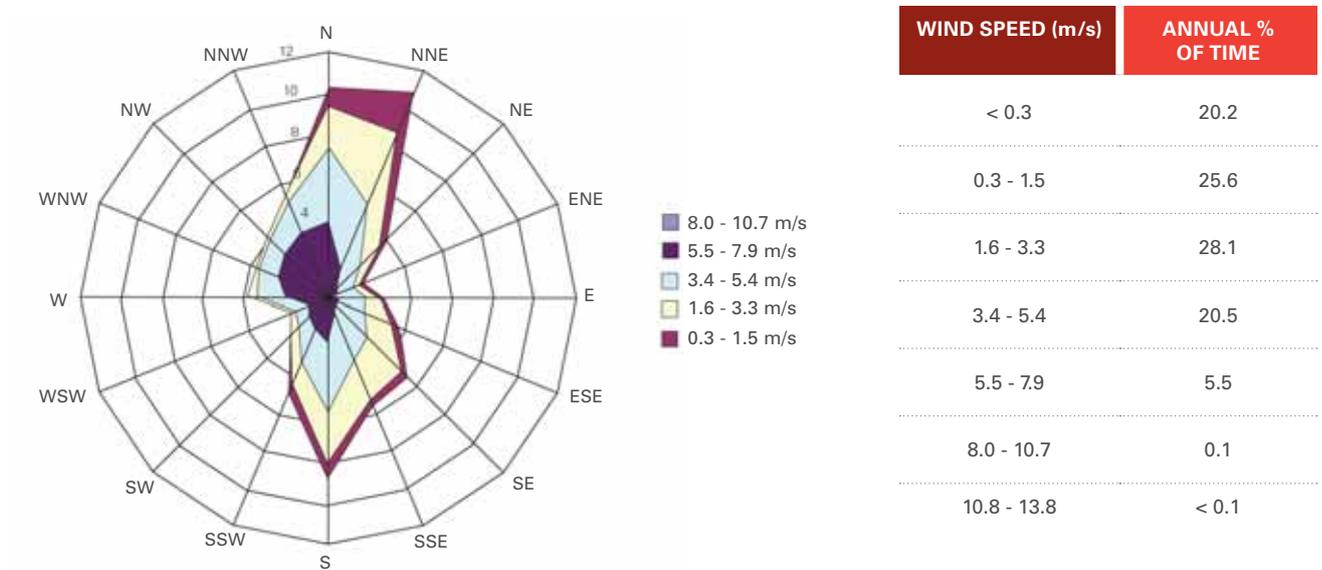


[Figure 4] Effective height of daylight glazing.

FOR NATURAL VENTILATION

At the initial planning, it is critical to take advantage of existing wind conditions and site-specific conditions as these will impact the massing and planning decisions. Please refer to Chapter 4 – Natural Ventilation for more details on natural ventilation design. A few simple reminders are:

In Singapore, wind directions are predominantly N-NNE and S-SSE throughout the year depending on the monsoon season. Although Singapore generally has low wind speeds, the velocities achieved are enough to provide comfort to spaces with the help of optimised design. Please refer to the table below for annual wind speed information [Figure 5].



[Figure 5] Singapore Wind Rose Data from Meteorological Service Singapore – Changi Station 1975 - 2006.

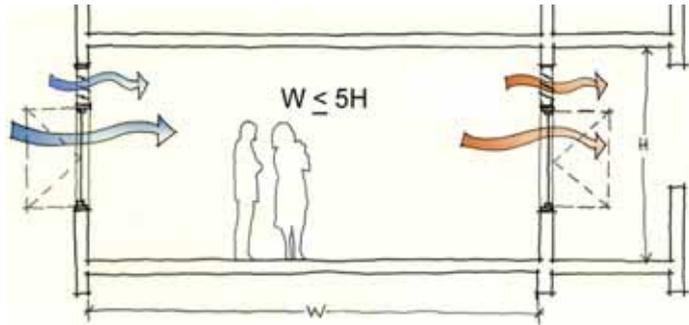
- o Consider mixed-mode ventilation for spaces. Allowing for natural and mechanical ventilation along with air-conditioning can significantly reduce energy use. The air-conditioning systems would only be used as and when necessary while natural or mechanical ventilation would be the primary operating mode. Spaces such as multi-purpose halls, classrooms and even hospital wards could be planned as mixed-mode. However, it is important to ensure no air leakage when switched to air-conditioned mode.
- o Identify the areas that are targeted to be naturally ventilated and locate them consistently with prevailing wind directions. Maximise the areas that do not require air-conditioning. Typically these would include semi-outdoor public spaces and common areas such as corridors, lift lobbies, toilets and staircases. Also consider non-typical areas such as interior atrium spaces or office spaces.

- o Design naturally ventilated spaces with single loaded corridors or narrow floor plate depths to encourage air flow. The narrower the floor plate, the easier it is to achieve effective cross ventilation [Figure 6].

SINGLE LOADED CORRIDOR BUILDING



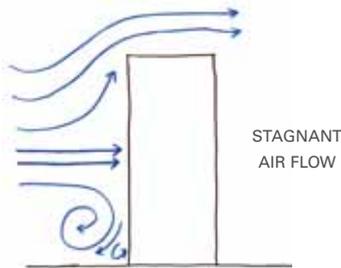
CROSS VENTILATION DIAGRAM



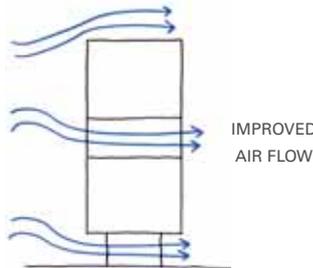
[Figure 6] Design of natural ventilated spaces.

- o Provide void decks at the ground floor, higher floor-to-floor heights and/or void spaces in between buildings to encourage air flow through and around buildings. This helps to mitigate stagnant air flow areas, as shown in [Figure 7] below.

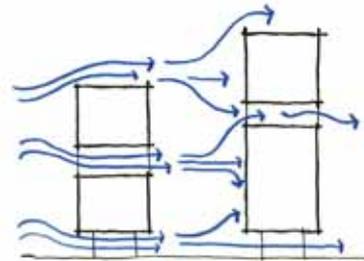
TYPICAL BUILDING: SOLID MASSING



BUILDING WITH VOID DECKS



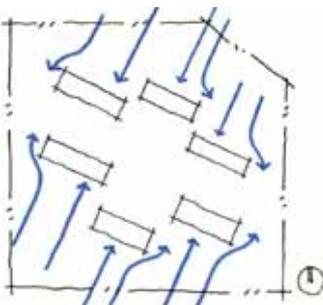
MULTIPLE BLOCK CONFIGURATION: STAGGER BUILDING HEIGHTS AND VOID DECKS FOR BETTER AIR FLOW



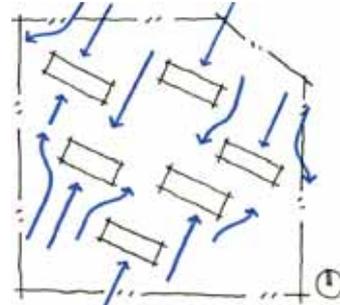
[Figure 7] Mitigation of stagnant air flow areas.

However, simply sticking to the NE / SW wind direction assumption may prove wrong on certain sites. The following conditions may affect the wind direction:

BLOCK CONFIGURATION 1



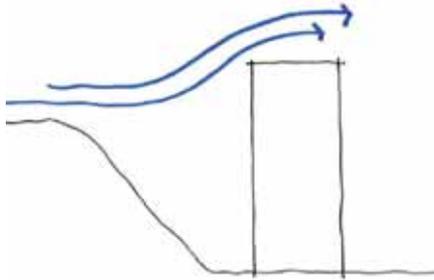
BLOCK CONFIGURATION 2



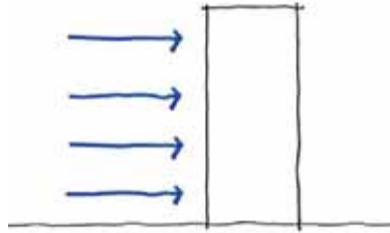
[Figure 8] Air flow diagram for different block configurations.

- o The buildings adjacent and around your site. They can serve to create different wind directions. For instance, in the city area e.g. Central Business District (CBD), wind directions vary significantly due to the number of tall buildings in the area that redirect wind flows. Similarly, in a project with multiple blocks, simply orienting the buildings to NE / SW does not ensure good natural ventilation [Figure 8].

STAGNANT WIND CONDITIONS



CONSISTENT WIND CONDITIONS

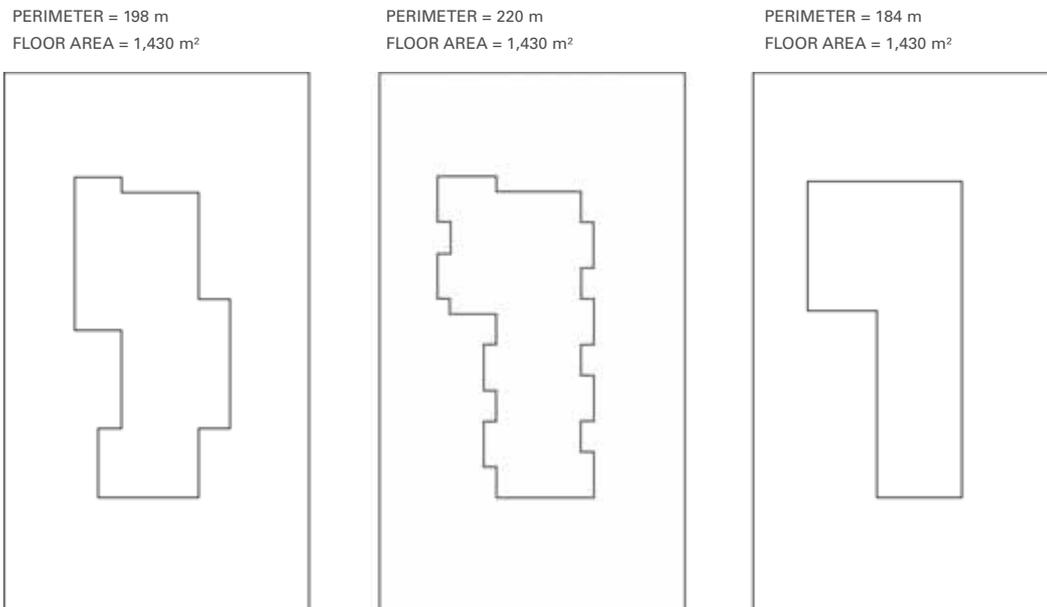


[Figure 9] Location of building resulting in different wind conditions.

- Consider the surrounding site topography. For example, whether your site is at a high elevation or in a valley condition or low point. Sites at a high elevation are more likely to have higher and more consistent wind conditions [Figure 9]. However, being on the leeward side of a hill could produce completely stagnant wind conditions even if your building is oriented correctly [Figure 9].

OTHER SUSTAINABILITY ISSUES

- Plan main entrances to the building to facilitate easier access to main roads and public transport (MRT and bus). This encourages use of public and mass transport. 800 m (approximately 10 minutes walk) to an MRT station and 400 m (approximately 5 minutes walk) to a bus stop are good distances for planning purposes.
- Step-back the building enclosure at the ground floor. This creates space for a covered walkway and provides shade and shelter during rain. Also, consider a void deck at the ground floor as this increases air movement through the site.
- Consider less perimeter area to use less materials. It is a delicate balance between "acceptable" and "too much" but too many jogs and changes in the massing can lead to significant increases in the building perimeter, which means more façade materials to enclose the building and therefore, larger façade costs. [Figure 10] below illustrates that floor plates with the same area can have significantly different perimeters.



[Figure 10] Same floor area with varying building perimeters – greater perimeter constitutes greater material use and cost for building envelope.

CASE STUDY

Optimised Orientation



QUAYSIDE COLLECTION SENTOSA, SINGAPORE

- o New construction on 23,263 m² site in Sentosa
- o 228 units in 19, 6 storey blocks
- o Green Mark Platinum certification

Key initiatives:

- o Optimised orientation to minimise solar heat gains with minimal direct west facing façade. Extensive overhangs, balconies and planters were also provided to block direct solar exposure.
- o Units are designed as 'through-units' to encourage natural ventilation and majority are oriented with prevailing wind conditions (NE / SW).
- o Parking is placed underground to maximise ground level as public / amenity space.
- o Public spaces are planned with lots of greenery and trees to provide shade and minimise heat island effects.



CASE STUDY

Optimised Orientation

TREELODGE @ PUNGGOL

PUNGGOL, SINGAPORE

- o A housing precinct of seven 16 storey blocks in a site area of 2.9 ha, comprising 712 public residential units
- o Green Mark Platinum certification

Key initiatives:

- o Building orientation is optimised with minimal direct west-facing facade (15%) to reduce solar heat gain.
- o Computational Fluids Dynamic analysis is carried out to optimise natural wind-flow through the development.
- o Sun shading devices are provided on the northwest to southwest facade openings.
- o Approximately 60% of the roof area is covered with a combination of PV panels and extensive green roof system.
- o Rainwater harvesting is adopted at the rooftop to supplement potable water usage for irrigation purposes and washing of common areas.
- o Pedestrian entrance is located nearest to the bus stops and MRT station to promote use of public transport.
- o Dedicated car-sharing spaces are provided.
- o Bicycle lots are provided to encourage green commuting.
- o A Landscape deck (also known as "Eco-deck") serves the following purposes:
 - » to minimise the urban heat island effect with enhanced greenery;



- » to provide shade and cover to the car park, as well as facilitate natural ventilation in the car park; and
- » to serve as a covered walkway to residents.

*Treelodge @ Punggol and Landscape deck: maximise greenery
By courtesy of HDB Building Research Institute*

HEAT ISLAND EFFECTS AND THERMAL COMFORT

Heat island effects are experienced as higher local temperatures due to the surrounding environment. Numerous strategies are available to mitigate heat island effects, ranging from roofing and hardscape materials to the amount of green space and shade provided.

Strategies to mitigate heat island effects include:

- Once hardscape surface areas are minimised, use pervious materials for surfaces. Pervious concretes, asphalts, pavers and open-grid paving materials are increasingly available. They provide the look of typical impervious surfaces but are porous (percentages vary) to allow infiltration during rain [Figure 11].
- Use light coloured or reflective materials [Table 1]. However, care must be taken to ensure not to create unwanted glare to neighbouring buildings. These materials have high solar reflectance values and therefore absorb significantly less solar radiation than darker coloured materials. This applies to paving, hardscape roads, walkways, façades and roof or canopy areas.



Source: concretenetwork.com



Source: gaia engineering

[Figure 11] Examples of porous concrete.

[Table 1] List of light coloured and reflective materials.

ROOF MATERIALS	SOLAR REFLECTANCE (ALBEDO)	INFRARED EMITTANCE	TEMPERATURE RISE
Gray EPDM	0.23	0.87	68°F
Gray asphalt shingle	0.22	0.91	67°F
Unpainted cement tile	0.25	0.9	65°F
White granular surface bitumen	0.26	0.92	63°F
Red clay tile	0.33	0.9	58°F
Light gravel on built-up roof	0.34	0.9	57°F
Aluminum coating	0.61	0.25	48°F
White-coated gravel on built-up roof	0.65	0.9	28°F
White coating on metal roof	0.67	0.85	28°F
White EPDM	0.69	0.87	25°F
White cement tile	0.73	0.9	21°F
White coating, 1 coat, 8 mils	0.8	0.91	14°F
PVC white	0.83	0.92	11°F
White coating, 2 coats, 20 mils	0.85	0.91	9°F

Source: Lawrence Berkeley National Laboratory Cool Roofing Materials Database.

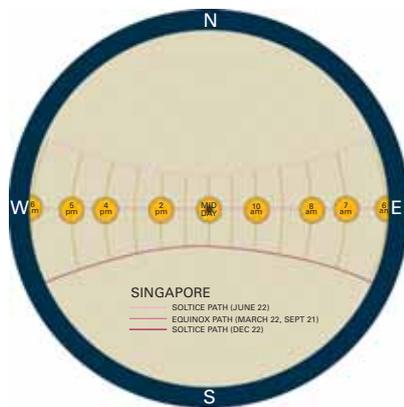
- Maximise the amount of greenery on site. Provide greenery wherever possible at ground level, in planters, indoors and on roof areas (i.e. green roof systems – extensive or intensive systems). Also consider vertical greenery systems. Plants (i.e. trees and tall shrubs) provide shade and reflect solar infrared radiation, which prevent heat gains to keep areas cool and significantly more thermally comfortable. Specify native or adapted plants to minimise water demand and other maintenance requirements. See Chapter 5 – Building Greenery and Landscaping for more information on greenery.

- Provide shade to outdoor, semi-outdoor spaces and natural ventilated spaces. Optimise building massing to provide more shade or consider using shading devices on the building envelope or roof. Providing canopies or

cover will also provide shade and therefore, further enhance thermal comfort. Also ensure that shading devices do not block wind or breezes since air movement also enhances thermal comfort.

- Provide shade or cover for all parking areas, especially for surface parking areas. They usually have impervious surfaces and providing shade through plants, constructing shelters, or optimising building massing will help to mitigate solar heat gains.

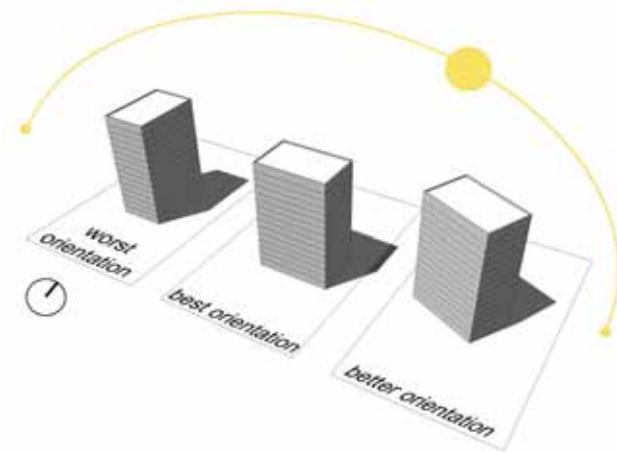
PASSIVE DESIGN: SOLAR HEAT GAIN MITIGATION AND SHADING



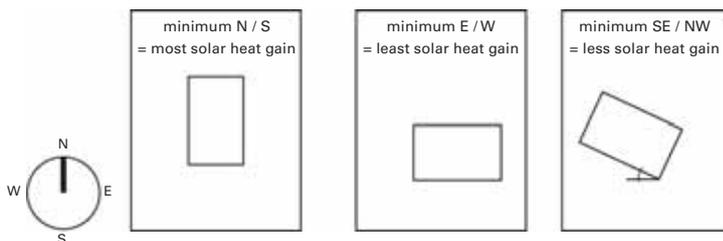
[Figure 12] Sun Path diagram for Singapore.

In Singapore, the sun is almost directly overhead throughout the year since Singapore is located only 1° north of the equator. East and West orientations receive the most solar exposure here and therefore have the most potential for solar heat gains. The Sun Path diagram for Singapore [Figure 12] indicates that both North and South orientations also receive solar exposure for a portion of the year.

Several strategies should be considered in the planning phase to address solar exposure:

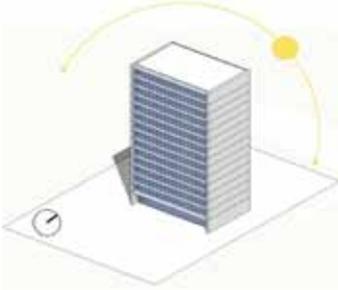


- First, plan the massing and orientation to minimise East and West facing façades [Figure 13]. North and South facing façades have significantly less exposure to solar gains, especially in Singapore. East and West facing façades are typically defined as siting within a 0° - 22.5° angle North / South to East / West.



[Figure 13] Massing and orientation of buildings to prevent exposure to solar gains.

OPTIMISE SOLAR ORIENTATION:
NO OPENINGS ON THE EAST OR WEST FAÇADE



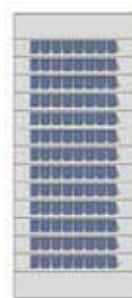
[Figure 14] Minimise solar heat gain by reducing openings on the East or West façade.

MINIMISE SOLAR HEAT GAIN: SHADE ALL EAST AND WEST FAÇADE OPENINGS



[Figure 15] Minimise solar heat gain by shading all the East or West façade openings.

EAST ELEVATION



MINIMISE SOLAR HEAT GAIN:
BALCONIES AS SHADING DEVICES

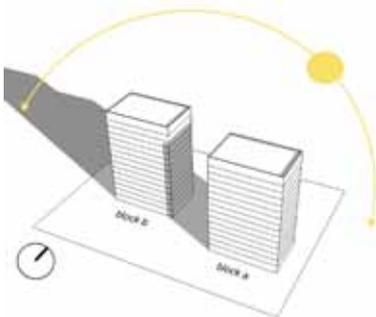


[Figure 16] Minimise solar heat gain by adding balconies as shading devices.

EAST ELEVATION



SELF-SHADING: BLOCK A SHADES
BLOCK B EAST FAÇADE



[Figure 17] Use of massing to provide shading for multiple blocks.

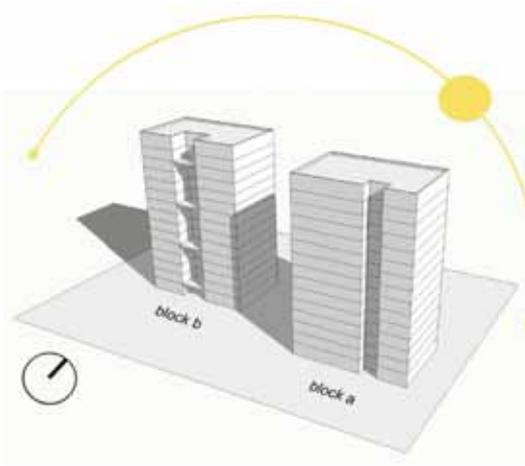
- o On East and West facing façades, consider minimising the number and size of openings [Figure 14]. The more opaque the wall area, the better since that almost always mitigate solar heat gain better than glazing. A good strategy is to plan stairs, elevators, bathrooms or other 'non-core' spaces towards the East and West.

- o For openings on East and West façades, incorporate some type of shading into the façade design to block direct solar exposure to mitigate heat gains [Figure 15]. Shading can take many forms including, horizontal or vertical projections, light shelves, exterior screening, greenery and/or balconies. Refer to Chapter 3 – Building Envelope for more details.

- o Plan balconies to be located on East and West façades. Balconies are effective shading devices that also provide outdoor access (amenity) to the building.

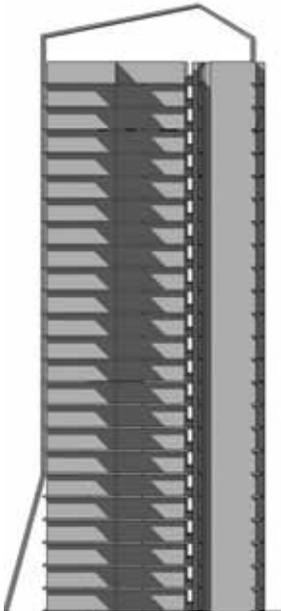
- o For projects with multiple buildings, use the massing to shade each other, particularly for East and West facing façades (i.e. self-shading) [Figure 17]. For projects with single or multiple buildings, use the massing to shade outdoor or semi-outdoor spaces.

SELF-SHADING: REVEALS IN BUILDINGS SHADE WALLS OR EXTERNAL AREAS

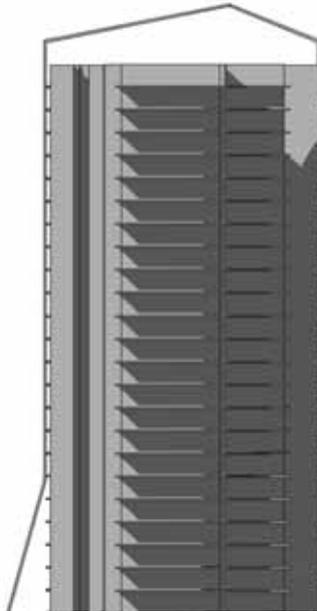


[Figure 18] Use of building mass or overhang to produce shadow / shade.

DIRECT SOUTH FACING FAÇADE AT 3PM



SOUTH FACING FAÇADE ROTATED 22° AT 3PM
WOULD SIGNIFICANTLY PROVIDE MORE SHADE
AT THE HOTTEST TIME OF THE DAY



[Figure 19] Rotation of south facing façade to provide more shade at the hottest time of the day.

- o Other strategies for self-shading include:
 - » Any building mass or overhang will produce a shadow / shade at some time during the day [Figure 18]. Understanding this and how the shadows / shade materialise can help to optimise the massing and orientation of the building(s). For example, an exterior courtyard is shaded in the afternoon hours (the hottest time of the day) or that a building is rotated just off 'true north' to help shade it from the afternoon sun [Figure 19].
 - » Provide cover to walkways, especially those that make up the primary means of circulation. This not only provides shade but also cover during rain.

There are numerous options in the planning phase via orientation and shade that can mitigate solar exposure and potential heat gains. Where strategies are specifically noted for East and West façades, employing these for North and South façades should also be considered.

[Putting It All Together]

In initial site planning, there are numerous variables to keep in mind in order to optimise passive design, land use and overall sustainability. There is always a balance to strike between variables that may seem to work against each other as there is no one-size-fits-all solution to these problems. Additionally, site constraints may limit implementation of certain strategies usually related to orientation. It is best to prioritise sustainability issues for the particular project and try to find solutions that work best for multiple variables, for example, orientation, natural ventilation and shade.

GLOSSARY

ADAPTED (OR INTRODUCED) PLANTS	Reliably grow well in a given habitat with minimal protection, pest control, fertilisation or irrigation once their root systems are established. Adapted plants are considered low maintenance and non-invasive.
BUILDING FOOTPRINT	Is the area on a project site used by the building structure, defined by the perimeter of the building plan. Parking lots, landscapes and other non-building facilities are not included in the building footprint.
DEVELOPMENT FOOTPRINT	Is the area affected by development or by project site activity. Hardscape, access roads, parking lots, non-building facilities and the building(s) itself are all included in the development footprint.
GREENFIELD	Is a site not previously developed or graded that could support open space, habitat or agriculture.
GREEN SPACE	Are areas that are vegetated, pervious and 'on grade'. It is usually calculated as the site area minus the development footprint. Roof gardens are not counted as green space (see 'open space').
HARDSCAPE	Consists of the inanimate elements of the building landscape. Examples include pavements, roadways, stone walls, concrete paths and sidewalks, concrete, brick and tile patios or plazas, etc.
IMPERVIOUS SURFACES	Have a perviousness of less than 50% and promote runoff of water instead of infiltration into the subsurface. Examples include typical parking lots, roads, sidewalks and plazas.
NATIVE (OR INDIGENOUS) PLANTS	Are adapted to a given area during a defined time period and are not invasive.
OPEN SPACE	Are areas that are pedestrian oriented and are not part of the building footprint or fully enclosed spaces (i.e. can be semi-enclosed). Examples include green space, roof gardens, amphitheatres and hardscape plaza areas.
PERVIOUS SURFACES	Or permeable surfaces, are porous enough (above 50%) to allow water to pass through into the ground or soils below. Pervious surfaces promote infiltration and therefore reduce stormwater runoff. Examples include vegetated / landscaped areas, open grid paving systems and pervious hardscape materials (i.e. asphalt and concrete).
PREVIOUSLY DEVELOPED SITES	Are sites that once had buildings, roadways, parking lots, or were graded / altered by direct human activities.
STORMWATER RUNOFF	Consists of water from precipitation that flows over surfaces into sewer systems or receiving water bodies. All precipitation that leaves the project site boundaries on the surface is considered stormwater runoff.
URBAN HEAT ISLAND EFFECT	Urban heat island effect refers to the elevated temperatures in developed areas compared to more rural surroundings. Urban heat islands are caused by development and the impact from buildings on the local micro-climate. For example, tall buildings can slow the rate at which cities cool off at night. It refers to the absorption of heat by hardscapes such as dark, non-reflective pavements and buildings and its radiation to surrounding areas. Particularly in urban areas, other sources may include vehicle exhaust, air-conditioners and street equipment; reduced air flow from tall buildings and narrow streets exacerbates the effect.

Glossary references :

LEED Reference Guide for Green Building Design & Construction, 2009 Edition.

US EPA (Environmental Protection Agency), "Reducing Urban Heat Islands: Compendium of Strategies", p6.

CASE STUDY

Optimised Orientation

ITE COLLEGE WEST REGIONAL CAMPUS

BUKIT BATOK ROAD, SINGAPORE

- o New construction on 114,800 m² site
- o 7 blocks ranging from 4 to 10 storeys
- o Green Mark Platinum certification

Key initiatives:

- o Optimised orientation to minimise solar heat gains with no direct west facing façades and extensive shade provision for buildings and semi-outdoor spaces.
- o Optimised orientation for natural ventilation of outdoor and semi-outdoor areas.
- o Green roofs installed for 40% roof area and extensive greenery provision throughout campus.
- o Rainwater harvesting for landscape irrigation.
- o Pedestrian 'innovation' walkways at levels 2, 4 and 6 shade each other and link all blocks together to encourage walking and reduce the need for lifts or other means of transport between blocks.
- o Site is located close to public transportation (LRT and bus stops). The main entrance to campus is located near the link to the LRT and secondary entrances to bus stops.
- o Naturally ventilated 2,700 m² events plaza with tensile structure to provide shade and enhance thermal comfort of occupants.



CHAPTER 3

Building Envelope



[Key Points]

A building envelope is the separation between the interior and the exterior environments of a building. It serves as the outer shell to protect the indoor environment as well as to facilitate its climate control. Building envelope design is a specialised area of architectural and engineering practice that draws from all areas of building science and indoor climate control.



Building envelope design includes five major performance objectives:

- o Structural integrity
- o Moisture control
- o Temperature control
- o Control of air pressure boundaries
- o Control of solar radiation including daylight

There are specific issues that need to be addressed when designing a building envelope in a hot-humid country like Singapore. A few tips to bear in mind are:

- 1 » Orientate your building and design your façade to mitigate heat gains. The East and West façades receive the greatest solar radiation, and should be designed to avoid direct sun.
- 2 » Use glazing in an effective and efficient manner for views and daylighting. Vertical glazing from the finished floor level (FFL) up to a height of 750 mm does not serve any daylighting or vision purpose. Glazing between 750 - 2,100 mm from FFL is considered 'vision glazing' but has minimal contribution to daylighting. Glazing above 2,100 mm from FFL is considered daylight glazing, and is most effective in

harvesting natural light for internal illumination; however, care should be taken to avoid creating glare or visual discomfort.

- 3 » Where insulation is applied to wall surfaces, the insulation shall be continuous to prevent heat conduction through the gaps.
- 4 » Glass with a lower U-value and Shading Coefficient (SC) reduces solar heat gains and subsequently, cooling loads. Low SC values are most effective at reducing heat gains. These properties need to be balanced with an appropriate Visible Light Transmittance (VLT), which affects daylighting.
- 5 » Consider life span, durability and life cycle-costing when selecting façade materials. An expensive but low-maintenance and durable material may be economical when factored over the building's life.
- 6 » Allow provision for easy access for maintenance and cleaning especially for curtain wall systems. This helps to ensure that your façade system will continue to perform at an optimal level.

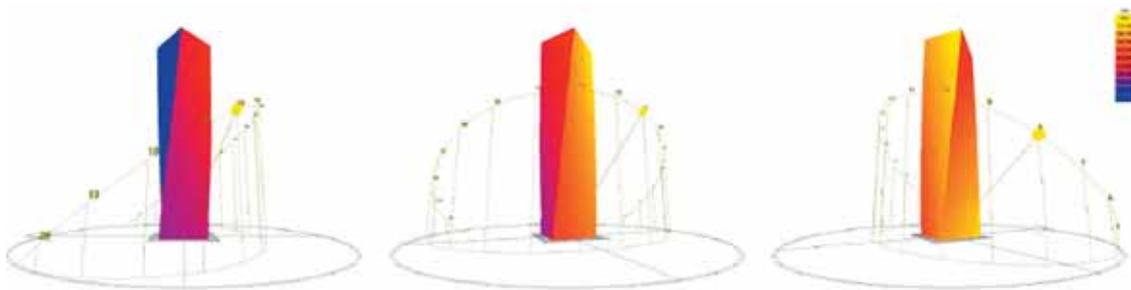
[Decisions by Building Owners and Architects]

For building owners and architectural designers, some of the most important decisions concern the building façade. It is typically the most identifiable feature of the building, and also has significant impact on the total building performance. Balancing aesthetics and performance is the key issue in building envelope design.

The performance of the building envelope is typically analysed through building physics. This process looks at

how the building envelope components react to heat, moisture and air transfer. [Figure 1] shows an example of solar radiation distributed on the building envelope. An understanding of how the envelope interacts with the outside environment is critical in designing energy-efficient and comfortable buildings. This is because the building envelope is the first step in controlling the internal environment. It keeps out moisture and insulates against

heat losses and gains, while admitting useful daylight. It influences building performance such as thermal comfort, daylight, glare, energy efficiency, natural ventilation and noise. A well-designed building envelope, as an effective environmental control measure, helps reduce reliance on mechanical systems. This eventually provides energy savings due to reduced cooling loads.



[Figure 1] Solar study to determine distribution of incident solar radiation on building envelope.

One of the more significant issues in façade design is how much and what type of glass to use. More glass means more solar heat gain, and vice versa. Significant cost savings in capital and operational costs can be achieved by

minimising the amount of glazing. Although glazing technology has advanced significantly in recent years, a typical high performance glazing unit (U-value of 1.7) still has five times the heat transmission of an insulated

spandrel panel (U-value of 0.35). Glass should therefore be placed and orientated to optimise views and daylighting whilst avoiding heat gains.

[Strategies]

Strategies to address the green building issues associated with building envelope design include:

HEAT GAIN AND ENERGY PERFORMANCE

As an environmental filter, the building façade or envelope is often the first line of defense against undesirable external elements. In Singapore, like all climates where cooling is the primary concern, the major issue is avoidance of solar radiation which leads to heat gain. This is quantified through the Envelope Thermal Transfer Value (ETTV) for non-residential buildings & Residential Envelope Thermal Transmittance Value (RETV) for residential buildings.

ETTV and RETV estimate heat gain through the building envelope, and is directly related to a building's cooling load. It takes into account the three basic components:

- o Heat conduction through opaque walls (U-value).
- o Heat conduction through transparent elements, i.e. windows (U-value).
- o Solar radiation through transparent elements, i.e. windows (SC value).

ETTV is tailored to assessing the building envelope for occupancy during the daytime (i.e. non-residential buildings' peak occupancy), while RETV is tailored to occupancy in the evening / night (i.e. residential buildings' peak occupancy). For more detailed information refer to the BCA's "Code on Envelope Thermal Performance for Buildings".

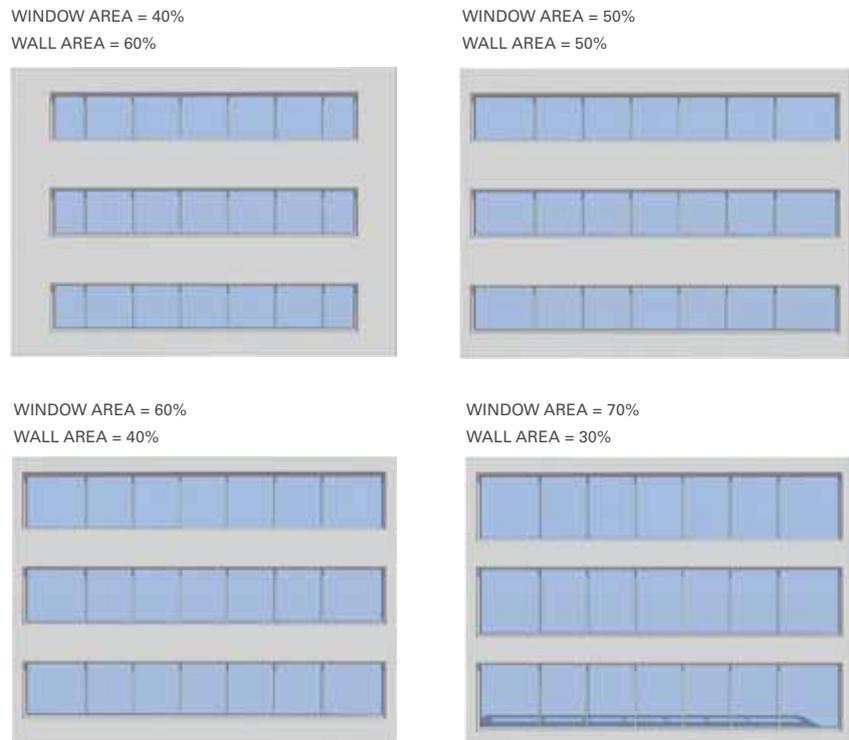
It is noted that in its current form ETTV / RETV calculations do not consider the effects of shading on opaque walls, only on glazed openings.

These three components of heat input are averaged over the whole envelope area of the building. As such, ETTV / RETV represents the thermal performance of the whole envelope. For the purpose of energy conservation, the maximum permissible ETTV has been set at 50 W/m² and for RETV, the maximum permissible level is set at 25 W/m². Roof Thermal Transmittance

Value (RTTV) operates on the same principle as ETTV, except that it addresses glazing areas and heat transfer through the roof. It is only applicable for skylights, and has the same limit of 50 W/m².

WINDOW-TO-WALL RATIO

Adjusting the window-to-wall ratio (WWR) of the building envelope affects the amount of heat entering a space [Figure 2].



[Figure 2] Window-to-wall ratios.

Some basic guidelines are:

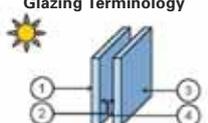
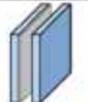
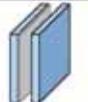
- o Lower the WWR (i.e. lesser glass and more wall). The lower the WWR, the better the ETTV / RETV. Opaque enclosures generally resist heat transfer better than glass. Reducing window size means more of the outside heat is prevented from being transferred inside because of the solid walls.
- o When the WWR goes beyond 50%, achieving acceptable ETTV / RETV and low heat gains becomes more difficult. A WWR above 50% would normally require high-performance glazing with very low SC, and/or heavy shading in order to comply with ETTV / RETV.

- Provide glazing where it is effective for views and/or daylight. Avoiding heat gains can be addressed by creative façade design, which should vary as a function of the orientation.
- Façade orientation should influence the WWR. A North facing façade receives the least solar exposure and should have the largest glazing area.

GLASS PROPERTIES

When selecting glass for any project, the most important considerations besides cost are performance properties, both thermal and visual. Glass performance can be indicated through a number of properties, such as Visible Light Transmittance (VLT), Shading Coefficient (SC) and U-value [Table 1].

[Table 1] Common glazing types and their properties.

Examples of Achievable Glazing Performance								
Double Glazing (Vertical)								
Glazing Terminology	Uncoated	Reflective Hard Low-E	Hard Low-E	Soft Low-E	Reflective Low-E	Fritted Glass + Low-E	Fritted Glass + Low-E	Fritted Glass + Low-E
	G1	G2	G3	G4	G5	G6	G7	G8
Glazing Layout								
All glass thickness = 6 mm Airfilled Cavity = 12 mm Glass =  Low-E Coating =  Selective Interlayer =  Fritted Coating = 								
U-value * Achievable centre of pane value	2.8 W/m ² K	2.0 W/m ² K	1.9 W/m ² K	1.6 W/m ² K	1.6 W/m ² K	1.6 W/m ² K	1.6 W/m ² K	1.6 W/m ² K
Shading Coefficient	0.81	0.64	0.71	0.45	0.33	0.39	0.33	0.28
T _L Visible Light Transmittance	0.79	0.60	0.73	0.68	0.42	0.59	0.49	0.38
T _{Sol} Solar Transmittance	0.61	0.46	0.52	0.33	0.23	0.27	0.22	0.17
R _{Vis1} External Visible Light Reflectance	0.14	0.29	0.16	0.10	0.34	0.15	0.20	0.25
R _{Vis2} Internal Visible Light Reflectance	0.14	0.31	0.17	0.11	0.14	0.16	0.22	0.28
STC/OITC (db)	35/30	35/30	35/30	35/30	35/30	35/30	35/30	35/30

*All values are calculated as centre of pane values for vertical applications. Spacer bars, frames and edge effects will increase the overall U-value of the glazing unit.

NB. Performance data (except acoustic) has been calculated using the LBNL Window 5.2a Software with environmental conditions NFRC 100-2001 Summer.

Glass properties have significant impact towards reducing the cooling load. Any number of measures can be undertaken to improve glazing performance, each with their own advantages and disadvantages [Table 2].

[Table 2] Advantages and disadvantages of various measures to improve glazing performance.

	+	-
Use double-glazed units	Lower U-value compared to single glazing Less heat transmission through conduction	Increased cost Greater structural loads
Use glass with lower SC	Less solar heat gain	Usually darker appearance Less opportunity for daylighting
Specify different glass according to function and orientation	Balanced budget – spend on high-performance glass where it is most beneficial	More difficult to keep track of various glass types for a single façade or window unit

Lowering the glazing SC has the greatest impact on a building’s ETTV / RETV. Best practice would have SC values in the range of 0.3 to 0.4; glass with this property effectively blocks solar heat gain.

In selecting glass options, consider balancing U-value and SC value with VLT to allow daylight in while keeping heat out. High-performance glass with VLT values of up to 62% is available in the market.

Finally, consider the use or purpose of the glass when specifying. Glazing used for daylight purposes (i.e. above 2,100 mm from FFL), could require different properties than glazing for strictly vision purposes (i.e. between 750 - 2,100 mm from FFL).

SHADING DEVICES

After considering the best options for glass, the next step in reducing heat gain would be to install sunshades. An external sunshade can often be used as a design feature but its primary purpose is to reduce solar heat gains. Its secondary functions would be to control views into and out of a building, reduce solar glare, provide rain protection for opening windows, and to serve as part of a maintenance strategy.



[Figure 3] Different types of shading devices.

CASE STUDY



High Performance Building Envelope

MAPLETREE ANSON

60 ANSON ROAD, SINGAPORE

- o New construction of 35,657 m²
- o 19 storey office tower
- o Green Mark Platinum certification

Key Building Envelope Initiatives:

- o Low ETTV of 42.78 W/m².
- o No direct East and West facing façades to optimise orientation and reduce solar heat gains.
- o Glazing specification is low-e double glazing:
 - » Highest performance on SW, NW and SE facing façades (SC value of 0.26 and U-value 1.62).
 - » NE façade has SC value of 0.45 and U-value 2.69.
- o 450 mm external louvres provide shade to the glazing to further reduce solar heat gains on SW, NW and SE façades.

Designed with a host of environmentally-friendly features including:

- o Highly energy-efficient cooling plants.
- o Innovative heat pipe technology to reduce the cooling load of the air-conditioning system.
- o Recycling of condensate to save water, thereby reducing the carbon footprint of the building.
- o Energy-efficient T5 fluorescent lights with electronic ballasts are installed in the building.
- o Motion sensors connected to the lights in the toilets reduce electricity consumption.



- o The estimated energy savings for the building is 2,300,000 kWh per year. This is equivalent to a carbon

dioxide emission reduction of approximately 1,200 tonnes a year.

Building shading devices come in different forms. In the tropics, horizontal overhangs are generally used to combat high-angle midday sunshine. Vertical fins are used to indirectly block low-angle sunshine in the early mornings and late afternoons. An egg-crate louvre, which is a hybrid of the two previous shading devices, can be used

in most façade orientations and may be the most effective solution.

Sunshading need not be limited to the above conventional examples. More unconventional solutions are louvres or screens, or adjustable external shading. Adjustable shading is considered more energy efficient than fixed shading

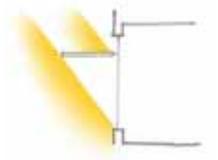
systems. However, adjustable shades often have a premium cost because of its variability, difficulties in developing robust and durable systems, and sometimes operating costs. There may also be a need to increase the façade zone depth which consequently, reduces the interior net floor area on constrained sites.

[Table 3] Different shading strategies.



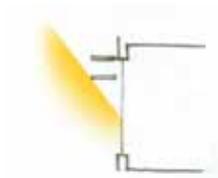
HORIZONTAL OVERHANG

- o Simple to construct
- o Effectively blocks high-angle sun
- o Ineffective in blocking low-angle east and west sun
- o Requires maintenance as leaves and bird droppings may reside on it



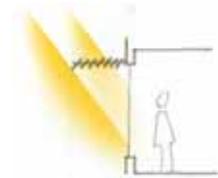
HORIZONTAL OVERHANG BELOW WINDOW HEAD

- o Simple to construct
- o Blocks high angle sun
- o Also acts as a light shelf and brings more diffuse light in
- o Ineffective in blocking low-angle east and west sun
- o Requires maintenance as leaves and birds dropping may reside on it



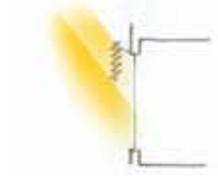
MULTIPLE SHALLOW OVERHANGS

- o Blocks high-angle sun within vision panel
- o Exposes lower portion of glazing to direct solar radiation
- o Can also act as a small light shelf
- o Ineffective in blocking low-angle east and west sun
- o Requires some maintenance



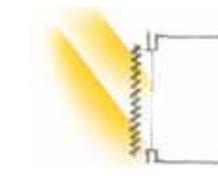
LOUVERED OVERHANG

- o Blocks high-angle sun and diffuses sunlight effectively
- o More complicated form, hence more maintenance
- o Ineffective in blocking low-angle east and west sun



LOUVERED SCREEN

- o Blocks low-angle east and west sun only at high-level
- o Exposes lower portion of glazing to direct solar radiation
- o More complicated form, hence more maintenance



FULL-HEIGHT LOUVERED SCREEN

- o Blocks low-angle east and west sun
- o Diffuses light effectively to create even daylighting
- o More complicated form, hence more maintenance
- o Obstructs views to the outdoors

In summary, sunshade design should always be informed by solar geometry and sun-path studies to ensure its effectiveness. Other factors to consider with fixed shading include:

- Architectural design.
- Potential reduction in daylight transmittance. (But equally well positioned shading can distribute daylight more evenly across a floor plate.)
- Reduced accessibility to glass for cleaning and maintenance.
- Potential impact on natural ventilation.
- Additional maintenance of shading device, especially for metal sunshades with coated or anodised finishes. Projections will typically gather dirt and other outdoor debris that require cleaning. Additionally, projections deeper than 700 mm can make cleaning and maintaining the building envelope more difficult.
- Cost and impact on ease of construction.

PERFORMANCE-BASED SHADING DEVICES

For shading devices that are more complex than conventional horizontal, vertical, or egg crate projections, a more advanced technique is required to derive the effectiveness of the shading device. Solar radiation analysis is able to demonstrate the effectiveness of a non-typical shading device (i.e. parallel screen) on a surface which then becomes a shading coefficient (SC2) applied to the ETTV calculation.

OPERABLE SHADING DEVICES

Operable, manual or automated shading devices are also available. Automated ones are typically linked to daylight sensors and/or sun tracking systems to adjust the opening of the shading device depending on the sky conditions (i.e. full sun or overcast) and/or time of day (i.e. morning or afternoon). They also help to mitigate solar glare.

DOUBLE SKIN FAÇADES

One currently popular form of façade concept in temperate climates is the double skin façade. There are several forms and arrangements but in essence the façade depth is increased to provide a zone for beneficial air flows. It is noted, however, that the efficiency of these systems are highly dependent on the local climate. From past examples, there are only two forms that may be effective in tropical climates.

The classic temperate climate (European) double skin façade features an additional external skin of glass with vents and operable windows. This design provides increased insulation for the building. In addition, air trapped within the cavity is warmed by the winter sun and provides a supply of warmed air for fresh air intakes. In summer, the stack of hot air can be used to pull drafts through the building.

To be effective for creating drafts, the cavity space should be warmer than ambient air. A significant temperature differential is needed to create buoyancy and drive air through the system. To achieve this in the tropics, the air in the cavity would also need to be hotter than ambient air. The outer skin would be effective in doing this but the result would be very hot air close to the façade, increasing heat flows into the building.



There have been design schemes that considered venting air-conditioning through this cavity but the quantities involved would increase energy to pull fresh air into the building. Furthermore, the energy spent to dehumidify this heated air would more than offset the savings from the reduced heat load.

In the tropics, double skins acting as deep shading screens could be effective passive design strategies. A screen of shading elements or even high-performance glass can be effective in keeping the building in the shade and therefore reduce heat loads. However, it is vital that the screen and cavity are well ventilated to prevent a build-up of hot air close to the inner skin.

MATERIALS

Selection of façade materials involves evaluating each decision against a range of criteria relating to their environmental performance. These criteria look into the extraction, sourcing, manufacture, maintenance and disposal of materials in relation to their performance and use.

Again, as an environmental control strategy, the building envelope or façade plays a big role in reducing heat transmission. From a sustainable point of view, the material selection and design of a building envelope should consider:

- **Insulation.** The insulating property of an opaque wall construction is indicated by the U-value. Use construction materials with low U-values to improve insulation in all opaque areas of the building envelope, not just the façade. Good roof insulation will have a major impact on reducing the solar heat gain of low rise buildings.
- **Thermal conductivity.** Some materials allow a greater heat flow than others. Colours also affect thermal performance; a white object will absorb less heat than a blue one. Good selection of materials, say ceramics and Glass Fibre Reinforced Concrete (GRC) in light tones, can reduce the heat buildup in poorly ventilated areas. Breaks in framing systems can also reduce direct heat flow. Although not required to address internal condensation, thermally broken systems can be used to avoid heat ingress.
- **Lifespan.** Durability and maintenance factor greatly reduce the life-cycle costs of a building. Use durable and low-maintenance materials to keep the running costs of a building down.
- **Recycled Content.** By using recycled materials, there is less demand for virgin material extraction, thereby helping to conserve the earth's finite, non-renewable resources. Use recycled content materials or materials with the Singapore Green Label.



A few of the common façade constructions using opaque elements [Table 4] are:

[Table 4] Common construction of opaque façade systems.

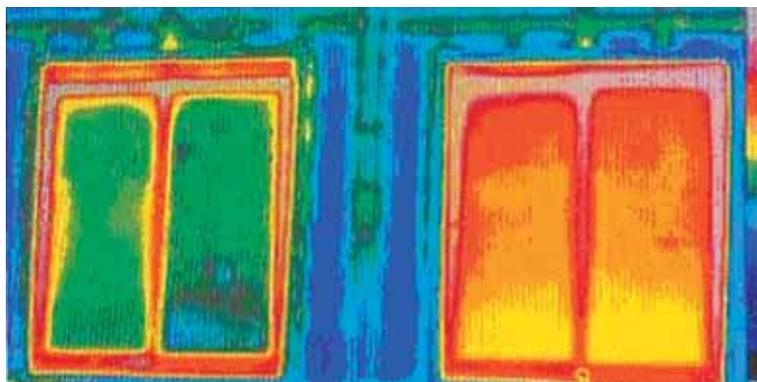
	TYPICAL WALL BUILD-UP	U-VALUE
Concrete	25 mm plaster + 300 mm concrete + 12 mm plaster	2.3 W/m ² K
Concrete with insulation	25 mm plaster + 300 mm concrete + 50 mm insulation + 12 mm plasterboard + 12 mm plaster	0.5 W/m ² K
Brick	20 mm plaster + 100 mm brick outer leaf + 100 mm brick inner leaf + 12 mm plaster	1.9 W/m ² K
Brick with insulation	20 mm plaster + 100 mm brick outer leaf + 50 mm insulation + 100 mm brick inner leaf + 12 mm plaster	0.4 W/m ² K
Metal panel	6 mm aluminium panel + 50 mm insulation + 12 mm plasterboard + 12 mm plaster	0.6 W/m ² K
Glass spandrel	12 mm opaque glass + 50 mm insulation + 12 mm plasterboard + 12 mm plaster	0.6 W/m ² K

[Other Performance Consideration]

AIR & WATER TIGHTNESS

In hot and humid Singapore, air leakage through the façade needs to be considered. Air infiltration lets in more hot and humid air, leading to higher cooling loads [Figure 4].

Best practice façade specifications require all external windows to comply with air leakage rates specified in Singapore Standard (SS 212:2007). This means that any fixed window under 300 Pa pressure differential should have air leakage rate of less than 0.95 m³/hr/m². This is typically achieved through:



- Installing a system that has a primary air seal in a dry cavity, and supporting seals and cavities;
- Verification of the façade performance through prototype testing. In best practice this may be supplemented by on site air infiltration testing. Air leaks can be identified by smoke test.

[Figure 4] Thermal image through building façade showing areas where leakages occur.

Another measure to reduce air infiltration or air leakage is to provide a vestibule or air lock, similar to building entryways in temperate climates. This prevents cool, conditioned air from spilling out into the street.

CASE STUDY

High Performance Building Envelope

TOKIO MARINE CENTRE

MCCALLUM STREET, SINGAPORE

- o New construction on 1,309.9 m² site
- o 21 storey office tower with 14,964.30 m² GFA
- o Green Mark Gold^{PLUS} certification

Key building envelope initiatives:

- o Low ETTV of 35.87 W/m² with 3 m tall glazing.
- o Use of structural elements as shading for the glazing serves one function but two purposes.
 - » The perimeter glazing of the office is wrapped within the columns of the building that is set 600 to 1,500 mm away. The column itself served both structural purpose and shading purpose for the building on all 3 façades.
 - » The perimeter beams with the recess glass form addition shading for the glazing.
 - » The result is an overall 30 plus percent of shading by both the columns and beams.
- o Double roof design increases insulation efficiency and decrease noise and vibration from chiller plant.





[Figure 5] Example of vertical greenery / green wall construction.

GREENERY

Vegetation helps reduce solar heat gain and improve the microclimate within any interior or exterior space. The incorporation of plants into buildings is a popular feature in bio-climatic design. Plants can mitigate the effect of urban heat islands, and may also reduce the energy demand of buildings. A new trend in urban greenery is the creation of urban farms – using green areas in buildings to grow crops and vegetables.

Greenery and its associated considerations are discussed more in Chapter 5 – Building Greenery and Landscaping of this book.

In terms of façade applications, green walls are becoming more popular as a design feature. In fact, plant cover within a building has long been used for its decorative and thermal effects. Sky gardens can reduce thermal load on the occupied space below. These also provide amenity and create a cool semi-outdoor space for building occupants. Semi-outdoor spaces with vertical green screens can also provide shading from the sun and contribute to the garden ambience.

Also, transpiration by plants extracts heat from the surrounding air and lowers the surrounding air temperature.

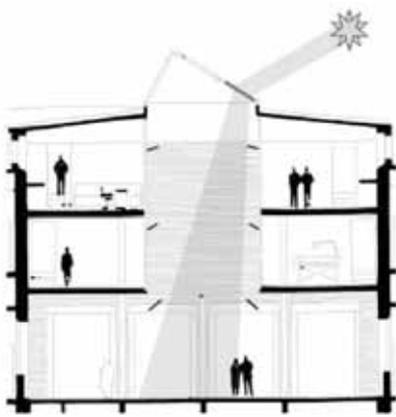
Finally, the inclusion of exterior climbing plants can lead to a noticeable decrease in chemical contaminants and air pollutants [Figure 5].

Advantages of green walls:

- Can cool a building significantly – shading and evapotranspiration removes heat.
- Visually attractive.
- Provides environmental benefits – stormwater attenuation, reduces urban heat island effect, improves air quality and insulates the building.
- Protects the wall of the building from heavy rain.

Special considerations when designing a green wall:

- Takes a long time to colonise a wall.
- Requires a trellis structure to hold it up.
- Wall needs to be solid and well built to prevent roots from taking hold in cracks and expanding, and so damaging the surface.
- Requires a relatively large amount of maintenance – irrigation, pruning etc.
- Plant selection plays a large part – consult landscaping specialist for recommendations.



[Figure 6] Daylighting strategy for internal circulation space.

DAYLIGHT AND GLARE

The presence of adequate daylight has been shown to be both beneficial for reducing the reliance on artificial lighting, and for occupant health and well-being. Good lighting design maximises the use of natural daylight to provide illumination. This minimises electrical lighting consumption and reduces internal heat gains from luminaires.

Good daylighting strategies and concepts are also discussed in the guide on BUILDING SYSTEMS. [Figure 6] shows a typical daylighting strategy to light-up internal circulation space.

When designing windows or openings for daylighting, it is good to consider some guidelines established from architectural practice and analysis of light in buildings:

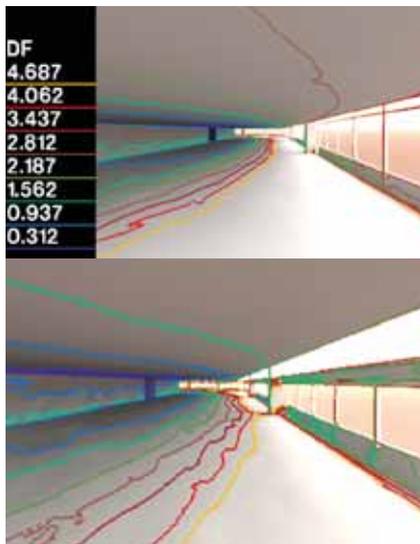
Glazing that stands above 2,100 mm is considered 'daylight panels' – these are the parts of a window that are most effective in bringing daylight into a space. The closer a panel is to the ceiling, the more effective it is in providing natural daylight.

Light shelves help to improve daylighting by throwing reflected daylight further into a space [Figure 7]. They can also provide shading and reduce glare in the perimeter zone. In this manner, light shelves help achieve a greater uniformity in daylight distribution on the working plane.

Window blinds are another means to modulate daylight and reduce glare. These are often manual systems which allow individual control. This enables users to block out unwanted daylight and glare during sunny days. However, oftentimes blinds remain drawn even during cloudy or overcast days. This reduces the daylighting potential of the window, and increases reliance on artificial lighting. Because of this, it is best to have blinds automated, with manual overrides for individual users. This ensures that the blinds are drawn up automatically during the day to maximise daylighting.

Some other things to bear in mind when designing the building envelope for daylight:

- o Computer modelling is a useful tool in determining indoor daylight levels. Daylight simulation can help inform the designer, especially at the early stages of potential problems such as glare, or poor daylight distribution.
- o Windows provide useful daylight penetration up to a depth of 2 to 2.5 times the window head height.
- o Use blinds or louvres (internal or external) to reduce glare. Use daylight simulations to design and select the type of blinds or louvers.
- o When glazing is confined to one wall, the recommended glazing width is at least 35% of the height of the wall.



[Figure 7] Daylight simulation showing an office space without light shelves (top) compared to an office space with light shelves (bottom). Daylight distribution is better with light shelves, with less glare at the perimeter zone next to the windows.

CASE STUDY



High Performance Building Envelope

**ROBERT BOSCH
SOUTH EAST ASIA
REGIONAL HEADQUARTERS**
BISHAN STREET, SINGAPORE

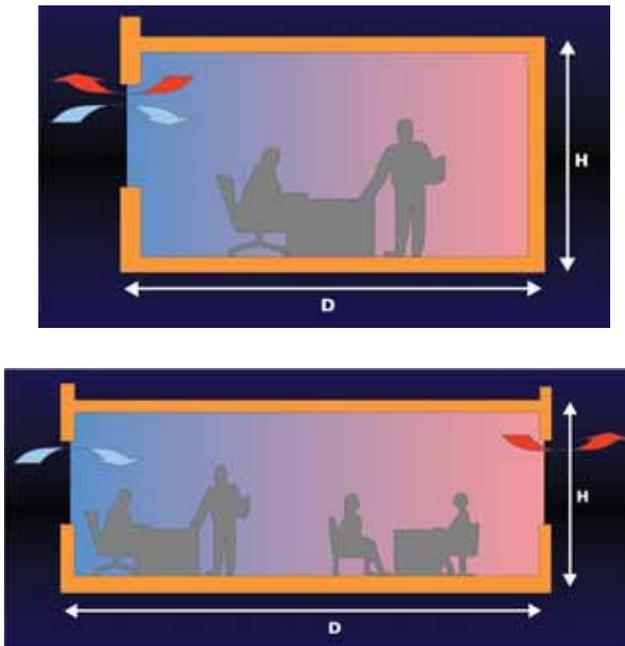
- o New construction on 0.98 ha site
- o 7 storey office tower
- o Green Mark Platinum certification

Key building envelope initiatives:

- o Low ETTV of 41.87 W/m² with each façade below 47.0 W/m².
- o Single and double glazing is used on the façade, according to orientation and solar exposure. All glazing (single or double) has SC value of 0.45 or lower.
- o External louvres provide shade to the glazing to further reduce solar heat gains.
- o Automated aluminium blind system responds to brightness, wind speed, humidity and solar position, reducing glare and providing better indoor daylight conditions.
- o Roof has thin film, mono and poly-crystalline PV panels installed for electricity generation and research purposes with a total power of 88.15 kWp.



NATURAL VENTILATION, OPERABLE WINDOWS & ACOUSTICS



[Figure 8] Ventilation strategies based on window location.

Windows in office and residential buildings are primarily designed to provide views and daylight; however, more and more architects and designers are considering windows as opportunities for natural ventilation [Figure 8]. Providing operable windows also safeguards fresh air availability in the event of mechanical failure.

Designing for air flow strategies requires an understanding of the convective loop. Hot air is lighter than cold air and hence, rises. It creates air movement that designers can capitalise on for ventilation. Low-level and high-level openings facilitate air flow within a room. The key issue in façade design is the location of operable windows. Openings can be on the same wall, or on opposite walls to facilitate cross-ventilation.

Though they are highly desirable in general, operable windows [Table 4] should only be used where spaces are to be naturally ventilated or offer a mixed-mode ventilation strategy. Otherwise, the building envelope needs to be as airtight as possible, to avoid hot air from creeping in and cold air from leaking out.

Noise ingress is a critical issue in naturally ventilated spaces. Acoustic mitigation measures should be designed into the building to address this. The guidebook on "Indoor Environment Quality and Ecological Impact" provides clearer guidelines for this.

Other considerations need to be taken into account in designing for natural ventilation, are mentioned in Chapter 2 – Natural Ventilation.



[Table 5] Types of operable windows.



SIDE-HUNG WINDOW

- o Has a fixed range of opening (usually up to 90°)
- o Can be fully open (100% of aperture unobstructed)
- o Operable panel can be used as a wind scoop to direct wind through the window
- o Size and hardware need to consider reach (distance) to close the window

SLIDING WINDOW

- o Has a limited range of opening (usually up to 50% of aperture size)
- o Tracks at base and head are difficult to effectively seal whilst keeping the window operable (high air infiltration and acoustic performance)

TOP-HUNG WINDOW

- o Has a fixed range of opening (usually up to 90°) but typically limited for safety to a 150 mm opening
- o Less effective for ventilation
- o Can provide partial protection from rain

LOUVRES

- o Has a wide range of opening
- o Blades can direct air flow into the space
- o Tends to obstruct views
- o More complex mechanisms required to make operable
- o Prone to air leakage

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GLOSSARY

DF	Daylight factor, unit-less; the ratio of outdoor illuminance to indoor illuminance. It is a building property that shows how much daylight enters a space through windows or openings in the building envelope.
DGU	Double glazed unit or insulated glass unit. Two sheets of glass separated by a structural and impermeable spacer to create a sealed cavity. Air is generally trapped, but air may be replaced by other gases to further improve thermal insulating performance.
ETTV	Envelope thermal transmittance value, expressed in W/m^2 ; a property that quantifies the amount of heat that enters a non-residential building through the external envelope. In Singapore, the maximum permissible value is $50.0 W/m^2$.
GLARE	A phenomenon wherein an occupant or observer experiences visual discomfort, which sometimes contributes to temporary visual impairment. It is caused by strong contrasts or large ratio of luminance between surfaces.
HARD COATS	Coatings applied to glass that are generally more robust than soft coats being applied directly to the molten glass in the float process.
LOW-E	Low emissivity. The effect of a low-e coating is to reduce the radiation of long wave length energy or emissions. However, it is increasingly used as a general term for all performance coatings to glass that change the glasses reflectance, absorption and transmission properties.
RETV	Residential envelope thermal transmittance value, expressed in W/m^2 ; a property that quantifies the amount of heat that enters a residential building through the external envelope. In Singapore, the maximum permissible value is $25.0 W/m^2$.
RTTV	Roof thermal transmittance value, expressed in W/m^2 ; a property that quantifies the amount of heat that enters a building through the roof. In Singapore, the maximum permissible value is $50.0 W/m^2$.
SC	Shading coefficient, unit-less; a property that quantifies a window's ability to transmit solar heat, as compared to a base case of 6 mm clear single glazing. It is expressed as a number between 0 and 1; the lower the SC, the less heat gets transmitted through the window.
SOFT COATS	Coatings applied to glass sheets individually once they have been cut into the required or a manageable size. Some can be heat processed, but generally are susceptible to damage and are generally used inside DGU.
THERMAL COMFORT	A state in which an occupant feels satisfied with his environment; it is affected by five major factors – air temperature, mean radiant temperature, humidity, air velocity, clothing level, and activity level.
U-VALUE	Overall heat transfer coefficient, expressed in W/m^2K ; a property that quantifies a material or construction's ability to conduct heat. The higher the u-value, the more heat passes through the material.
VLT	Visible light transmittance, unit-less; a property that quantifies a glazing's ability to allow light to pass through. It is expressed as a number between 0 and 1; the higher the vlt, the more light gets transmitted.
WWR	Window-to-wall ratio, unit-less; the proportion of window area to total wall area, expressed as a number between 0 and 1.

CASE STUDY

High Performance Building Envelope

OCEAN FINANCIAL CENTRE RAFFLES PLACE, SINGAPORE

- o New construction on 6,100 m² site
- o 43 storey office tower with 96,000 m² GFA
- o Green Mark Platinum certification

Key building envelope initiatives:

- o Low ETTV of 42.76 W/m² with 73.7% WWR.
- o Façade is triple low-e coated glazing (SC value of 0.25 and U-value 1.51).
- o Triple glazing is 8 mm (glass) - 15.5 mm (air gap) - 6 mm (glass) - 1.5 mm (clear pvb) - 6 mm (glass).
- o Carpark is naturally ventilated and has extensive vertical greening (1,665 m²) to reduce heat gains.
- o 4 levels of roof gardens provide 74% greenery coverage to roof area.
- o 400 m² of PV panels installed on roof area for electricity generation with a total power of 75 kWp.

Developed by Keppel Land, Ocean Financial Centre is the first office development in Singapore's CBD to be presented the BCA Platinum Green Mark Award.

*Through its green features, Ocean Financial Centre will achieve **overall energy savings of 35%**. The harvesting of rain water, recycling of condensate water and use of water-efficient tap fittings will contribute to savings of **42 million litres of water** annually, which can fill 21 Olympic-sized swimming pools. The introduction of a paper recycling chute designed into the office premises to encourage tenants to recycle paper will help **save more than 10,000 trees** annually.*



CHAPTER 4

Natural Ventilation



[Key Points]

Natural ventilation is a term used to refer to a situation where air movements occur across or within buildings without the aid of any mechanically driven machines such as fan or air conditioning. In the drive towards energy and environmental efficient design of buildings, it is imperative to optimise building designs to draw clean fresh air from the outside environment into building openings. Enhancing natural ventilation within the built environment aids in:

- 1 » Removing heat build-up from dense urban areas.
- 2 » Reducing energy consumption especially from mechanical ventilation means.
- 3 » Improving human comfort within occupied spaces.
- 4 » Increasing controllability of thermal comfort controls.
- 5 » Improving indoor air quality.



Being 'natural' and dynamic in nature, the behaviour of wind is random and at times, difficult to predict. Good natural ventilation may be achieved in a building through careful site selection and building design. Considerations to optimise natural ventilation should be discussed right from the start of the project, preferably during site selection. Good building designs promoting airflow can then be planned progressively from location, block massing, and orientation and moving on to the details such as the spatial arrangement within the building, opening sizes and locations, etc. Simulation tools should also be used to assist in these design development right from the beginning. However, where outdoor air conditions and acoustics do not permit for naturally ventilated spaces, mechanical means may then be the preferred option. Traditionally, natural ventilation will appeal to building types such as residential homes, schools, recreational buildings, sports facilities and public buildings, and even in specific spaces within air-conditioned buildings.

[Decisions by Building Owners and Architects]



To achieve good natural ventilation around a site and within occupied spaces, careful considerations must be taken right from the beginning of the project starting from site selection phases and through to detailed design phases. Airflow prediction models such as Computational Fluid Dynamics (CFD) and wind tunnel testing are useful in studying wind effects due to building designs to aid the design process and not just used as a verification tool. Generally, the Owner should note the following during site selection:

- What is the general topography or terrain roughness of the site? The rougher the terrain, the slower the wind.
- Are there surrounding buildings or structures that may obstruct or aid in wind flow towards the site? Usually buildings in close proximity obstruct wind flow.
- Where is the prevailing wind direction and velocity?

Once the site is selected, the architect should note the following when planning and designing his building:

- building height and roof geometry
- building shape
- external building projections
- window / door size and location
- room partitions

.....

[Getting Started]

Local design codes such as the Singapore Fire Code (2007) stipulates the design of ventilation openings for fire safety compliance for exit passage ways such as lobbies or staircases while the BCA Building Control Regulations prescribe requirements with the objective to protect people from loss of amenity due to lack of fresh air. The Building Control Regulations (Regulation 27) requires natural ventilation to be provided by one or more open windows or openings with an aggregate area of not less than 5% of the floor area of the room or space required to be ventilated.

In addition to fire safety and the provision of tenable spaces, a well ventilated building is energy efficient, provides thermal comfort to the occupants and achieves good indoor air quality. Understanding the benefits of good ventilation ensures that the project team explores all available opportunities to provide good natural ventilated spaces over mechanically ventilated ones.

ENERGY EFFICIENCY

In a well designed naturally ventilated building, no energy is needed to cool or move the air. Occupied spaces can achieve good thermal comfort through passive designs such as good orientation, well insulated building envelope systems, good sunshading devices, vegetations, etc. Furthermore, a naturally ventilated building does away with costly mechanical ventilation system which often brings along problems of noise, sick building syndrome and higher maintenance and operational costs. It also reduces the building's carbon footprint consequently. For example, public housing in Singapore is generally designed to allow for good natural ventilation and hence active mechanical cooling is not required.

THERMAL COMFORT

Human thermal comfort is defined as the condition in which a person would prefer neither warmer nor cooler surroundings. The thermal sensation experienced by a person affects his perception of comfort and as with any comfort parameters, this is highly subjective and varies from person to person. Several comfort standards exist internationally that determine conditions whereby a specified percentage of occupants will find themselves thermally comfortable. Most of these standards are however developed for air-conditioned space conditions (e.g. ASHRAE Standard 55:2004 or ISO 7730:2005).

In general, there are six primary factors driving the sensation of comfort. These are:

- | | | |
|-------------------------|---------------|-------------------------|
| 1 » Air temperature | 3 » Air speed | 5 » Metabolic rate |
| 2 » Radiant temperature | 4 » Humidity | 6 » Clothing insulation |



CASE STUDY

Natural Ventilation



BISHOPSGATE RESIDENCES

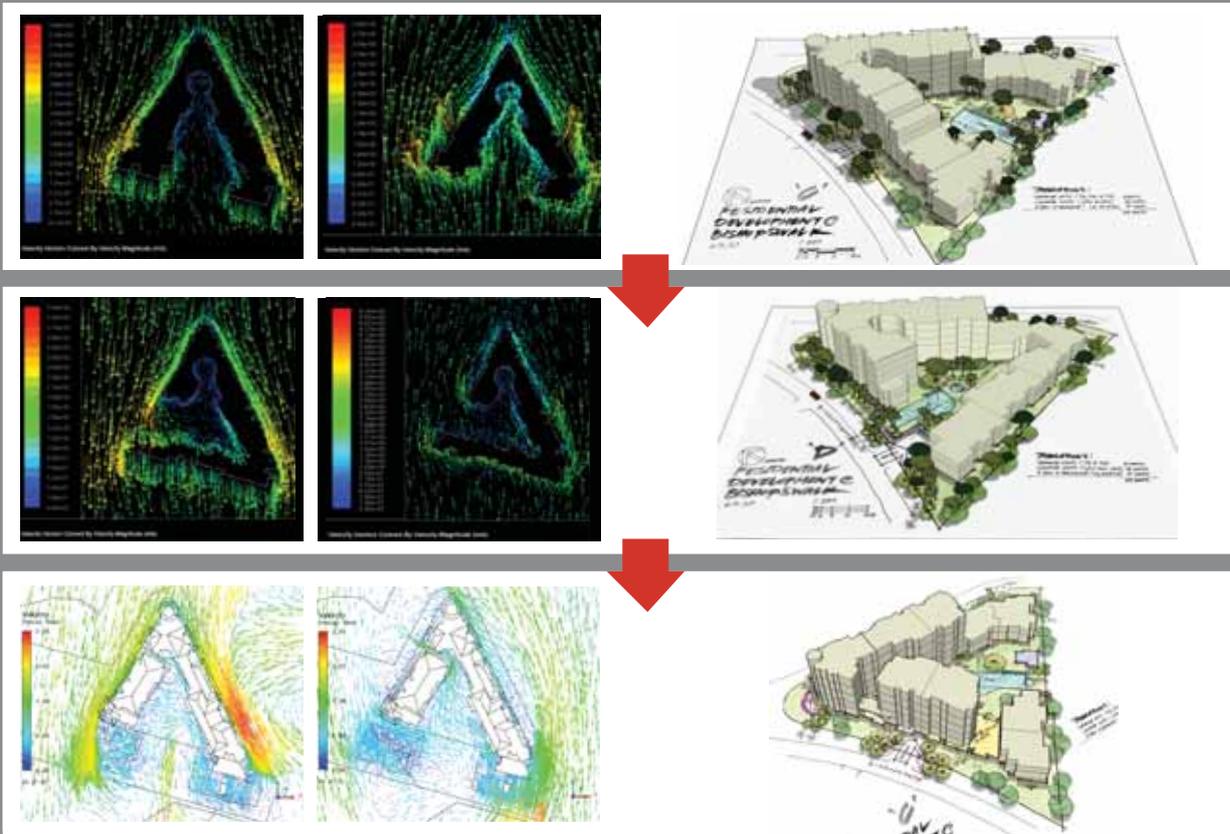
NO. 1 BISHOPSGATE, SINGAPORE

- o 29 nos. of super-luxury condominium residences and a pair of semi-detached houses
- o Passively designed to maximise natural light, ventilation and temperatures
- o Green Mark Platinum certification



Key initiatives to improve natural ventilation in residential units:

- o Units are configured to allow cross ventilation and this includes naturally ventilated service lobbies.
- o Simulations were conducted during concept design stages to assist in block massing and layout of units.
- o At estate level, building massing was studied and simulations were conducted to evaluate permeability of blocks in channelling wind movement throughout development especially to the centre garden court.
- o Final scheme consisted of gaps between blocks to allow airflow to reach centre garden court. Heights of the blocks were also staggered to prevent obstruction to wind movement.



In a naturally ventilated environment, air temperature and humidity closely follow that of the external ambient conditions while radiant temperature can be controlled using good wall materials and sunshading devices. Air speed remains the parameter that may be improved through

good design. Increasing air speed can shift the thermal comfort zone to regions of higher air temperatures. This is because air movements determine the convective heat and mass exchange of the human body with the surrounding air. A higher air velocity will increase

the evaporation rate at the skin surface and consequently enhance the cooling sensation. This means that occupants can be in good thermal comfort conditions at higher air temperatures. Hence, it is crucial that buildings are designed to maximise air movement.

Thermal Comfort Criteria in Singapore

Studies have been conducted in Singapore to develop a thermal comfort criteria for tropical outdoor conditions. [Figure 1] shows the comfort chart that has been developed from this study based on the weather data in Singapore (having Relative Humidity (RH) between 55 to 85%). The equations below may also be used for the determination of Predicted Mean Vote (PMV).

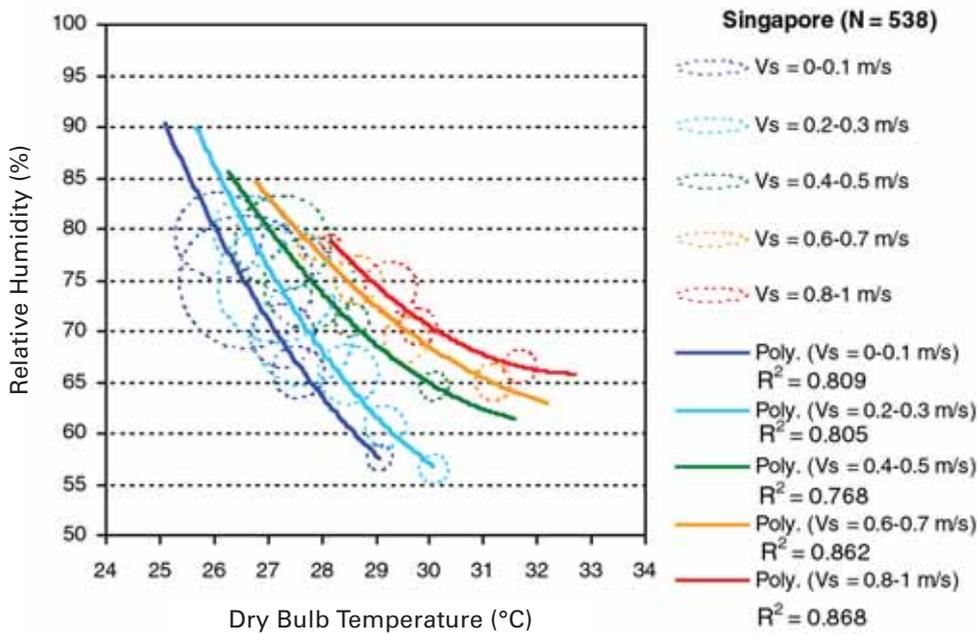
Equation 1---- Predicted PMV = 0.2447*Temp-1.5727*Wind^0.5+0.0957*(MRT-Temp)-5.7

Equation 2---- Predicted PMV = 1.2*((0.4257*Temp-12.04)+(0.26-1.231*Wind))

where Temp, MRT and Wind denote air temperature, mean radiant temperature and wind speed respectively.

Under a hot and humid condition (RH of 65 - 80%) with average wind speed of 0.4 - 0.5 m/s, the air temperature should be maintained under 30°C in order to maintain a thermally comfortable condition.

At lower wind speeds (0 to 0.1 m/s) and RH not higher than 85%, one may feel fairly comfortable only within the temperature range of 25 to 29.5°C. At higher wind speeds of 0.8 - 1 m/s, comfort can be achieved at the temperature range of 28 to 32°C. In general, a higher wind speed allows a person to tolerate higher air temperatures and yet still achieve thermal comfort.



[Figure 1] Thermal Comfort Chart for Singapore.

Source: Givoni, B., J. Khedari, N H Wong and M. Noguchi. (2006). "Thermal sensation responses in hot, humid climates: effects of humidity". Building Research and Information, 34, no. 5 (Special on Indoor Environmental Quality).

In general, the following air velocities in [Table 1] may be used as a guide to achieve human comfort. [Table 2] gives recommendations for wind velocity under various air temperatures (dry bulb) under indoor naturally ventilated environment.

[Table 1] Recommended air velocities for achieving thermal comfort.

WIND FOR INDOOR AIR COMFORT	~ 1 m/s	Over occupant body sitting indoors
WIND FOR OUTDOOR AIR COMFORT	~ 1.5 m/s	When in shade, sitting or walking
WIND GUST	< 5 m/s	When walking

Source: Department of Architecture, CUHK. (2006). "Final Report for Feasibility Study for Establishment of Air Ventilation Assessment System".

[Table 2] Recommended air velocities for achieving thermal comfort under various air temperatures.

AIR TEMPERATURE (°C)	RECOMMENDED WIND VELOCITY (m/s)
28	0.3
29	0.5
30	0.8
31	1.2
32	1.5
33	1.8
34	2.2

INDOOR AIR QUALITY (IAQ)

Natural ventilation is also a good strategy for achieving acceptable indoor air quality. A poor environment can result in occupants suffering from sick building syndromes such as allergic reactions, respiratory problems, eye irritation, sinusitis, bronchitis and even pneumonia. The source of indoor pollutants may vary depending on the types of building and the occupants. Typical contaminants may be categorised into five major classes as follows:

- 1 » Microbial contaminants
- 2 » Gases (Carbon monoxide, radon, volatile organic compounds)
- 3 » Particulates
- 4 » Chemical substances, i.e. solvents
- 5 » Environmental Tobacco Smoke (ETS)

By promoting good air exchanges between internal and external spaces, the concentration of contaminants may be diluted and removed.

WIND CONDITIONS IN SINGAPORE

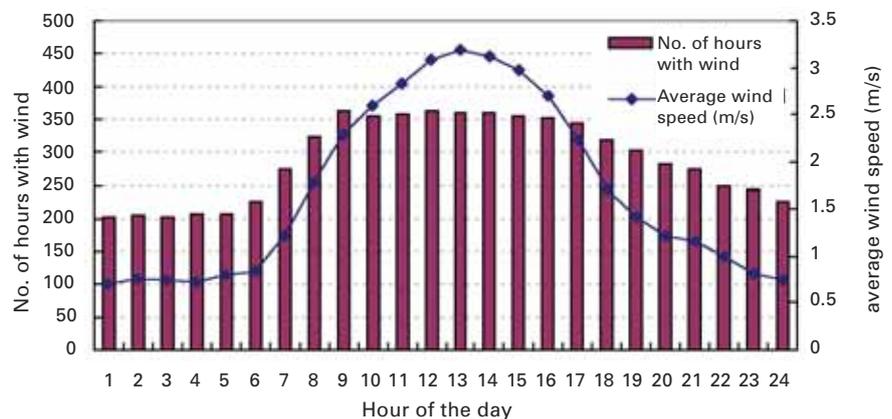
Singapore is situated at 1°20 North of equator and has a climate with uniformly high temperature, high humidity (about 84 RH%) and abundant rainfall throughout the year. It has a diurnal temperature range of minimum 23 to 27°C and maximum 30 to 34°C.



The climatological year in Singapore can be divided according to the direction of prevailing winds. The Northeast monsoon prevails during December to March and the Southwest monsoon from May to September, both of which are characterised by generally rainy periods with persistent trade winds, and separated by two relatively short inter-monsoon periods with light and variable wind. In Singapore, the prevailing wind directions are from the North and Northeast directions during the Northeast monsoon while those in the Southwest monsoon are from the South and Southwest.

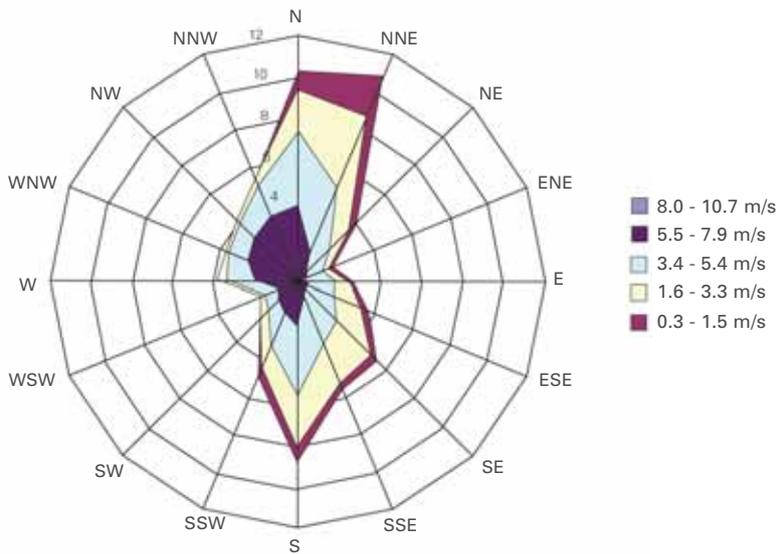
Variability of wind velocities occurs between day and night. Night time velocities from 11pm to 7am are generally below 1.0 m/s. However, as surface heating progresses during daylight hours, thermally driven local circulation can give rise to higher wind speeds. [Figure 2] shows the wind frequencies in Singapore throughout the year. The average wind velocities in Singapore is about 2 m/s. The windiest months of December, January, February and March fall within the Northeast monsoon. Wind direction during the inter-monsoon periods tend to be variable. [Figure 3] shows the wind rose diagram of predominant wind directions from North and South in Singapore. [Table 3] shows the winds effects on people based on different types of speed.

Wind direction and velocities are key input data in building orientation and air flow prediction. It is important to note that wind data are location dependent and if possible, data from the weather station nearest to the project site should be referred to. Climatic data may be obtained from the Meteorological Services Division, NEA.



[Figure 2] Wind velocity distribution in Singapore.

SINGAPORE WIND ROSE



WIND SPEED (m/s)	ANNUAL % OF TIME
< 0.3	20.2
0.3 - 1.5	25.6
1.6 - 3.3	28.1
3.4 - 5.4	20.5
5.5 - 7.9	5.5
8.0 - 10.7	0.1
10.8 - 13.8	< 0.1

[Figure 3] Wind data from Meteorological Service Singapore – Changi Station 1975 - 2006.

[Table 3] Beaufort Scale – Wind effects on people.

TYPE OF WINDS	BEAUFORT NUMBER	WIND SPEED (m/s)	EFFECTS
Calm, light air	1	0 - 1.5	Calm, no noticeable wind.
Light breeze	2	1.6 - 3.3	Wind felt on face.
Gentle breeze	3	3.4 - 5.4	Hair is disturbed, clothing flaps.
Moderate breeze	4	5.5 - 7.9	Raises dust, dry soil and loose paper – hair disarranged.
Fresh breeze	5	8.0 - 10.7	Force of wind felt on body.
Strong breeze	6	10.8 - 13.8	Umbrella used with difficulty, hair blown straight, difficult to walk steadily, wind noise on ears unpleasant.
Near gale	7	13.9 - 17.1	Inconvenience felt when walking.
Gale	8	17.2 - 20.7	Generally impedes progress, great difficulty with balance.
Strong gale	9	20.8 - 24.4	People blown over by gust.

Source: Penwarden, A.D. and Wise A.FE. (1975). "Wind Environment around Buildings": BRE report, London.

WIND CHARACTERISTICS

Being able to understand the fundamental flow behaviour of airflow across and through obstacles could give a huge advantage over achieving a well ventilated building. In essence, air moves through a building due to pressure gradients across it. Pressure gradients may be created from 2 manners:

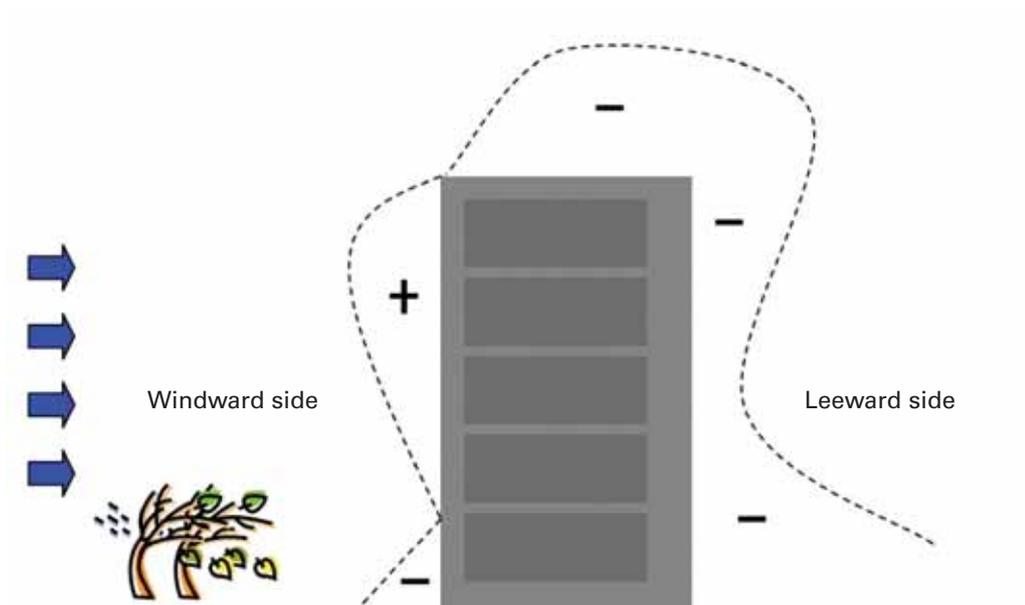
- 1 » Pressure differences due to distribution of wind pressures on buildings.
- 2 » Pressure differences due to variations in air density (due to air temperature) with height (stack effect).

Wind flow pattern is hence dependent on the pressure distribution across the building or other forms of obstruction.

FLOW AROUND BUILDINGS

Wind incident perpendicularly on a building face will produce a positive pressure on the windward side and a relative negative pressure (suction on the leeward side). The pressure difference created, together with the pressure differences inside the building vis-à-vis that externally will drive airflow [Figure 4].

When wind direction is oblique, there is an even sharper drop in pressure from the windward to the leeward corners and this induces a greater flow than when the wind impacts perpendicularly.



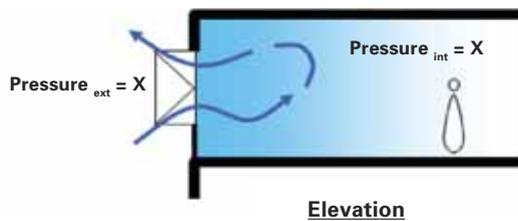
[Figure 4] Positive and negative pressure on windward and leeward side respectively.

FLOW VERTICALLY WITHIN BUILDINGS

In situations where a temperature difference exists between outdoor and indoor air (possibly due to solar radiation gain, internal heat loads, etc), a thermal buoyancy effect is created. This results in warmer air rising upwards to escape through an outlet at the top. This creates a negative pressure in the building, thereby inducing cooler air from outside to enter the building through an inlet nearer to the ground [Figure 5]. Known as 'Stack effect', it usually occurs in cold winter climates where the internal and external temperatures differences are more significant. In tropical climates, the use of 'Stack effect' (both passive stack that uses solar radiation to heat up the top of the stack, or active stack that uses a mechanical means to draw air upwards) to bring about ventilation requires further study. However, this strategy will likely see greater potential only for buildings with tall atriums or stacks.

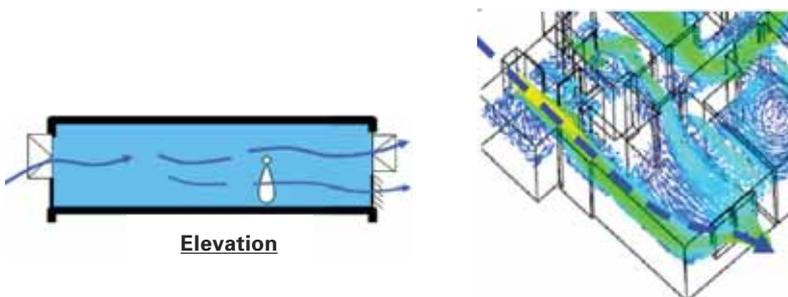
FLOW INTO BUILDINGS

Providing windows only on either the windward wall or leeward wall of a room does not promote good ventilation. This is because in cases of such single sided ventilation, the indoor pressure rises or falls to equal the external pressure and as a result, the flow of air into the room will not be able to reach the far side of the room [Figure 6].



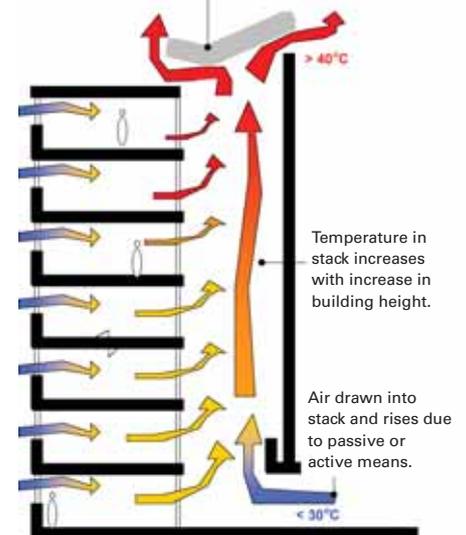
[Figure 6] Single-sided ventilation.

When windows are provided in both the windward and leeward sides of the building, a flow of air is induced through the building from the high to the low pressure regions. [Figure 7] shows cross ventilation occurring as air enters the building on one side, sweeps the indoor space and leaves the building on another side. Aligning the inlet and outlet to directly face the incident wind will let the air stream continue in an undeflected path. Though cross ventilation is achieved, the building is not effectively ventilated. Rather, if the inlet is at 45° to the wind, a circular turbulent motion is created and this ventilates the building more effectively [Figure 8]. Hence it may be better if the air stream is allowed to change directions within the building than to let it flow directly from inlet to outlet. It is important to note that cross ventilation will not occur when windows face zones of similar air pressures.

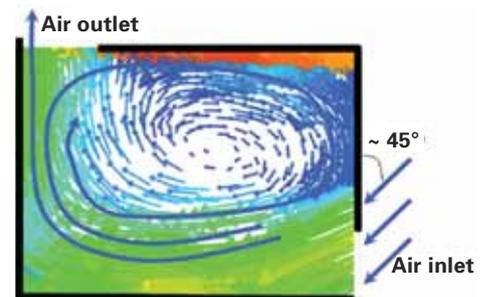


[Figure 7] Wind driven cross ventilation.

Top of stack may have heating element (passive stack) or exhaust fan (active stack) to induce air movement



[Figure 5] Stack pressure driven natural ventilation.



[Figure 8] Wind enters inlet at 45° and circulates within room before exiting from outlet.

CASE STUDY

Natural Ventilation



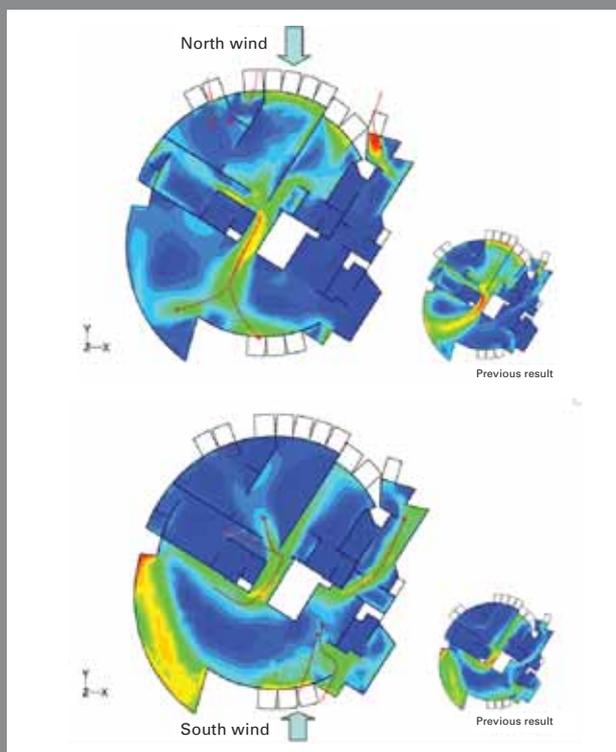
CLIVEDEN @ GRANGE
NO. 24 GRANGE ROAD, SINGAPORE

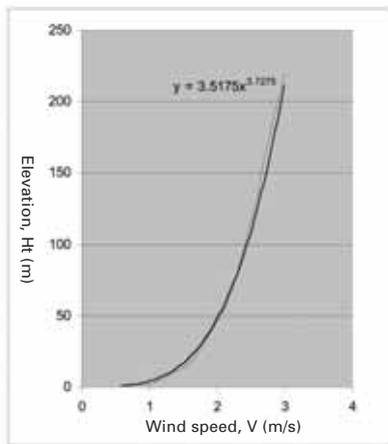


- o 4 blocks of 24 storey luxury residential development
- o Total of 110 units
- o Green Mark Platinum certification

Key initiatives to improve natural ventilation in residential units:

- o Airflow simulation was conducted at conceptual design phase and used as basis to explore possible design changes to improve airflow into and within the units.
- o The following design changes were made as a result to improve airflow and comfort conditions within the living spaces:
 - » new openings were made at the master bathroom.
 - » window openings at bedroom was repositioned.
 - » openings at dining area was enlarged by 15%.
 - » internal wall was redesigned to channel airflow into bedroom.
- o The airflow simulation was re-run following the design changes to verify the improvement in airflow profile and velocities.





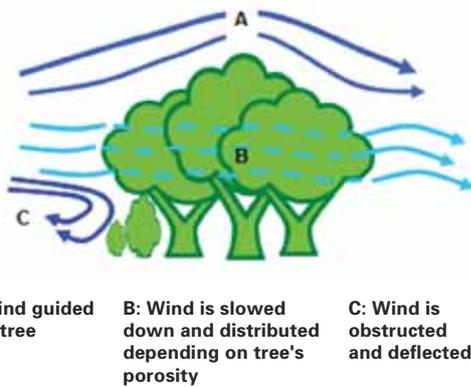
[Figure 9] Wind profile used for boundary input.

VARIATIONS WITH HEIGHT

Wind speed varies with height where its intensity increases exponentially with the height from the ground. Typically at 100 m above the ground, the wind speed may rise up to 2.5 m/s. The wind profile power law is usually used to determine wind speeds at greater heights. [Figure 9] shows the wind speed variation with respect to building height above the ground level. Wind nearer to the ground is affected by the terrain roughness and generates turbulence. Turbulence decreases with increasing height.

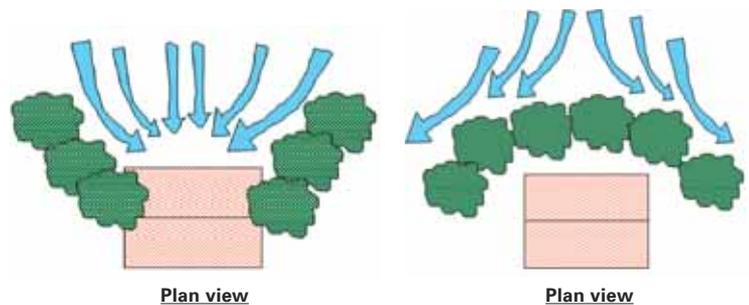
WIND FLOW AROUND VEGETATION

The form, density and rigidity of vegetation will affect air movement differently. They may even reduce the heat content of the air passing through its foliage to bring about a temperature reduction of the wind. Shrubs outside a window can also create positive and negative pressure zones, thereby channelling and increasing the wind velocity as it enters the room. [Figures 10 and 11] below show the influences of vegetation on airflow path.

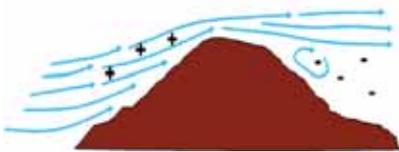


A: Wind guided over tree **B: Wind is slowed down and distributed depending on tree's porosity** **C: Wind is obstructed and deflected**

[Figure 10] Vegetation influences the pattern of air movement.



[Figure 11] Vegetation can divert wind to flow (left) towards or (right) away from a building.



[Figure 12] Wind characteristics as it flows over a hill.

WIND FLOW OVER A HILL

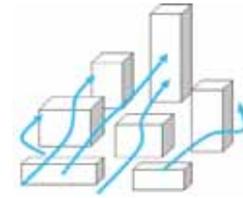
Generally, when a mass of air approaches a hill, most of it is deviated upwards along the upwind slope and flows downwards along the downwind slope. A small portion of the flow may pass the hill around the sides. A higher pressure zone (higher velocity) is created at the vicinity of the summit and a low pressure zone (low velocity and turbulence) is created at the foot of the slope [Figure 12].

STRATEGIES AT ESTATE LEVEL TO ACHIEVE GOOD NATURAL VENTILATION

Good natural ventilation depends on the macro-environment. Some of these strategies at estate and building level include:

1 » Create flow paths. Open spaces should be linked; open plazas should be created at road junctions; low-rise structures should be maintained along routes of prevailing wind; and greater road widths should be allowed to increase overall permeability of the district.

2 » Arrange buildings according to ascending heights. Buildings should be laid out in rows with the lower heights in front and towards the direction of the prevailing wind [Figure 13]. This will create better wind flows at higher levels.



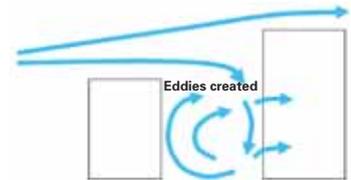
[Figure 13] Increasing height of buildings to allow wind to reach blocks behind.

3 » Stagger buildings. The arrangement of the blocks should be staggered such that the blocks behind are able to receive the wind penetrating through the gaps between the blocks in the front row [Figure 14].



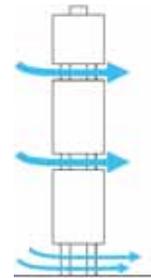
[Figure 14] Staggered arrangement of blocks with sufficient spacing between blocks.

4 » Create downwash wind. Building design should consider capturing the downwash wind to reach the street level. Eddies may form in the canyon and this may assist in providing air movement within the canyon as well as into the buildings [Figure 15].



[Figure 15] Building geometry and layout to allow downwash to ventilate streets and allow air movement into buildings.

5 » Improve building permeability. Buildings should be as permeable as possible to channel airflow to the blocks in the back row [Figure 16]. Sky gardens and double volume void decks can increase the permeability of blocks.

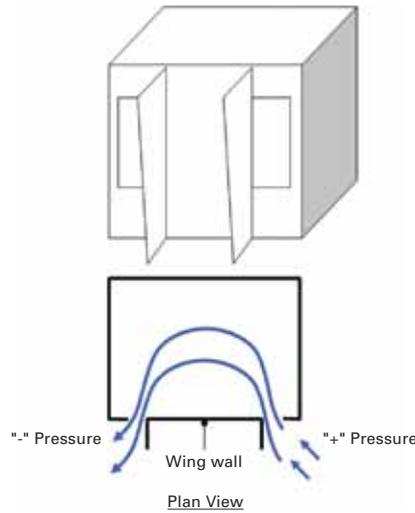


[Figure 16] Sky gardens and void decks increase permeability of block.

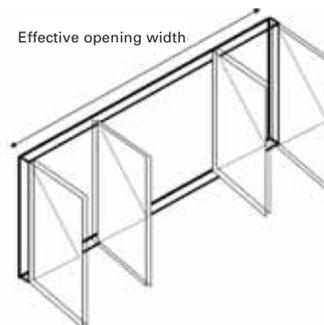
STRATEGIES AT RESIDENTIAL UNIT LEVEL TO ACHIEVE GOOD NATURAL VENTILATION

At the residential unit level, considerations should be given to window design, space layout and room partitioning to optimise air movement into the residential unit. Efficient space layout would ensure a positive pressure gradient to drive wind across those spaces. Besides that, window openings should also be designed according to its potential to draw in fresh air from the environment. Different types of windows design may have different ability to draw in fresh air into a building. Thus, when deciding types of windows (casement, sliding, top-hung, monsoon, etc) to be used, criteria such as locations, opening sizes and numbers must be taken into consideration. Some of these strategies include:

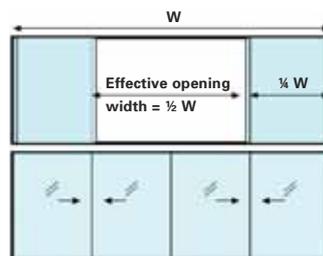
- 1 » If windows are possible only on one side of the wall, vertical projections can be provided to create artificial pressure and suction zones. These are known as 'wing walls' [Figure 17]. They are useful for improving ventilation if placed on the windward side of the building.
- 2 » Windows should be positioned at 45° to the wind direction.
- 3 » Windows should be provided at both windward and leeward walls.
- 4 » Unequal inlet and outlet sizes can induce higher air velocities.
- 5 » Casement windows allow for larger opening sizes and allow wind to be deflected into the interior [Figure 18]. Sliding windows [Figure 19], louvred windows [Figure 20] and pivot windows reduce the opening sizes. Monsoon windows promote ventilation even during times of rain [Figure 21].



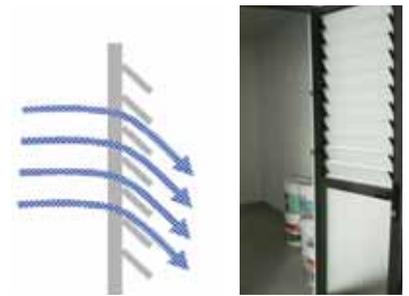
[Figure 17] Wing walls improve ventilation into a space where openings can be made only on one side of the space.



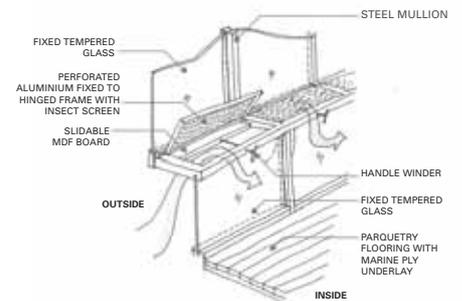
[Figure 18] Casement window unit allows the opening size to be maximised when all the windows are opened.



[Figure 19] The effective opening size of a casement window unit depends on the manner of sliding its leaves.



[Figure 20] Section view of louvred door / window. It has the effect of deflecting airflow downwards and reducing the airflow into the space depending on its percentage of perforation.



[Figure 21] Monsoon windows allow wind movement into the unit without allowing rain to penetrate into the unit.

Photo courtesy of Tim Griffith
Sketch © WOHA All Rights Reserved



[Figure 22] A typical wind tunnel setup.

TOOLS FOR AIRFLOW PREDICTION AND ASSESSMENT

The commonly used tools for the study of airflow are wind tunnel testing and Computational Fluid Dynamics (CFD) simulation. Unlike wind tunnel testing, CFD simulation is based on computer modelling and hence allows wind patterns due to each design change to be studied quickly.

WIND TUNNEL

In wind tunnel testing, scaled models (usually 1:500) are placed in the wind tunnel and subjected to wind effects generated by a fan unit placed at the end of the wind tunnel [Figure 22]. Wind sensors are then placed at areas where wind velocities and pressures are monitored. Though it allows data on wind movements and velocities around and in building to be assessed, the method is typically expensive and tedious since scaled models of the building have to be made and tested under laboratory conditions.

A qualitative investigation of the effect of wind movement around and in a building is usually made using visual assessment aided by photographic and flow visualisation techniques. A quantitative investigation obtains point velocities in and around buildings. This can also be made usually for wind-load considerations of high rise buildings.

COMPUTATIONAL FLUID DYNAMICS (CFD) SIMULATION

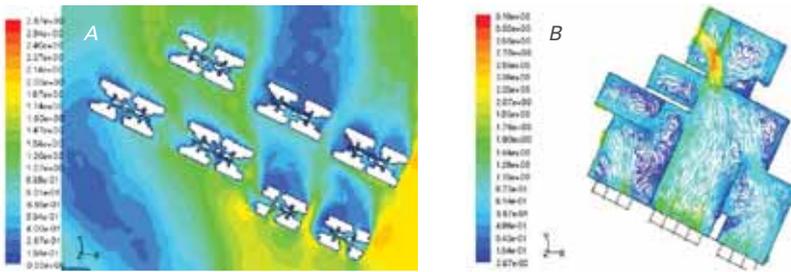
Computational Fluid Dynamics (CFD) simulation is an alternative tool to predict wind movement accurately. It allows the impact of design changes to be effectively studied before the design is confirmed.

CFD simulation generally involves 3 stages:

- 1 » Pre-processing. This is the first step in building and analysing a flow model. It includes building the model, creating and applying computational mesh, and entering flow boundary conditions. Typical flow boundary conditions generally applicable for use in Singapore include:
 - Flow domain with minimum 3 times the characteristic lengths of development buildings.
 - Mesh density at estate level set at 10 m at far field.
 - Finer resolutions mesh of 0.5 - 1 m near buildings and at ground level.
 - Wind velocity as shown in [Table 4]

[Table 4] Recommended wind velocity for use as boundary conditions.

NORTH	2.0 m/s
NORTHEAST	2.9 m/s
EAST	3.0 m/s
SOUTHEAST	3.2 m/s
SOUTH	2.8 m/s
SOUTHWEST	2.3 m/s
WEST	1.8 m/s
NORTHWEST	1.4 m/s



[Figure 23] Air velocity contour plots at estate level (left) and vector plots at unit level (right) conducted for HDB's demo eco-precinct: Treelodge @ Punggol.

Source: HDB

- 2 » Solving. A CFD solver / program will perform the calculations to generate airflow profiles and data.
- 3 » Post-processing. It involves the organisation and interpretation of the predicted flow data and the production of CFD images such as the velocity contour and vector diagrams [Figure 23].

[Putting It All Together]

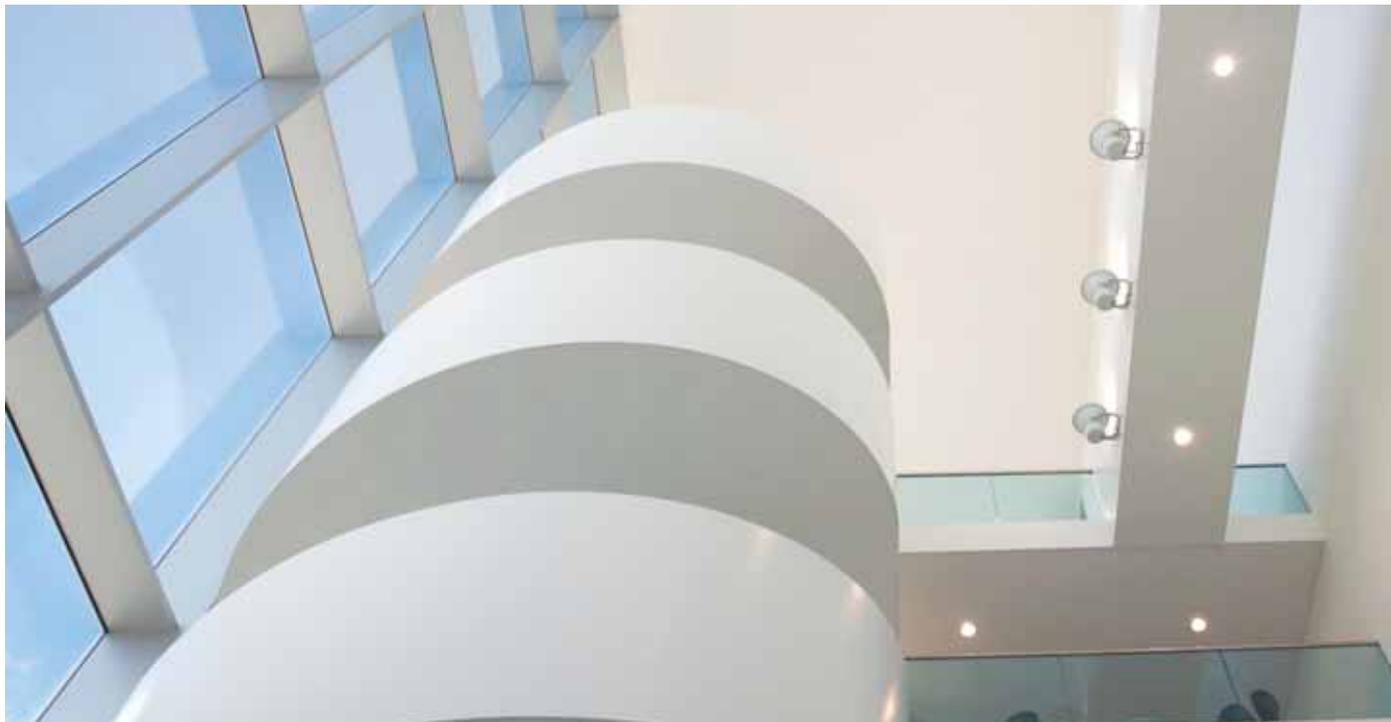
Singapore's tropical climate is generally hot and humid with average temperature remaining largely similar across the year. With good passive designs that promote natural ventilation, most of our common areas within buildings can be thermally comfortable without the need for air-conditioning and fan systems. This brings about energy savings. Design for good air movement begins from site selection and progresses into detailed architectural and space planning. Tools such as wind tunnel test and airflow simulation help to develop designs for good cross ventilation.

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GLOSSARY

COMPUTATIONAL FLUID DYNAMICS	A computational study of air movements in motion. Computers perform calculations to simulate the interaction of air movement with the building site model conditions.
EDDIES	Air currents that are moving contrary to the direction of the main wind flow, especially in a circular motion.
LEEWARD WALL	A wall surface which the wind is blowing away from.
NATURAL VENTILATION	A situation where air movements occur across or within buildings without the aid of any mechanically driven machines such as fan or air-conditioning.
PREDICTED MEAN VOTE (PMV)	This index predicts the mean response of a large group of people according to the ASHRAE thermal sensation scale of +3 (hot) to -3 (cold). It is usually read together with Predicted Percentage Dissatisfied (PPD) which is a quantitative measure of the thermal comfort of a group of people at a particular thermal environment. As PMV changes from zero to either the positive or negative direction, PPD increases.
PREVAILING WIND	Wind that blows most frequently across a particular region.
RADIANT TEMPERATURE	The temperature that takes into consideration the radiant heat emitted by surrounding objects.
STACK EFFECT	The flow of air that results from warm air rising, creating an area of positive pressure at the top of a building and a negative pressure at the bottom of the building. This induces the infiltration of cool air into the space. Also known as 'Chimney effect'.
THERMAL BUOYANCY	Refers to the upward movement of particles when it is hotter than its surrounding environment.
WINDWARD WALL	A wall surface which the wind is blowing against.
WING WALL	A wall that is attached to the main wall surface to induce wind movement into the building.



CASE STUDY

Natural Ventilation

VOLARI CONDOMINIUM

12 BALMORAL ROAD,
SINGAPORE 259820

- o 1 block of 12 storey residential development
- o Total of 85 units
- o Targeting Green Mark Platinum certification

Key initiatives to improve natural ventilation in residential units:

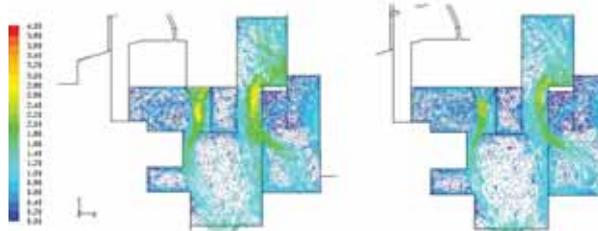
- o Extensive airflow simulations were conducted to assist in design development and ensure good natural ventilation.
- o Simulations were used in one particular instance to study if changes in window opening sizes would affect airflow velocities and profiles.
- o It was noted that under prevailing South wind conditions, the reduction in opening sizes resulted in a 30% reduction in air velocities. However, the wind velocities remained within comfort ranges.
- o The simulations assisted the designers in determining the optimum window sizing for comfort conditions.



North Wind Scenario

Original windows height – 1,450 mm

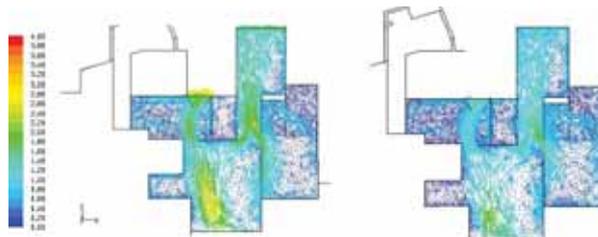
Modified windows height – 1,200 mm



South Wind Scenario

Original windows height – 1,450 mm

Modified windows height – 1,200 mm



CHAPTER 5



Building Greenery and Landscaping

[Key Points]

Extensive greenery and landscaping within a development can reduce ambient air temperature, improve air quality, reduce the building's heat gain and energy consumption and mitigate **Urban Heat Island** effect. In planning for greenery and landscaping, the team should not only consider the aesthetic effect plants have on the architectural outlook of the development but also their environmental and social benefits. The Greenery Provision (GnP) measures the extent of greenery within the development and the shading effects of various forms of greenery. In general, three main types of greenery may be considered for a development. These are:



GROUND GREENERY

External ground greenery is the most effective strategy to protect against heat build-up and control ambient temperatures at a macro level. External landscaping at ground level may be in the form of trees, palms, shrubs and turfing. The landscaping plan sometimes may include waterbodies such as fountains as a mean to add 'blue architecture' to the overall 'green' effect of the development.

GREEN ROOFS

The greatest benefit of green roofs is that it provides thermal insulation to interior spaces below it and also becomes a habitable space for people and animals, thereby promoting biodiversity. These also help to slow stormwater runoff and improve its quality. Creating a roof garden requires careful planning since the roof space is traditionally also a highly sought-after location to site building services such as water tanks, cooling towers, plant rooms, etc.

VERTICAL GREEN WALLS

As buildings grow taller, the façade area also increases. Growing plants on the external walls not only reduces heat transmission into the building, especially if installed on the east and west façades but also protects the façade from weathering and forms feature walls that express creativity. Planning for vertical green walls requires early consideration for maintenance, structural safety, irrigation and long-term durability of the backing wall.

[Decisions by Building Owners and Architects]

Different building types have different requirements for greenery. For example, a residential development may like to have extensive green spaces to give residents a natural and tranquil environment. On the other hand, a warehouse development with a small number of full-time occupants may choose to maximise usable floor area instead. For owners and architects, the functional requirements expected by the building users, such as to increase visual interest, provide recreational space for

the occupants or create a natural environment must firstly be considered. Proper design of planting and greenery strategies is important to fully support the needs of activities expected by building users.

During the design stage, it is important to ask the following questions:

- Are there trees that can be protected and conserved [Figure 1]? If not, can these be removed and transplanted back after the development is completed?
- How much green space can be provided? The percentage of green space may sometimes be specified in a land sales agreement.
- Where are the ground areas that could be green? Sidewalks, carparks, circulation spaces, etc.
- Can the roof be freed up for greenery? Can building services be located elsewhere?
- Can vertical greenery be implemented? Do windows need to be provided for viewing and daylighting?
- What are the irrigation needs for the development? Can the development rely fully on non-potable water for irrigation?
- Are the maintenance and replacement of plants easy?

[Getting Started]

The successful implementation of a greening plan requires early site planning and requires an integrated design approach, involving the landscape designer, architect, owner, maintenance team, engineering consultants and environmental consultants. In developing the greening strategy, the following information would be helpful:

- 1 » What is the original site like?
If the site is a green field with dense vegetation and rich biodiversity, it will be important to retain as much of these characteristics as possible. Strategies can include ensuring that sufficient green areas are set aside so that as much plant and animal life as possible may be restored to the pre-development level. Green belts should also be provided within the development to connect adjacent green pockets together. Greenery may also help to control rainwater runoff quantity and quality such that the pre and post-development levels are maintained.
- 2 » What is the sun's path across the site? Areas receiving intensive solar exposure can be covered with greenery to minimise heat accumulation and at the same time optimise plant growth. However, the right plants must be selected to withstand the intense solar exposure.
- 3 » What is the building design?
Are there façades, atrioms and balconies that can be greened?
Can spaces be naturally ventilated instead of providing air-conditioning?
Can vegetation be provided as a means to cool the space?
- 4 » Can greenery be designed to fulfill other functions such as space identification, way of finding, demarcating site boundaries, water filtration as well as noise and ventilation control?
- 5 » What are the native plants that could provide for maximum shading at maturity and at the same time fulfill aesthetical requirements?
- 6 » What is the quantity of water that could be harvested from rainwater, air-conditioning condensate or recycled from grey / black water and stored for irrigation? This would help decide how much greenery and the type of plants to use.

[Strategies]

The strategies to 'green' your development include:

GROUND GREENERY AROUND THE DEVELOPMENT

External landscaping is one of the most cost effective ways for improving and sustaining the quality of life. Open green spaces such as parks and fields can be a reliable source of carbon reduction. The greenery absorbs heat and cools the area through **evapotranspiration**. It provides pleasure from an aesthetic sense and will have direct benefits in reducing energy consumption and sizeable amounts of carbon emission.

To increase greenery around the development:

- Identify trees that can be protected and conserved. Depending on the type of species, trees can take at least 5 years to reach maturity. Hence, they should be left intact as long as possible. If not, they should be removed and transplanted back to the development when it is completed.
- Trees provide the most protection against solar exposure, followed by palm, shrubs then turfing. They contribute greatly to a development's GnP. Provide for as many trees (defined as those with canopy radius of at least 1.5 m at maturity) as possible within the development [Figure 2].



[Figure 1] Preparation of trees for conservation and transplanting to another location.



[Figure 2] Trees with big canopy provide good shading.

- Shrubs, palms and small trees may be planted densely and linearly or as an alternative to fencing, boundary walls, etc. They can soften and disguise the boundary lines and create an overall green appearance for the streetscape and neighbourhood. They can also be used to demarcate different areas of use, restrict movement into the area or hide unpleasant structures away [Figure 3].



[Figure 3] Shrubs and small plants can be creatively used as an alternative to fencing or for a guiding pathway and at the same time create an aesthetically pleasing environment.

- Open grid paving slabs that allow for plant growth should be considered when surface carparks are designed for. These allow grass to grow over as well as allow for surface rainwater runoff to infiltrate into the ground. Both reduce heat build-up in the hard surface [Figure 4].
- Evaluate possibilities of using indoor plants. Atriums or lobbies of shopping malls, offices, etc may be suitable for internal planting [Figure 5]. Consider skylights, roof opening, natural ventilation and irrigation systems at such places to create a conducive environment for plants to grow. In return, the plants provide shading, diffuse daylight, control noise reverberation, cool the environment and have therapeutic effects on occupants.

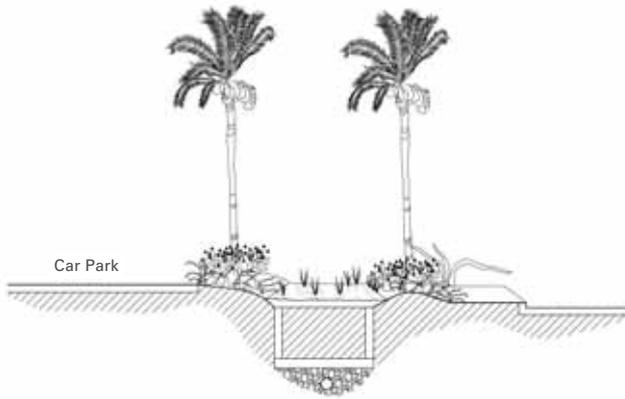


[Figure 4] Open grid carpark paving.

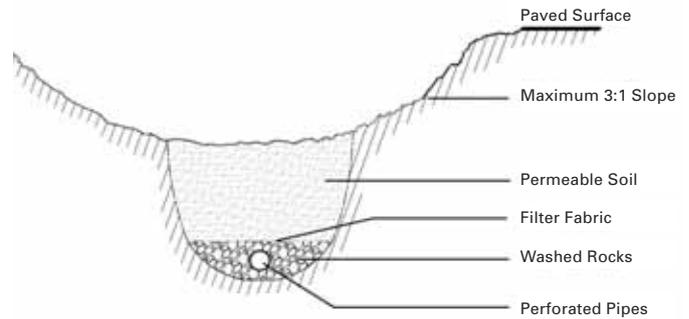


[Figure 5] Indoor planting creates good indoor environment.

- o Construct bioswales instead of concrete drains. Bioswales are densely vegetated open channels constructed with gentle slopes to allow runoff to be channeled and filtered by vegetation. The runoff that passed through the bioswales can be directed away for re-use or to public drains. Bioswales further help to slow down the flow and reduce the amount of storm water runoffs [Figures 6 and 7].



[Figure 6] Section showing a bioswale.



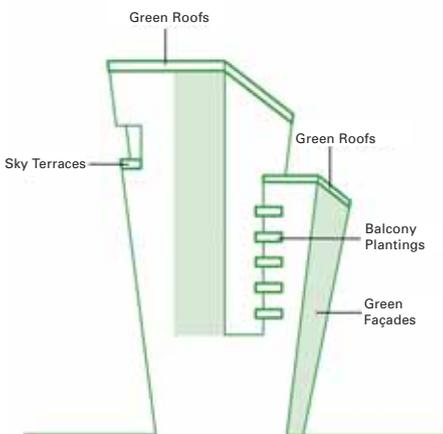
[Figure 7] Section through a parabolic-shaped dry swales.

Encourage planting edible plants to form part of the greenery (urban agriculture). This can increase the amount of fresh vegetables and fruits available to people living in cities. It also offers the potential to use organic waste for composting, thereby reducing the need for landfill. Larger benefits exist for the community such as the creation of small businesses that can be owned and operated by the community to sell home-grown vegetables and fruits.

When the above strategies have been maximised or when site constraints do not allow for sizeable planting at ground level around the development, greenery can then be integrated into our buildings – skyrise greenery.

SKYRISE GREENERY

In land-scarce countries like Singapore, where development covers about 90.2% of the land area of the country, the external landscapes can sometimes be viewed as a luxury of space. Sky-rise greening becomes an alternative way of integrating greenery into the urban spaces. As we continue to build taller buildings, huge opportunities are created for greenery to be incorporated into our façades, sky terraces, balconies and roofs. These are known as sky-rise greenery [Figure 8].



[Figure 8] Forms of skyrise greenery.

Strategies to increase greenery within the building include:

- o Vertical greenery systems on façades
- o Sky terraces, balcony planters and green roofs

VERTICAL GREENERY SYSTEMS

Vertical greenery systems are defined as the growing of plants on, up, or against the façade of a building or feature walls. They can be broadly classified into two (2) major categories: **support system** or **carrier system** (For more details, please refer to “Vertical Greenery for the Tropics” by NParks-CUGE, NUS and BCA).

In support systems, plants are grown directly from the ground adjacent to the façade or grown from soil contained in planters housed at regular floor intervals. The plants are allowed to climb on specially designed supporting structures such as wire mesh, cables, trellis, etc [Figures 9 and 10]. They are generally more economically attractive than the carrier system but the climbing plants may take some time to provide ample coverage to the façade. Maintenance of the system is relatively simple by manual pruning and ensuring that plants are watered at the planters where the plants are grown from.



[Figure 9] The modular trellis panel system (left) and its close up (right).



[Figure 10] The cable and wire-rope net system (left) and its close up (right).



[Figure 11] The plant-cassette system (left) and its close up (right).



[Figure 12] The modular system (left) and its close up (right).

[Figures 13 to 15] show typical vertical greenery applications in Singapore. They consist of different species of plants to create an interesting pattern.



[Figure 13] Green wall at Singapore Changi International Airport.



[Figure 14] Overview of the living wall and its close-up view (insert).

Carrier systems (also known as 'living walls' systems) consist of pre-vegetated panels that are fixed vertically to a wall structure. These panels can be made up of a wide range of materials including plastic, synthetic fabric, clay or metal and support a great diversity and density of plants.

Carrier systems give a totally different feel as the plants are not climbers but small, creeping herbaceous perennials, ferns, grasses and small shrubs. Usually, an intricate and robust irrigation system needs to be built into the structure since the growing media generally do not retain water so well due to gravity. The increased loading onto the walls, the types of plants, water tightness requirements of the wall, etc are all factors leading to higher capital and maintenance costs for carrier systems.

A variety of alternative designs have been derived from the living wall systems, such as planter-cassettes or the modular system with patented substrate seen in [Figure 11] and [Figure 12] respectively.



[Figure 15] The green façade of the multi-storey car park at Republic Polytechnic.

Strategies to implement vertical greenery system include:

- Identify locations where they can be implemented. Look out for staircase cores, gable end walls or façades that face East or West. Conducting a sun path analysis or solar radiation study may help in identifying walls that receive good solar access. Internal walls at atriums, lobbies, core walls, etc are also good locations for green walls although special lamps may be required to support photosynthesis.
- Assess if there are structural implications if a green wall is installed. Green walls should be avoided at locations where high winds are expected since it may affect the growth of plants and the structural safety of the system.
- For example, the corner of a building where the wind tends to concentrate may adversely affect the growth of plants and structural stability of the system.
- Discuss with owners, users, facility managers and landscape contractors to understand the capital costs and downstream maintenance costs of different greenery systems. Generally, support systems are simpler and more cost effective to implement than carrier systems.
- Regardless of the system selected, design for proper and safe access for regular pruning, replacement, and fertilising of the plants as well as maintenance of irrigation systems and building wall behind the green wall.
- Work with landscape consultants / contractors who are familiar with vertical greenery. Different plant species grow differently when planted from a horizontally or vertically inclined growing media.

CASE STUDY

Enhanced Greenery



TREELODGE @ PUNGGOL

HOUSING AND DEVELOPMENT
BOARD'S ECO-PRECINCT



- o A housing precinct of seven 16 storey blocks in a site area of 2.9 ha, comprising 712 public residential units
- o The enhanced landscaping concept has allowed it to achieve a higher overall Greenery Provision above 4.0

Greenery features in precinct:

- o Planter boxes and green balconies at selected units to encourage skyrise greening.
- o Low maintenance green roof system using one of HDB's green innovations i.e. Prefabricated Extensive Green (PEG) roof system.
- o Podium car park design concept where the residential blocks sit on a single storey car park extended across the entire precinct. The roof of the car park (Eco-Deck) has a Green Spine that links the precinct amenities. The Eco-Deck is landscaped, with provision for a community garden, green pavilion roof, trellises and vertical greening. Extensive greening of the Eco-Deck creates a larger green footprint. The Eco-Deck also features a 'hybrid green roof system' which reduces the depth of the soil bases required for planting, and hence also reduces the size of the deck structures.
- o There is also a Green Path of approximately 600 m on the peripheral of the precinct to allow residents to jog or take leisure walks.



The Treelodge @ Punggol demonstrates how the provision of greenery in an urbanised setting can provide environmental, ecological and socio-economic benefits, especially in a densely built-up city-state like Singapore. The enhanced greenery also mitigates the Urban Heat Island Effect, cools the surroundings and further improves and enhances the living environment in HDB estates.

*Treelodge @ Punggol and Prefabricated Extensive Green (PEG) roof system
By courtesy of HDB Building Research Institute*

SKY GARDEN

Sky terraces and green roofs serve as green communal spaces for building occupants but also offer environmental and ecological benefits. In addition, green roofs also increase the thermal resistance of the roofs thereby reducing heat flux through the roof and into the spaces below. Roof top gardens have been measured to reduce surface temperatures of roof by more than 10°C.

Sky terraces are covered spaces located within the building serving as public spaces for communal use and enjoyment. These usually double up as recreational areas and may contain outdoor dining areas, swimming pools, observation decks and smoking areas, etc.

Green roofs, as the name describes are located on the roof of the building and generally classified as either **extensive green roofs** or **intensive green roofs**.

ROOFTOP AT HDB APARTMENT



GREEN ROOF AT SCHOOL OF ART, DESIGN AND MEDIA AT NTU IN SINGAPORE



[Figure 16] Extensive green roofs.

Extensive green roofs have relatively shallow soil bases grown with plants that need low maintenance and are self-generative. They require minimal maintenance and usually do not need irrigation systems. They can be placed on the roof with slopes up to 35°, although a baffle system is needed for the slopes above 20° to prevent the soil slump. They are mainly designed to provide aesthetic and ecological benefits and mostly not accessible for public use [Figure 16].



[Figure 17] Intensive green roofs in Singapore.

Intensive green roofs are developed to be accessible for public use and they are sometimes known as 'roof gardens'. They have a deeper soil base than extensive green roofs and often include trees, palms, shrubs and turfing. Being a garden, they may also be designed with walkway, water features, seats and irrigation systems. Due to the weight of the plants, deeper soil base requirement and amenities, etc, they need to be specially designed into the building and roof structure [Figure 17]. Furthermore, regular garden maintenance such as mowing, fertilising, watering and weeding is required for intensive landscapes.

Strategies to implement sky-rise gardens include:

- Recognise that sky-rise gardens if properly planned and designed can become a useful and highly valued spaces in buildings. They can improve the property value and the marketability of the development.
- Plan for sky terraces and roof gardens into the design concept so that structural, irrigation and access for maintenance issues are discussed and allowed for. Some mechanical services may need to be relocated to other parts of the building as well.
- Sky-rise gardens ideally should be opened to building users so plan for recreational facilities to be incorporated so that they can be fully utilised.
- The roof of machine rooms, bin centres and guard houses, etc, are also opportunities for extensive green roof systems to be considered.
- Roofs of existing buildings may also be converted into green roofs easily without extensive structural retrofitting. For example, HDB has installed green roofs on many of its existing public housing apartment blocks as well as multi-storey carparks.
- To reduce heavy water consumption for irrigation needs, consider strategies for rainwater and condensate water harvesting as well as recycling of wastewater.



BALCONY PLANTERS

Balconies and planter boxes are other suitable places for greenery integration [Figure 18]. They bring small pockets of greenery and nature to building users and can be enjoyed from indoors. Different types of plants, turf, and shrubs, can be used to create a small garden above the ground but to encourage planting, planter boxes and balconies have to be provided together with water taps and drainage points. They can even contribute to Urban Agriculture by producing food such as herbs and vegetables.

TREELODGE @ PUNGGOL



[Figure 18] Balcony planters.



IRRIGATION OF GREEN AREAS

A suitable irrigation system is necessary to promote the growth of greeneries and landscapes. Strategies that ensure efficient irrigation of greenery include:

- Determine irrigation requirements of a development based on the development's Greenery Provision (GnP), precipitation deficiency, soil's water holding capacity, seasonal distribution of rainfall and quantity of plants to be maintained.
- Check and calculate the availability and accessibility of existing water supplies, including non-potable water sources. The consumption of potable water for irrigation should always begin by using non-potable water sources such as captured rainwater, recycled grey water, treated wastewater or collected condensate water from air conditioning systems.
- Work out monthly watering schedules and duration right from the start
- Use drip, micro-misters and sub-surface irrigation systems where applicable, and smart irrigation control throughout.

[Putting It All Together]

Due to urbanisation, we seemed to have lost more and more of our green spaces to concrete landscapes. Fortunately, concerns on Urban Heat Islands have allowed us to formulate strategies that balance urban landscapes with natural greenery. Ground greenery should be maximised as a first strategy with planting of trees being the most effective in providing shading and mitigating heat build-up. When external areas are scarce, greenery can also be incorporated into the building, taking the forms of vertical greenery, sky terraces, roof gardens, balcony planters or simply providing areas for internal green walls or indoor planting.

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GLOSSARY

BIOSWALE	Landscape elements primarily designed to remove silt and pollution from surface runoffs.
CARRIER SYSTEM (LIVING WALLS)	Type of vertical greenery that comprises pre-vegetated composite panels that are fixed vertically to a wall structure.
EVAPOTRANSPIRATION	This term refers to the movement of water to the air (evaporation) and the movement of water within a plant and the subsequent loss of water as vapour through its leaves (transpiration).
EXTENSIVE GREEN ROOFS	Green roofs not designed for public use and mainly developed for aesthetic and ecological benefits.
GREY WATER	Untreated household wastewater which has not come into contact with toilet waste.
INTENSIVE GREEN ROOFS	Green roofs developed to be accessible to the public. They are also known as roof gardens.
NATIVE PLANTS	Plants that are indigenous or non-invasive plants adapted to a given area during a defined time period.
POTABLE WATER	Water that is suitable for drinking and is supplied from wells or municipal water systems.
SKY-RISE GREENERY	A group of greeneries that consist of green roofs, planter boxes and balcony greeneries and green walls.
URBAN AGRICULTURE	The growing of plants and the raising of animals within and around cities.
URBAN HEAT ISLAND EFFECT	A phenomenon where urban areas have a higher average temperature than surrounding rural areas. The phenomenon is attributed to the heat build-up resulting from urbanisation and the introduction of developments within densely-constructed areas, which result in an overall reduction in green spaces and increase in hard surfaces within these areas.

CASE STUDY

Vertical Greenery

GOODWOOD RESIDENCE

261 & 263 BUKIT TIMAH ROAD,
SINGAPORE

- o 12 storey condominium of 39,750 m² (210 units)
- o Green Mark Platinum certification
- o Sustainable features include vertical green wall, climate-responsive façade, 'Zero' building waste concept, ground water harvesting system, reeds beds with natural bio-filtration, dual chute pneumatic waste disposal, cross ventilation for all units, sun pipes, energy efficiency, 'green' construction materials.

Vertical green wall explained:

- o Vertical green wall of 1,800 m² complimenting up to 50 nos. of conserved trees and 500 plants of indigenous species.
- o The structural framework for green wall will be installed during the construction of the building, while the modular green panels are pre-grown off site.
- o The system consists firstly of a steel frame anchored to the building's façade. The planting system is made up of a combination of panel-type planting units integrated into the frame and steel wire mesh frame for creepers to climb. The 2 systems combine to form the wall. Different plant types are used to allow flexibility in the wall design.
- o The planting media consists of a solid but lightweight sponge-like mass that has excellent water retention and drainage properties so that plants are able to grow on it.



- o The irrigation system consists of water pipes running within the green wall as well as a mist spray at the top of the frame. They are turned on via automatic timer controls. Excessive water is collected at the reed bed filters located at the bottom of the green wall.
- o Gardeners maintain the greenery easily and safely from building staircase or corridor without the need for temporary staging.
- o The green wall insulates against heat transmission into the building, increases the green plot ratio of the site, reduces ambient temperatures as well as provides social and aesthetic benefits to residents.

CHAPTER 6

Renewable Energy



[Key Points]



[Figure 1] Examples of Vertical-axis wind turbines (VAWTs).

Pictures courtesy of Turby VB and quietrevolution ltd

Renewable energy is energy that is derived from natural processes that are replenished constantly. Unlike fossil fuel, renewable energy does not pollute the environment because it is a part of nature. Renewable sources most often used are solar, wind, water (hydropower), biomass and geothermal energy. The potential to generate energy from renewable sources is largely dependent on the availability of these natural resources. In Singapore, some of these natural resources (such as wind, geothermal and tidal) are unavailable or not sufficient for us to economically harness energy from it.

WIND ENERGY

Energy from the wind can be harnessed by converting the kinetic energy from the wind into mechanical energy using wind turbines. Wind turbines are designed with aerodynamically-shaped fin blades that rotate when wind flows across. The rotating blade in turn drives a shaft that is connected to a turbine to generate electricity.

Wind turbines can be separated into two (2) types based on the axis in which the turbine rotates – Vertical-Axis Wind Turbines (VAWTs) and Horizontal-Axis Wind Turbines (HAWTs). VAWTs are turbines with a vertical axis of rotation and a shaft that points up [Figure 1]. HAWTs are turbines with the main turning shaft placed horizontally and points into the wind [Figure 2]. The HAWTs are more commonly used compared to the VAWTs.

A typical commercial wind turbine has rated power of about 200 W to 3 kW. A group of wind turbines located in the same area is called a wind farm. The wind turbines selected for wind farms are very efficient at high wind speeds and suitable for relatively smooth airflows in open field.

The natural wind environment of Singapore urban areas can be very different. Some sites – parks, open spaces and river banks areas – may have relatively high wind speeds and low turbulence. In these places, the same turbines that are found in wind farms may work well. However, elsewhere in urban areas, the presence of buildings and other features tends to cause turbulence, and average wind speeds tend to be lower than desired. This has to be considered in the selection of the type of wind turbine.



[Figure 2] Examples of Horizontal-axis wind turbines (HAWTs). 6 bladed wind turbine generator installed beside conventional 3 blade wind generator – near Bi-young Bridge at Kyunggi-Do South Korea.

Pictures courtesy of Green & Clean Technologies www.gnctech.biz

Wind turbines are usually designed to operate at a minimal wind speed in order to generate electricity. In Singapore, the annual average wind speed is about 2 metres per second (m/s). In general, wind speed of up to 4.5 m/s is highly preferred to achieve desirable electrical outputs.

SOLAR THERMAL ENERGY

Solar hot water systems (or solar thermal) use the sun's energy to heat hot water through solar collection panels. Solar radiation is absorbed by solar collectors to produce hot water. There are mainly two (2) types of solar collector for building application: flat-plate collector or vacuum tube collector. Hot water produced from collectors is stored in insulated storage tanks.

Solar thermal system can be used for both residential and commercial buildings. Moreover, the hot water generated can be a 'fuel' to drive adsorption / absorption chillers to produce chilled water and cool buildings. Such system is also known as solar air-conditioning. Large-scale commercial applications to generate hot water to drive chillers are still in the development stages.

The application of solar thermal system is becoming common in residential buildings. Due to the uncertainty of solar radiation, solar thermal systems normally work in parallel with conventional water heating systems to ensure hot water is always available.

GEO THERMAL ENERGY

Geothermal: Geo (Earth) + thermal (heat) energy is heat energy from the Earth. Geothermal energy is ideal where hot underground steam or water can be easily tapped and brought to the earth surface for a variety of usage, including electricity power generation and the heating or cooling of buildings [Figure 3].

Geothermal applications in Singapore are limited.



[Figure 3] Geothermal energy generation plant.

Picture courtesy of Gretar Ivarsson, geologist at Nesiavellir

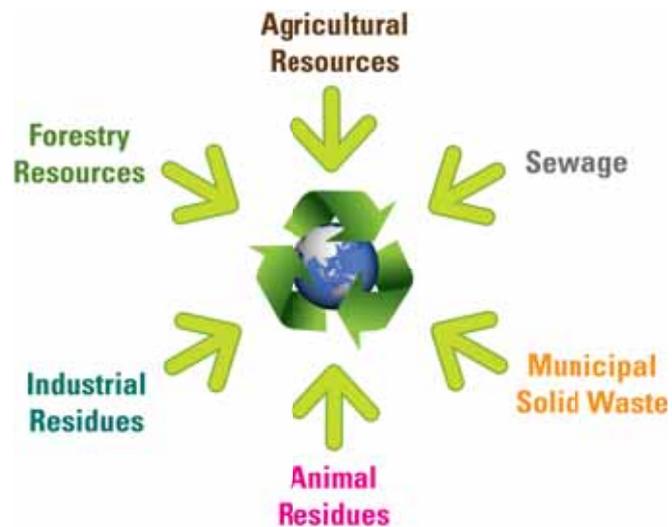


BIOMASS

Bioenergy is renewable energy made from any organic material (e.g. plants or animals). Sources of bioenergy are called 'biomass' which include agricultural and forestry residues, municipal solid wastes, industrial wastes and, terrestrial and aquatic crops grown solely for energy purposes [Figure 4]. Bioenergy is considered renewable because biomass is considered a replenishable resource.

Today, biomass resources are used to generate electricity and power, and to produce liquid transportation fuels, such as ethanol and biodiesel. A majority of ethanol is made from corn, but new technologies are under development to make ethanol from a wide range of other agricultural and forestry resources. Biodiesel can be generated from waste food or waste cooking oil. The energy in biomass is harnessed from waste-to-energy plants or cogeneration plants to produce electricity.

The biomass in Singapore's municipal waste is mainly wood waste, horticultural waste, food waste and waste paper. This waste is being harnessed in waste-to-energy plants. The combustion of municipal waste produces heat, which in turn heats up steam to drive a turbine to produce electricity.



[Figure 4] Various sources for Bio-energy generation.

HYDROPOWER

Hydropower is generated when rapid water flows through a turbine to generate electricity [Figure 5]. A good site for hydro electricity facilities should have adequate river flow and a sufficient head (vertical distance traveled by the water) to enable efficient momentum to rotate the turbine. Hydroelectric power plants normally require the construction of a dam to store the river water and create this vertical height. This provides the water sufficient head to flow through tunnels in dams and subsequently turn the turbines and thus drive generators.

'Low impact' type of hydropower facility is preferred. It produces clean power using a stream or a canal's existing natural drop in elevation thus avoiding any environmental impact on site that may be needed to create that differential elevation (e.g. creation of a dam).

Hydropower does not pollute the water or the air. It is much more reliable than wind, solar or wave power. Hence, electricity can be generated constantly.

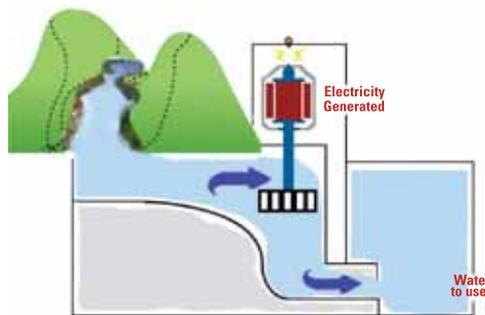
Hydropower may not be applicable in Singapore.

TIDAL POWER

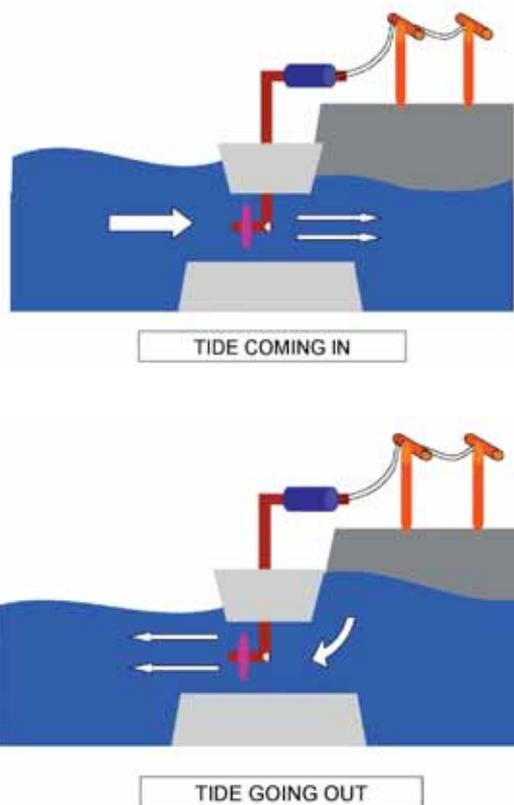
Tidal power is a form of hydropower that converts energy of tides into electricity [Figure 6]. It is generated by the relative motion of the Earth, Sun and Moon which interact via gravitational forces. The tide 'moves' a huge amount of water twice each day. The advantage of the tides is that it is more predictable than wind and solar energy.

Tidal power traditionally involves erecting a dam across the opening to a tidal basin. The dam includes a sluice which when opened allows the tide to flow into the basin. The sluice is then closed. As the sea level drops, traditional hydropower technologies can be used to generate electricity from the elevated water in the basin.

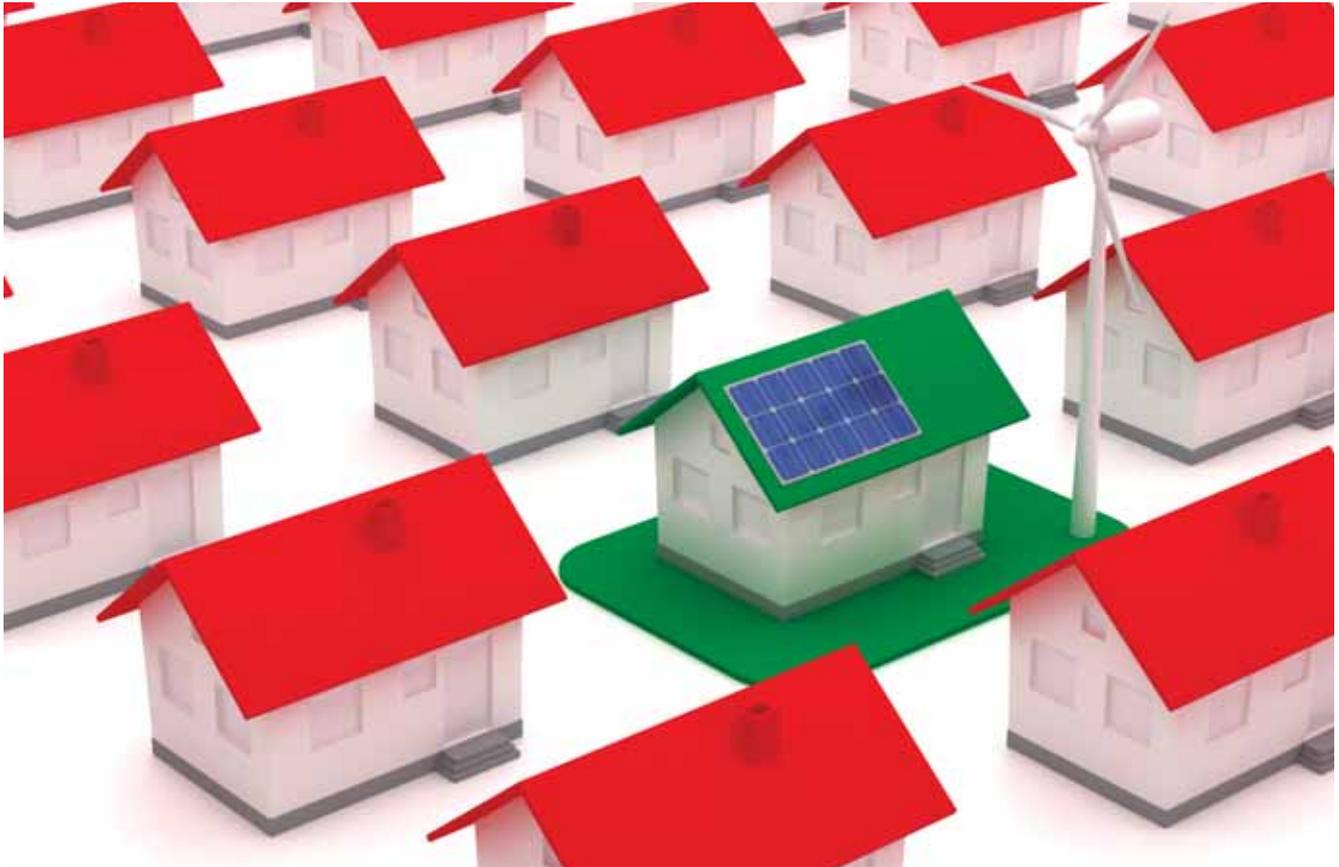
Tidal power applications in Singapore are limited.



[Figure 5] Illustration of Hydropower generation plant.



[Figure 6] Illustration of tidal energy generation during high tide and low tide.



IN SUMMARY

Globally, energy generation through renewable sources is growing at a rapid pace. In Singapore, renewable sources such as solar and biomass show greater potential due to their availability. Many of our Green Mark buildings are already installed with PV systems with some even tapping on biofuels as an alternative source of energy. With advanced technologies, it is only a matter of time before more renewable sources become financially and technologically feasible for our buildings.

PHOTOVOLTAIC (PV)

Due to the constraints of natural geography and the high degree of urbanisation in Singapore, there are strong limitations to the exploitation of renewable energy such as wind, geothermal and hydropower. But there are still viable alternatives, and one that is increasingly gaining popularity is Photovoltaic (PV). PV offers its own advantages, but in the context of Singapore, the fact that Singapore is blessed with abundant sunlight due to our proximity to the equator and that it can be integrated into built-up areas makes it especially appealing.

[Key Points]

Photovoltaic (PV) systems convert sunlight directly into electricity without generating any CO₂ or other greenhouse gases. They are quite different from solar thermal technology, in which the sun's heat energy is trapped and transferred to another medium such as water. Both technologies are excellent ways of harnessing renewable energy from the sun but this chapter deals exclusively with PV.

Singapore's main island is very well served by the national power grid. The principal PV application would be grid-connected. As land is scarce and expensive, most systems will be installed on buildings. Since Singapore sits almost exactly on the Equator, PV modules installed on the roof (not too steep) will generate much more electricity than those mounted on façades.

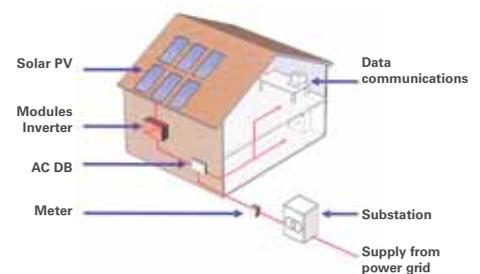
When comparing today's installed costs of PV systems with current retail electricity tariffs, it will take over 20 years to achieve simple payback. Building owners therefore need to also evaluate intangible benefits when considering a PV system.

[Operating Principle of Grid-Connected PV System]

PV modules generate direct current (DC) electricity when exposed to sunlight. The conversion from light to electricity is instantaneous. An inverter converts the DC to alternating current (AC) electricity and synchronises it to the grid so it can feed seamlessly into the building's AC distribution board (ACDB) [Figure 7]. There is no changeover switch between the two supplies. All electrical circuits connected to the ACDB are supplied simultaneously by both the PV and PowerGrid.

At night, PowerGrid supplies 100% of the demand. During the day, the PV system supplies anything from 0 to 100%, depending on its size relative to demand, and the intensity of the sunshine. In case the PV system generates more than the building's demand, excess electricity will feed back into PowerGrid.

If for any reason the grid should fail, or stray beyond voltage or frequency tolerances, the PV inverters will automatically disconnect. This is a safety feature but it means a grid-connected PV system generally cannot operate when the grid is down. This is not a concern in Singapore due to a very reliable national grid.



[Figure 7] Grid-tied system configuration.

[Decisions by Building Owners and Architects]

When contemplating a PV system, there are several factors to consider, and different people will have different priorities. This chapter will explore each of the following:

- Why do you want to install a PV system? – Environmental appeal, reduce carbon footprint, money saved on electricity costs, novelty value, differentiation?
- Do you want maximum visibility or maximum performance?
- How well suited is your building to a PV installation? Is it well exposed to the sun, or shaded by other (taller) buildings and trees? Will these assumptions stay valid for the next 20 years?

Your responses to the above questions will influence your choice of PV technology.

.....

[Why Install a PV System?]

Installing a PV system can definitely enhance a building's appeal by making it stand out from the crowd. It also reduces a building's carbon footprint because it generates electricity without emitting any greenhouse gas or other pollutant.

From another perspective, some greenhouse gases are emitted during the manufacturing process of a PV module and energy is also required to manufacture the various components of PV modules. We call this the embodied energy of the product. But in our sunny climate, the energy payback time – or time taken for a PV module to generate the equivalent of its embodied energy – is typically less than 2 years. Since most PV modules have a 25-year power warranty, they will repay their embodied energy many times over during their active service.

Although energy payback is one aspect to consider, developers who are hoping for a shorter financial payback will not be convinced to invest now. At current PV system market prices and comparing with current electricity retail tariffs, even a large rooftop PV system has a payback time exceeding 20 years.

The return on investment (ROI) calculation must therefore consider intangible benefits in addition to the tangible benefit of reduced electricity bills. Some of the intangible benefits are discussed above and are worth different things to different people. If you do not see enough value in them, a recommendation is to wait a few years for market growth to bring down the price of PV systems until their ROI meets your criteria.



[Maximum Visibility or Maximum Performance?]

The most visible part of a building's exterior is usually one of the façades and it is tempting to follow the example of some outstanding PV project examples in Europe or Japan, by installing a PV system on the façade [Figure 8]. This could be in the form of cladding or fully integrated into the building structure. Much of Europe and Japan lie between 35° and 55° north of the Equator, which means the sun is always in the southern hemisphere and shines adequately on south-facing walls. In this case, a south-facing façade installed with a PV system combines prominent visibility with fairly good energy performance.



[Figure 8] The Doxford building in northern England, with an imposing PV façade.

Photo courtesy of Dennis Gilbert

However in Singapore, the façade is not an ideal location to harness solar energy [Figure 9]. We are barely 1.5° north of the Equator, meaning the sun is usually high overhead. Our walls receive direct sunlight only half of the daylight hours at most. An east-facing wall is exposed in the morning, but obscured in the afternoon. A north-facing wall receives the sun all day from 21 March to 21 September but is in the shade for the other 6 months of the year.

As a first approximation, you maximise energy production in a grid-connected system by tilting the PV modules towards the Equator at the same angle as the latitude of the location.

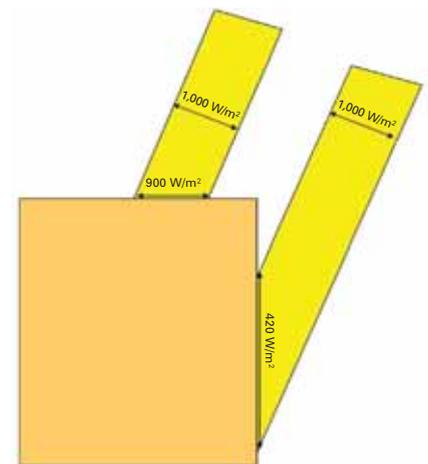
IN SUMMARY

A PV system installed on a well-exposed rooftop location will generate around five times as much energy as one of the same rated capacity installed in a vertical location. It is important to note that the prominent visibility of a façade installation comes at the cost of forfeiting most of the energy generating potential.

That means in Singapore, PV modules should be installed on roofs at just over 1° tilt facing south.

However, it is better to mount the modules at slightly steeper angles – at least 3° for frameless modules and at least 10° for modules with frames, to enable better rainwater surface runoff. Installing any steeper than around 30° comes at the price of reduced energy output.

Fortunately, our location so close to the Equator means that the modules can face any compass direction, rather than pointing strictly south.



[Figure 9] Equatorial sun shines more intensely on the roof than the walls.

[The Dilemma of Shade]

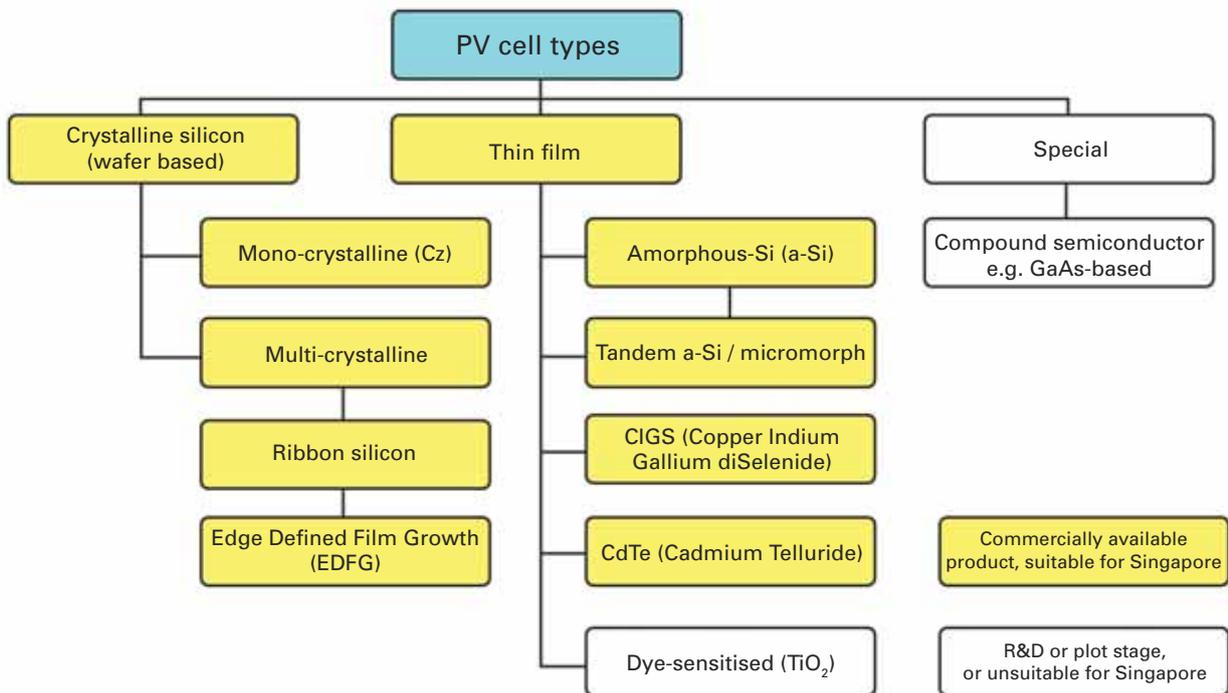
PV modules generate electricity when exposed to sunshine. When the modules are shaded, they instantly stop generating electricity. With crystalline silicon modules, even partial shading results in disproportionately high output losses. Thin film modules tolerate partial shading better than crystalline ones but a well-designed PV system should avoid shading if possible.

Considering that a PV installation is an investment that should last 25 to 30 years, will your assumptions stay valid for that period? Check zoning regulations to see if a neighbouring building could shade your building in future. Remember also that nearby trees tend to grow taller!

[PV Technologies]

PV technologies can be commonly classified into crystalline silicon (wafer-based) and thin-film technologies.

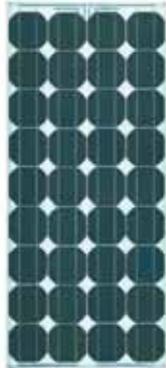
[Figure 10] below illustrates the 'family tree':



[Figure 10] PV technology family tree.

Crystalline silicon modules make up around 85% of the market. They are further divided into two main types: mono-crystalline and multi-crystalline. The difference stems from the way the silicon ingots are grown, although in both cases, the ingots are sawn into thin wafers of approximately 150 - 200 microns thick (200 microns is one fifth of a millimetre, or about as thick as a human hair).

MONO-CRYSTALLINE SILICON



MULTI-CRYSTALLINE SILICON



FLEXIBLE AMORPHOUS THIN FILM



CIGS THIN FILM



[Figure 11] Common PV module technologies (mass-produced modules).

The wafers are processed into light sensitive cells which generate an electric current when exposed to light. Several cells (typically 36 - 72 cells) are connected in series and packaged into a PV module. We can then connect several modules in series into a string. Several strings connected in parallel form an array, which feeds into an inverter.

With thin film technologies, the cells are deposited and connected together directly on the surface of a substrate such as glass or stainless steel. The term 'thin film' derives from a much reduced layer of light-sensitive semiconductor that is applied to the substrate. This is typically less than 1% the thickness of a silicon wafer-based cell.

Referring to [Figure 10], dye-sensitised thin film is a promising very-low cost

technology that has not yet achieved stable mass production, while Gallium Arsenide-based (GaAs) compound semiconductors are highly efficient (up to 40% in the lab) but also extremely expensive. This is overcome by using low cost mirrors or lenses to focus sunlight onto very small GaAs cells. Some systems concentrate sunlight up to 300 times onto the special cells.

As the sun moves over the course of the day, a tracker is required for concentrating solar devices to keep the sun beams focused on the GaAs cells.

It is only possible to focus direct sun beams from a clear sky. Cloudy and hazy conditions produce diffuse light, which is direction-less and impossible to focus with mirrors or lenses. In Singapore, roughly 40 - 60% of our

light is diffuse and cannot be used in a concentrating PV device, thus rendering them useless for half of the time.

There is no 'best' technology and the choice will depend on circumstances. It is useful to understand the pros and cons of each technology before selecting which to use. The common PV module technologies are as illustrated in [Figure 11] above.

EFFICIENCY

Efficiency is the most obvious factor to consider [Table 1]. Crystalline modules are more efficient than thin films. A typical crystalline (c-Si) module, at 13% efficiency, will pack 130Wp of capacity into 1 m² of surface area, whereas a typical amorphous silicon (a-Si) module with 6.5% efficiency needs 2 m² to achieve the same 130Wp.

The main consequence is that a-Si requires more space per unit of generating capacity than c-Si, and this also means higher costs for support structures and cabling. To compensate for these additional costs, a-Si modules are typically priced lower per Wp than c-Si. However, if installed costs are similar and space is not a constraint, it would not matter which technology should be used. Efficiency should never be the only factor to be considered when selecting a PV technology.

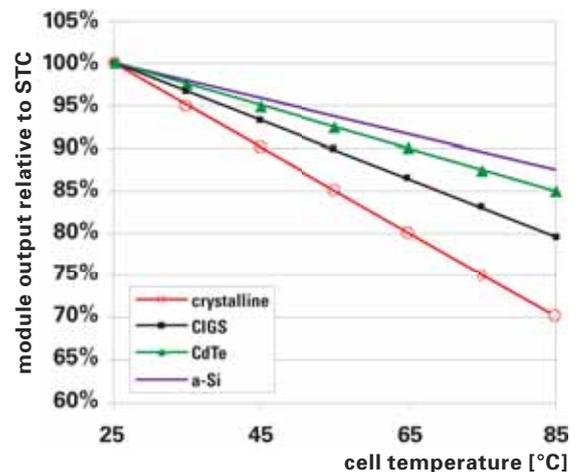
[Table 1] Conversion efficiencies according to technology.

TYPICAL COMMERCIAL – PRODUCED CELL & MODULE EFFICIENCIES		
TECHNOLOGY	CELL EFFICIENCY	MODULE EFFICIENCY
Mono-Si (most) Sunpower	15 - 17%	12.5 - 15%
	20 - 23%	16.1 - 19.3%
Multi-Si	13 - 16%	11 - 14%
CIGS	-	10 - 13%
CdTe	-	9 - 12%
a-Si on μ -Si	-	8 - 10%
a-Si	-	5 - 7%

TEMPERATURE COEFFICIENTS

The temperature coefficient of different PV technologies is an important differentiator in our hot climate. Module efficiency declines as temperature rises, while temperature is quite closely correlated with sunlight intensity. [Figure 12] compares the temperature coefficients of module technologies and shows how temperature affects performance.

TECHNOLOGY	TEMP COEFFICIENT [% / °C]	DERATING AT 65°C [%]
Crystalline silicon	-0.40 to -0.50	16.0 to 20.0
CIS	-0.32 to -0.36	12.8 to 14.4
CdTe	-0.25	10.0
a-Si	-0.21	8.4



[Figure 12] The effects of negative temperature coefficient on module performance.

Module capacities are rated under standard test conditions (STC), with sunlight intensity of $1,000 \text{ W/m}^2$ and a cell temperature of 25°C . These only exist in the testing laboratory. In Singapore between 12noon to 2pm, the sun can shine with an intensity of

$1,000 \text{ W/m}^2$ and will typically heat a module up to around 65°C . This is 40°C more than the STC temperature, causing a crystalline module to lose $40 \times 0.50\% = 20\%$ of its performance at this temperature, while an amorphous silicon module will lose only $40 \times 0.21\% = 8.4\%$.

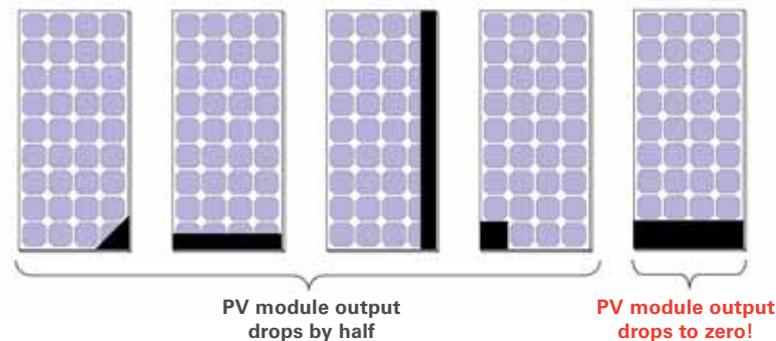
The temperature over an average day will rise and fall, such that an a-Si module will probably generate 5 - 10% more energy than a c-Si module of the same rated capacity. Other thin film technologies perform anywhere between these two extremes.

SHADING TOLERANCE

As already discussed, shading and partial shading are detrimental to system performance and the impact it has on a PV system is usually underestimated. Covering just half a cell (for example with leaves or bird droppings) will reduce module output by as much as half [Figure 13]. In other words, the drop in output is not directly proportional to the shaded area.

This happens because the shaded cell becomes a resistor, impeding the flow of current from the exposed cells. Over the long term, the resistive cell can overheat and damage the module. Bypass diodes installed in the module junction box protect against this, by rerouting the current around a group of cells that includes the shaded cell. Ideally, there would be a bypass diode around each cell but this is not practical, so any single shaded cell results in one third to one half of the cells in that module being bypassed. That explains the big drop in output.

Thin film modules, with their long, narrow cells can tolerate shading better than c-Si modules because shade is much less likely to cover an entire cell. As long as the shade only covers a portion of each cell, the module generates power in proportion to the exposed area.



[Figure 13] Examples of partial shading on a 36-cell module.

DIMENSIONS, WEIGHT AND AESTHETICS

Apart from technical performance considerations, you need to consider dimensions, weight and aesthetics, which will affect the appearance of a system. Some modules will fit better than others onto a given space.

The loading limit of a building's roof support structure must be considered. Conventional, rigid glass fronted modules typically add $15 - 20 \text{ kg/m}^2$ to a roof, including aluminium support structures. Some "sandwiched"

glass modules can be even heavier. Lightweight modules on a flexible stainless steel substrate are also available and can add less than 4 kg/m^2 to the roof.

BIPV

Besides simply adding PV modules on top of a building structure, you can integrate them into the building design – in some cases the PV even serves an additional structural function. Such systems are generally called Building Integrated PV or BIPV.

[Figures 14 to 17] illustrate customised BIPV modules integrated into building façades or canopies. Their dimensions can be tailored to the millimetre but the resulting installed system cost will be double or triple the cost of using mass-produced PV modules. Lead times are also much longer as the BIPV modules are only made to order, rather than supplied from stock.

There is a form of BIPV that uses cost-effective mass-produced flexible modules, which stick onto metal roofs. [Figure 17] shows an example of such an installation on a residence in Sentosa Cove. These modules weigh less than 4 kg/m². They require a flat steel or aluminium substrate with an approved polyvinylidene fluoride (PVDF) coating. Make sure to specify the correct roofing materials and order them well in advance, because Singapore suppliers typically only keep stock of roofing materials with a cheaper, non-compliant coating.



[Figure 14] Amorphous silicon BIPV modules (dark squares) integrated into a façade (No. 7 Tampines Grande).

Photo courtesy of Phoenix Solar



[Figure 15] Crystalline silicon BIPV modules integrated into a skylight canopy (Savannah Condo).



[Figure 16] Crystalline silicon BIPV modules integrated into a façade (Biopolis).



[Figure 17] Flexible amorphous silicon laminates glued to a curved metal roof (Sentosa Cove).

Photo courtesy of Sheet Metal International

SUMMARY OF ADVANTAGES AND DISADVANTAGES FOR PV TECHNOLOGIES

	ADVANTAGES	DISADVANTAGES
TYPICAL THIN FILM	<ul style="list-style-type: none"> + Most thin films (a-Si, tandem, CdTe) outperform c-Si in hot climates (But CIGS only very slightly better than c-Si) + Thin films are generally more shade tolerant than c-Si 	<ul style="list-style-type: none"> - Some thin films require blocking diodes <ul style="list-style-type: none"> • more points of failure - Many thin films require negative grounding <ul style="list-style-type: none"> • excludes more efficient transformerless (TL) inverters (note some can use TL inverters)
TYPICAL CRYSTALLINE SILICON (WAFER BASED)	<ul style="list-style-type: none"> + c-Si is more efficient <ul style="list-style-type: none"> • requires less space than a-Si + c-Si has much longer track record than thin films 	<ul style="list-style-type: none"> - SunPower (highest efficiency c-Si) requires positive grounding <ul style="list-style-type: none"> • excludes TL inverters
TYPICAL BIPV	<ul style="list-style-type: none"> + Fully customisable dimensions and design to blend in or stand out 	<ul style="list-style-type: none"> - Much more expensive than mass-produced modules - Longer lead times to produce and to replace damaged or defective modules - Often shorter warranty periods than mass-produced modules

[Warranties and Certifications]

PV systems are quite expensive investments and should be designed to last a long time – two decades or longer. Fortunately, all reputable manufacturers of PV modules offer long warranties of 20 - 25 years on the power output. These need careful interpretation.

There are two main components to a PV module warranty:

- o A workmanship warranty offers to repair, replace or refund the purchase in case of defects. These vary from 1 to as much as 10 years, depending on the manufacturer. Typically, a workmanship warranty is 2 to 5 years.
- o A limited power output warranty offers a variety of remedies in case the module's output under STC drops below certain levels. Most manufacturers warrant at least 90% of minimum rated output for 10 years and 80% of minimum rated output for 20 - 25 years. Note that minimum rated output is usually 95% of rated output, to allow for manufacturing and measurement tolerances.

For example, an array rated at 20 kW under STC is warranted to produce 95%, or 19 kW when new, and at least 90% of 19 kW, i.e. 17.1 kW for the first 10 years and at least 80% of 19 kW, i.e. 15.2 kW from the 11th to the 15th year.

Note that under the limited power warranty, manufacturers seldom offer to replace the module itself. Rather, at their sole discretion, they will offer to:

- Repair the defective modules.
- Supply enough new modules to replace the lost power output in a PV array. For example, if 6 years after installation, you find that your 20 kW array only produces 16.1 kW under STC, the manufacturer could opt to supply you with 1 kW of modules to make up the shortfall.
- Refund you for the lost power output, after deducting according to the number of years already in use. For a 25-year warranty, the annual deduction is normally 4%. For example, if 6 years after installation, you find that your 20 kW array only produces 16.1 kW under STC, the manufacturer could opt to reimburse your purchase price minus 24% (6x4%).



In all cases, the manufacturer does not cover your costs of dismantling, transporting and reinstalling the modules. The warranty also excludes problems resulting from improper installation; repairs, changes or dismantling by unqualified personnel; accidental breakage or abuse; lightning strikes and other Acts of God.

Significantly, most manufacturers specify that the module output will be determined by the flash testers in their own premises, rather than by a third party.

Your PV system integrator should assist in determining whether a PV module defect is covered by warranty and handle the situation with the manufacturer.

Another thing to beware of is that module manufacturers are constantly upgrading their products and adapting formats to market requirements. This means that only a few years after installation, you might no longer be able to buy an identical module to replace a defective one in your array. Future modules are likely to be more powerful or have different physical dimensions and no longer fit exactly into the gap left by the old module.

On a large ground-mounted PV power plant this does not matter much, because the new modules can form a new row. But on a building-mounted system it can spoil the aesthetics as well as cause problems with the electrical configuration.

It is better therefore to select a reliable module manufacturer with a proven track record of long-lasting modules, as well as having the right certifications. For example, IEC61215 for crystalline modules and IEC61416 for thin film modules.

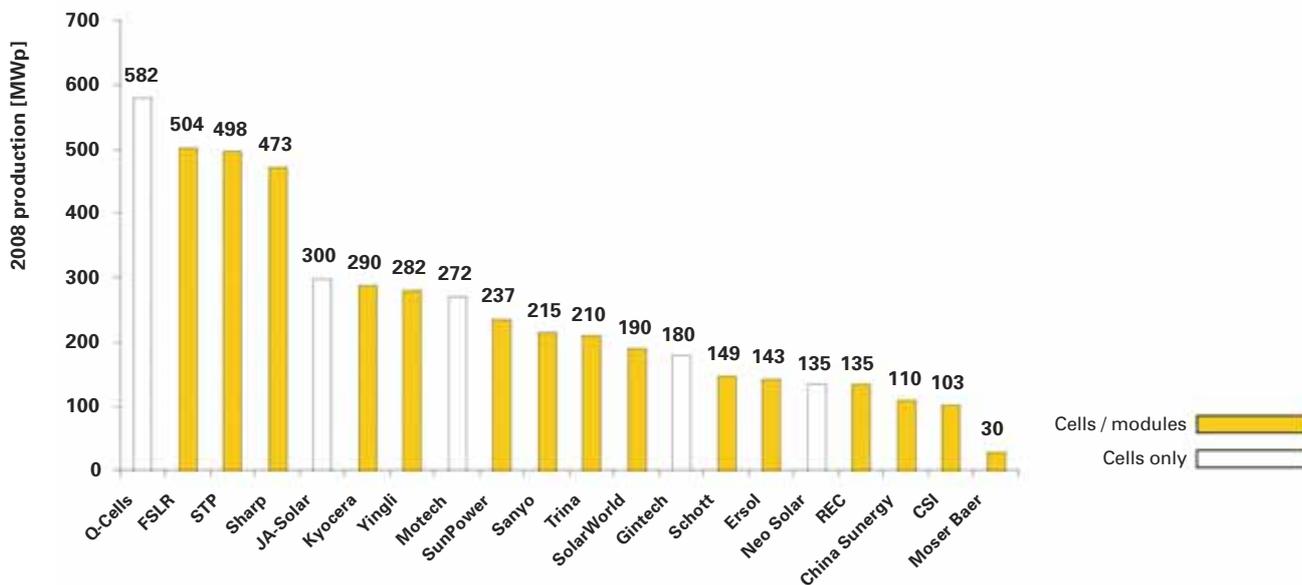
IEC stands for the International Electrotechnical Commission, the international standards and conformity assessment body for electrotechnology. The above certificates are awarded by institutions such as TÜV Rheinland in Germany, ISPRA in Italy and ASU in USA, after a number of modules have passed rigorous testing to simulate 20 years of exposure to the elements.

IN SUMMARY

- 1 » Read the warranty carefully.
- 2 » Verify the certificates. If in doubt, you can check the test agency's web site to ensure the test certificate number is indeed genuine.
- 3 » Check the credibility of the manufacturer – how much experience does it have, and are you convinced that the company will be able to honour its warranty should the need arise in 10 or 15 years from now?

At the height of the PV market boom in mid-2008, there were over 350 PV module manufacturers in China alone. By the end of that same year, over 200 of those had gone bankrupt or closed down their PV manufacturing operations. Their 25-year module warranties are now worth nothing.

In 2008, global PV cell production hit 7,900 MWp, with the top 20 manufacturers accounting for 5,038 MWp, or 63% of this. The top 19 manufacturers each produced over 100 MWp [Figure 18].



[Figure 18] Top 20 crystalline and thin film cell producers in 2008.

The white columns represent companies making cells only, while those in orange produce modules.

Source : Photon International (production volumes)

PV is still a very young and dynamic industry and we can expect several changes in the list of top 20 manufacturers. But the odds of long term survival are higher for those companies that are currently on the list.

[Inverters and Other Balance of System Components]

Much of the attention has been paid to the PV modules. A PV system also comprises inverters, cables, disconnect switches, protection equipment and support structures. These components form the Balance of System (BOS) for a PV system.

Of these, the inverter is the most critical piece of equipment. Its primary function is to convert DC electricity generated by the PV array into AC electricity to feed into the grid. It must be able to synchronise its output with the grid instantaneously.

In March 2009, Singapore's electrical code of practice CP5 was revised to include rules for grid-connected PV systems, including criteria for inverters and DC-rated components like cables, disconnects and lightning surge arrestors. Reputable inverter manufacturers such as SMA, Fronius, Xantrex and Power-One offer products that meet Singapore criteria.

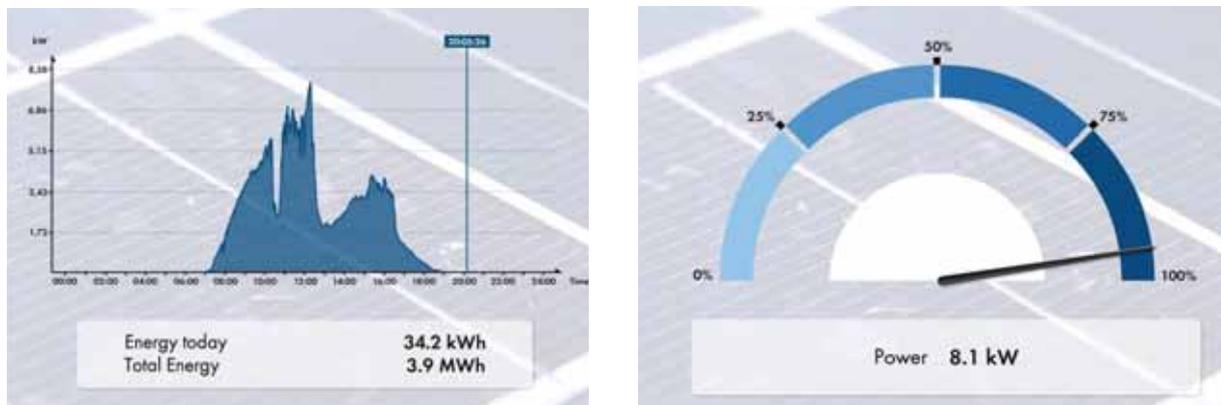
When planning a PV installation, you should identify a suitable location to install the inverter or inverters. Some must be mounted indoors, while others

are waterproof and can be installed outdoors. However, the inverters must be shaded from direct sunlight to avoid overheating. If mounted indoors, allow sufficient airflow to dissipate the heat that the inverters will generate. A 95% efficient inverter for example, will dissipate 5% of the incoming DC electricity as heat.

[Maintenance and Performance Monitoring]

Unless trackers are used, PV systems have no moving parts. Maintenance thus is not a major issue for PV systems. Typically, an on-site inspection should be carried out once a year to check for structural corrosion, physical damage, worn out lightning surge arrestors or other potential problems.

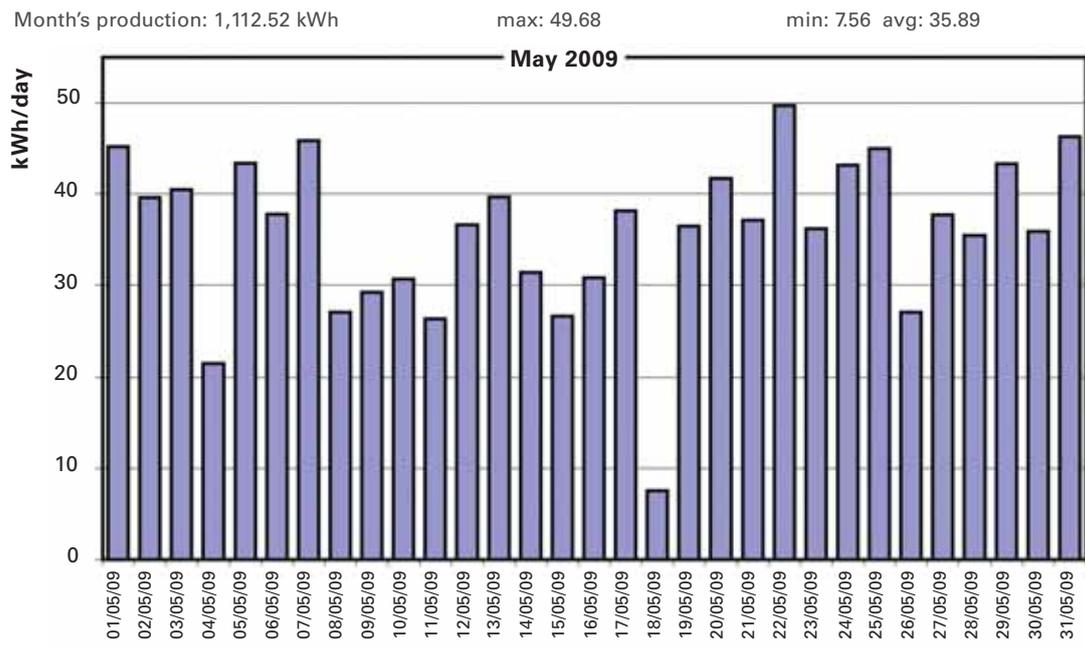
Fortunately in Singapore, we are blessed with abundant rainfall. This greatly aids in cleaning the PV modules. Most of the maintenance consists of remotely monitoring system performance. The inverters keep track of vital parameters such as DC and AC voltage, current, power, cumulative energy, line frequency and any error. Inverter manufacturers supply data loggers that can collect these data and transmit them for display on a remote computer or Internet web page [Figures 19 and 20].



[Figure 19] Examples of live performance monitoring displays from an SMA inverter.

Source: Phoenix Solar

The addition of some low-cost sensors to measure module temperature, ambient temperature and incident sunlight will allow you to verify that your system is producing what it should according to the sunlight it receives and the operating temperature of the modules.



[Figure 20] Example of a monthly performance report.

Source: Phoenix Solar

[Putting It All Together]

- It is easier, neater and cheaper to include a PV system in the design of a new building than to retrofit later.
- A holistic approach should be taken when designing a PV system. For example, in selecting a metal roof material, consider that a cheaper roof might require a more expensive seam clamp to attach the PV array sub-structure.
- Make sure to leave enough lead time to order any non-standard PV components, such as customised modules.
- When selecting a PV system integrator, make sure to check the company's track record and references.



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- 4 » *Handbook for Solar Photovoltaic (PV) Systems*, Energy Market Authority and Building and Construction Authority

GLOSSARY

BIOMASS	Bioenergy is renewable energy made from any organic material (e.g. plants or animals). Sources of bioenergy are called "biomass".
GEOTHERMAL	Geo (Earth) + thermal (heat) energy is heat energy from the Earth. The use of recovered heat as steam or hot water from the Earth to heat buildings or generate electricity is a form of geothermal energy.
HYDROPOWER	Hydro (water) power is energy that comes from the force of moving water. It is generated when rapid water flows through a turbine to generate electricity.
RENEWABLE ENERGY	Renewable energy is energy that is derived from natural processes that are replenished constantly. Renewable sources include solar, wind, water (hydropower), biomass and geothermal energy.
SOLAR THERMAL	The conversion of the sun's energy or solar radiation into heat for hot water production, comfort heating / cooling and cooking purposes through solar thermal collectors.
STANDARD TEST CONDITIONS (STC)	The testing conditions to measure photovoltaic cells or modules nominal output power. Irradiance level is 1,000 W/m ² , with the reference air mass 1.5 solar spectral irradiance distribution and cell or module junction temperature of 25°C.
TIDAL POWER	Tidal power is a form of hydropower that converts energy of tides into electricity. It is generated by the relative motion of the Earth, Sun and Moon which interact via gravitational forces.
WIND POWER	Wind power is the conversion of wind energy into a useful form of energy, such as electricity, using wind turbines. A wind turbine is a rotating machine which converts the kinetic energy of wind into mechanical energy.



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