GUIDELINES FOR SOCIO-CLIMATIC DESIGN OF SEMI-OPEN ENTRANCE SPACES OF TROPICAL HIGH-RISE APARTMENTS

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SUMMARY

Design guideline plays an important role in the decision making process of architects. This thesis reports on a framework for developing a particular set of guidelines for socio-climatic design of semi-open entrance spaces of tropical high-rise apartments. The concept of sustainable socio-climatic design, proposed by Bay (2002a, 2004), brings together two major concerns: sustaining community and environment. Bay’s studies (2000, 2004) show that in Bedok Court Condominium, the semi-open space at the entrance of each apartment unit provides comfortable environment for high levels of social activities and sense of community. This study discusses the optimal size of such entrance spaces that can sustain environmental comfort and community.

The guidelines are created with interdisciplinary knowledge, namely, architecture design, social behaviour and climatic condition. They are developed through a descriptive account of architects’ design thinking, rather than the normative approach that focus on the description of the general rules, principles or examples. Alexander Tzonis’s design thinking (Tzonis 1992) about *Context-Morphology-Operation-Performance* is discussed and used to
organise the knowledge and information, which makes the guideline compatible with architects’ design thinking process.

In practice, designers use heuristics for design thinking that are pre-parametric for complex design problems, and hardly use parametric methods. Although precedents are necessary for solving design problems, analogical means cannot be totally relied on to accomplish a sustainable design. An effective tool is needed to help satisfy the requirement of accuracy of sustainable design. The parametric tool based on building simulation can assist pre-parametric design thinking depending on its quantitative property. Simulation techniques are crucial for decision-making process of environmental design because they represent environmental reality and predict real-life situation. It foretells the performance and ensures the accuracy of design morphology. In this study, parametric building simulation is used to prepare guidelines suitable for pre-parametric design thinking, which makes design guideline effective, efficient and compatible with architects’ design thinking process.

The research methodology includes three steps: 1. discuss case study and analysis of two high-rise dwellings in Singapore; 2. building simulation to arrive at optimal sizes and thermal comfort and; 3. structuring the guidelines for pre-parametric design using Alexander Tzonis’s framework for representing architectural knowledge. The guidelines are in the form of visual charts,
showing the correlations of expected social patterns, predicted bio-climatic behaviours, and sizes.
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INTRODUCTION

This dissertation,

i. Investigates why some available sustainable design guidelines cannot be used effectively and efficiently by architects in design practice,

ii. Explores an approach to frame the information from precedents and to develop them into guidelines using pre-parametric simulation, and

iii. Develops a socio-climatic design guideline for semi-open entrance space of high-rise apartment based on the cases of tropical dwellings in Singapore.

Sustainable design and planning have become a popular catchphrase in the nineties. Environmental design, as one of the expressions for this concept, was not looked as a part of architect’s work for a long time. At the beginning of the book, The Environmental Tradition: Studies in the architecture of environment, Hawkes (1996, 11) criticizes that ‘the environmental function of buildings, as the technologies of environmental control evolved through the nineteenth and twentieth centuries, was progressively relegated to a secondary place in the discourse’. He mentions, in the schools of architecture, it was founded as a branch of building science, relying for its
substance upon the achievements of the building scientist, and in practice it had effectively been handed over to the merging profession of mechanical and electrical consultants.

However, with the increasing concern for environmental impacts on buildings and the quality of their internal environment, ecological building has drawn the attention of designers. People are more concern with the role architects play in the environmental design, which has become an important part of their work.

How does an architect do environmental design? Bay (2001b) mentions two ways: one is to refer to designer’s personal experience of various environment he has been in the past including those he has designed; the other is to refer to various publications on environmental design for guidelines. The former one, heuristic thinking based on experiences, is a normal way for architects when making a judgment or decision. In fact, with this design thinking, judgement errors and wrong decision-making will happen in the design because of the heuristic biases (Bay, 2001). Particularly in sustainable design, total dependence on experience is probable to lead to unexpected performance of the building. So, architects need some tools to aid them in environmental design. Normally, three methods are often used to design the climatic responsive building. The first way is to construct a building depending on experience first, test its performance and make changes where possible. For the second one, a model can be set up in the computer system, and simulations and changes are done to arrive to an accurate prediction on the performance. The third and last way is to refer to the design guidelines during the design process.
Introduction

Brief background

In this study, we will examine the problems of sustainable design guidelines in the case of environmental responsive design. Environmental design guidelines play an important role in the decision making process of architects. Particularly when the environmental control of a building no longer only rely upon the building scientists, mechanical or electrical consultants, architects need effective tools to them help in the design which carries more technological factors. Guidelines assist design in the three aspects.

First, as mentioned before, environmental design guidelines can help avoid unexpected performance caused by heuristic thinking based on experiences.

Secondly, guidelines transfer information from research to practice. Here, we can compare architects as computer users, and what the researchers have developed are like computer programming languages. User friendly software is needed to translate the programming languages into a computer tool which can be directly used. Accordingly, guidelines function as a media, transferring the data, theories and technologies to design practice, and translating the scientific language into architectural language.

Thirdly, design guidelines help deal with knowledge from multiple resources and disciplines. Sustainable design is a comprehensive process because it involves knowledge of various disciplines like ecology, physics, environmental technology and others. A large amount of information, from building science researchers, civil engineers, environmental design coordinators and even users, is transferred to
architects. Handler (1970) argues that ‘In attempting to cope with problems of present-day buildings, architects have sought to expand the amount and kind of information at their command. The behaviour of structures, operation of mechanical systems, effect of microclimates, physical, as well as social and perceptual behaviour and requirements of people, urban configuration and development --- all have been grist to the architectural mill.’ But architects lack of time and mental recourses to go through all those information. Ofori and Ho, (2004) did a survey among 100 architects in Singapore, and found that “designers require relevant information to guide them in making appropriate choices; the absence of such information was highlighted by respondents as one of the obstacles to their adoption of green design principles.” Their research also shows that information on new developments and issues on green design being made easily available by relevant professional institutions is an appropriate measure to be adopted by architects for increasing environmental awareness and implementing green design and building processes.

Since 1960s, there have been many kinds of rules, principles and theories to guide environmental design, such as those proposed by Olgyay and Olgyay (1963), Banham (1969), Hawkes (1996), Lam (1997), Yeang (1999), Hyde (2000), Smith (2001), and Wong (2002). All of the guidelines work as useful aids to architects for different aspects of environmental design.
Introduction

Problem statement

Although there are all kinds of rules, principles and theories to guide environmental design, architects are still facing many problems when doing environmental design. For example, some guidelines are too general, and some others are very specialized and narrow. The main problems are:

1. Much research on environmental buildings have been done in the way of engineering and the guidelines are not written from the view of architects. As a result, architects would not like to waste their time to refer to the guidelines which seem to have no direct relation with their designs.

2. Many books, on how to create natural building environment, only show some basic principles or the morphologies of the examples. Architects still do not know how to apply the information they get from the books to their designs after reading references like that.

3. The way of achieving good performance is not clearly explained in the guidelines. Architects use the same morphologies as the precedents, but the designed building does not perform as well as expected.

4. Exemplary buildings, as shown in the guidelines, do not perform as well as described in reality, although large numbers of sustainable design principles and methods are applied. Architects often get wrong information from them because of short of evaluations.
5. Some guidelines are too complicated, such as those include weather files analysis, surrounding environment assessment, building performance simulation and user feed back collection. Architects are short of time and energy to study on these guidelines during a comprehensive architecture design process.

*To summarise, the main problem mentioned above is that the environmental design guidelines are not written in the way of architects. This leads to theories with high academic value being far away from design practice. In this study, we will explore a way to make the design guidelines compatible with architects’ design thinking process, which is complex and deals with multiple criteria of performance.*

**Method of investigation**

To solve the problem, we should make clear what is ‘in the architects’ way. In brief, ‘in the architect’s way’ refers to ‘compatible with architects’ design thinking process’. That means every guideline should be in accordance with the sequence of building design process and the thinking mode of architects.

This thesis reports on a framework for developing a particular set of guidelines from the view of architects. This set of guidelines embodies correlations of interdisciplinary knowledge, namely, architecture design, social behaviour and climatic condition. It stems from Bay’s proposal of socio-climatic design (Bay 2002a, 2004).
Bay (2001b, 2003) developed a framework for environmental design, which is developed into a digital Precedent Design Knowledge System for use in the design studio. The framework uses the Performance-Operation-Morphology-Context structure and elements for digital knowledge discussed by Tzonis, 1992. In this study, a framework about Context-Morphology-Operation-Performance is used to organise the knowledge and information and develop the design guideline of semi-open entrance spaces of high-rise apartments.

We will begin by reviewing the general bio-climatic design and introduce the concept of socio-climatic design in chapter 1. The relationship of social activities and environment sustainability in architecture design will be discussed. Social activity, which is an important part of sustainable design, will be re-emphasised in the design guidelines. (The procedure of study is shown below, Table I-1.)

In Chapter 2, Alexander Tzonis’s design thinking of Context-Morphology-Operation-Performance and its application to design guidelines will be discussed in detail. In order to develop a guideline suitable for architects, it is useful to understand elements and structures of architectural design thinking. A critical review on the types of the sustainable design guidelines will be done. The framework of Context-Morphology-Operation-Performance will be used to assess the various types of guidelines with the criteria of good guidelines summarised in Chapter 1. It is worth to assess the effectiveness of the available guidelines as it can help understand the key points of developing guidelines from the view of architects.
## Table I-1
### Procedure of study

<table>
<thead>
<tr>
<th>Procedure of study</th>
<th>Chapter</th>
<th>Description of procedure</th>
</tr>
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</table>
| Problem statement                   | 1       | Discussion of the relationship of sustainable design and social activities  
[Introduction of socio-climatic design guidelines] |
| Design thinking & Critical Review    | 2       | Expatiation of a theoretical framework  
[Critical review of the available design guidelines] |
| Research Methodology                | 3       | Description of an approach to develop socio-climatic guidelines  
[Discussion of parametric simulation and pre-parametric design thinking] |
| A case study (Pre-parametric design thinking) | 4       | Descriptive case study of semi-open space in two specific buildings  
[Analysis of the precedent knowledge from the cases] |
| Simulation of thermal comfort (Parametric tools) | 5       | Computer-aided simulation on the shading effect against the solar radiation  
[Analysis of the threshold of good environmental performance] |
| Simulation of ergonomics (Parametric tools) | 6       | Calculation of the limited spaces for social behaviours  
[Combination of social activities with the simulation of physical environment] |
| Guidelines                          | 7       | Structuring knowledge of semi-open space design guidelines obtained from the results of case study and simulation  
[Explanation of a prototype of socio-climatic design guidelines] |
| Evaluation & Conclusion             | 8       | Summary of findings in the study  
[Discussion on limitations, applications and extension of the study] |
In Chapter 3, a proposal of socio-climatic design guideline of high-rise semi-open space based on Tzonis’s framework will be discussed. A research methodology on parametric design thinking and pre-parametric simulation tools will be described based on the case of tropical architecture in Singapore (Figure I-1). In practice, designers use heuristics for design thinking that are pre-parametric for complex design problems, and hardly use parametric methods. In this study, parametric building simulation will be used to prepare guidelines suitable for pre-parametric design thinking.

Figure I-1
Methodology of developing the socio-climatic design guidelines

Two cases of Singapore

Simplification of models

Simulation of thermal comfort  Simulation of ergonomics

Organization of Patterns

Semi-open space design Guidelines

Knowledge of pre-parametric design thinking

Knowledge of parametric design thinking

Structuring knowledge of guideline

In Chapter 4, we will discuss a case study and analyze two high-rise dwellings in Singapore. The case study is based on Bay and Lam’s research on socio-climatic studies of high-rise high-density semi-open spaces (Bay 2004). The research will focus on the semi-open entrance spaces of the apartments because those spaces
involve passive-mode design strategies and play an important role in social lives of high rise. Method of getting precedent knowledge for the guidelines from the case study will be discussed.

In Chapter 5, building simulation will be done to arrive at the optimal sizes and thermal comfort. The simulation will focus on the shading effect of semi-open space against solar radiation, which has great impact on the thermal comfort condition in tropical regions. The depths of the semi-open space will be changed to predict the performance of various shape and to find out the threshold of good environmental performance.

Chapter 6 will focus on the simulation of ergonomics. We will calculate the limited area for different social activities. Combined with the results from the simulation of thermal comfort in Chapter 5, a threshold of good socio-climatic performance will be analyzed.

In Chapter 7, we will structure the guidelines for pre-parametric design using Alexander Tzonis’s framework for representing architectural knowledge. The guidelines are in the form of visual charts, showing the correlations of expected social patterns, predicted bio-climatic behaviours, and sizes. The findings of this study and their general application will be summarized in the final chapter, Chapter 8.

**Outcomes of the study**

The anticipated outcomes and contributions of this study are:
1. Developing a sustainable design guidelines, through a descriptive account of architects’ design thinking, rather than the normative approach that focus on the description of the general rules, principles or examples. Much efforts and emphases are placed on the discussions of the theories of Context-Morphology-Operation-Performance. It is therefore useful to understand how to make the guideline compatible with architects’ design thinking process.

2. An interpretation and exploration of the socio-climatic design guideline. It is a way of involving social activities in the design to full fill the requirement of sustainable environment and sustainable community.

3. A prescriptive tool for aiding architects in obtaining knowledge and information from precedents. An addition to the multi-disciplinary research in design thinking and design knowledge systems (Tzonis 1992, Fang 1993, Bay 2001b). Learning from precedent is a pre-parametric design thinking which is often employed by architects when they facing design difficulties. Parametric design tools can help make this process more accurate and efficient. It is a way to fill the gap between architects and engineers.

4. A set of knowledge on the semi-open space design that can be referred to by designers in architectural practice. The methodology can be extended to help designers in other areas to improve their design thinking and decision-making.
The framework can also be used to guide the preparation of design guidelines in architectural domain.
CHAPTER 1

SOCIO-CLIMATIC DESIGN

*Discussion of socio-climatic design, and the way of involving human factors in environmental design*

In this chapter, we will generally review the bio-climatic design and introduce the concept of socio-climatic design. The relationship of social activities and environment sustainability in architecture design will be discussed and re-emphasised. We will investigate the ways of involve social activity, which is an important part of sustainable design, in architecture design guideline.
Bioclimatic design

Development of bioclimatic design

Bioclimatic approach to architecture offers a way to design long-term and sustainable use of environmental and material resources. The concept of design with accordance to climate is an old architectural objective. The traditional vernacular architecture around the world is full of examples of climate conscious shelters. The development of different architectural styles and expressions in different parts of the world resulted from the utilization of some basic principles whereby buildings and climate join to produce comfort.

Dean Hawkes (1996) reviews the development of environmental design and argues that Vitruvius gave the earliest extensive account of bioclimatic design in architecture in Ten Books on Architecture. Vitruvian Tri-partite Mode of Environment (Figure 1-1) shows the fundamental relationship among climate, comfort and the role of architecture. Hawkes (1996, 13) argues that “The model, in great simplicity, is sufficient to describe the nature of environmental control as exercised by buildings for many centuries, in which the building’s fabric, its architecture, was the primary agent of mediation between the external and internal environments”.

Bioclimatic design was not recognised as part of modern architectural thought until 1953. It was initiated by the brothers A. Olgyay and V. Olgyay. When air-conditioning systems became widely available at the end of the 1950s, interest in bioclimatic design suddenly became less evident in professional and popular literature.
In 1960s, Olgyays developed a lucid model of the environmental design process. In the book, Design with Climate (Olgyay, 1963), the process of building a climate-balanced house is divided into four steps: climate data, biological evaluation, technological solutions, and architectural application (Figure 1-2). The idea of bioclimatic architecture is introduced to show that environmental control is achieved through working with, rather than against, climate. Olgyay (1963) argues that the necessary function of a balanced shelter should be analyzed by ‘calculative methods’. Olgyay’s model is extended to include the function of ‘technology’, of plant and system, in the environmental scheme of modern buildings (Hawkes, 1996).

The topic of bioclimatic design reemerged in response to energy shortages of the 1970s. Banham (1969), with foresight in the problem of energy consumption of building, drew out alternative futures though either ‘power-operated’ or the ‘conservative’ modes of environment control. But, Hawkes (1996, 11) criticizes that, “he offered no clear judgement about the virtues or vices of either”. Based on Banham’s (1969) three distinct modes, the ‘conservative’, the ‘selective’ and the ‘regenerative’, of environmental control in historic buildings, Hawkes (1996) issued the ‘selective’ and ‘exclusive’ modes to distinguish between buildings that use ambient energy sources in creating natural environments and those that rely predominantly upon mechanical plant to create controlled, artificial environments. He developed a complete picture of the system that is possible in a modern building.

With the emergence of global environmental concerns of the 1990s, more attention is paid to bioclimatic design. Now it has developed out of concern on ecological and regional contexts and the need to conserve energy and environmental
resources. In using the term ‘bioclimatic’, architectural design is linked to the biological, physical and psychological need for health and comfort. Bioclimatic approach to architecture attempts to create comfort condition in building by understanding the microclimatic and resulting design strategies that include natural ventilation, daylighting, and passive heating and cooling (Watson 1998, 24).

**Figure 1-1**
**Vitruvian Tri-partite Mode of Environment**
Source: Hawkes 1996

**Figure 1-2**
**Interlocking fields of climate balance**
Source: Olgyay 1963
Absence of social activities in bioclimatic approach

Bioclimatic approach endeavourers, including architects, engineers, and any one devoted to sustainable building, mainly focus on the environmental performance of the building, such as environmental impact, energy burden, or the interior thermal comfort condition\(^1\). However, too much emphasis on environmental performance leads to the ignorance of people, for whom the building serves. In fact, one efficient way to keep the building running well is that the buildings can be utilized by people. Sustainable building design should not keep the social activity out because providing suitable spaces for people is the aim of architecture design.

The fact that green building or ecological building serves human is often forgotten by sustainable endeavourers and even by the users themselves. Designers always focus on nature or energy. Clare Marcus Cooper (1997,73) pointed out, in her guidelines for park design, that “Although most park users claim that ‘contact with nature’ is their main motivation for going to a park, observation of what people actually do in parks suggests that social contact--- both overt and covert--- is equally important. It is easier for most people to say they use a park because they like the greenery than to say instead that a park offers opportunities to meet and watch other people”.

Protecting environment and saving energy should not be achieved at the price of leaving out people’s activities. That is a passive strategy. The active way to promote

\(^1\) Thermal comfort is an important factor that influences occupant’s satisfaction with the thermal environment. ASHRAE defines an acceptable thermal environment as “an environment that at least 80% of the occupants would find thermally acceptable” [Olesen, et al., 1993]. Thermal comfort is defined by ASHRAE (1989) and ISO (1984) as “that condition of the mind which expresses satisfaction with the thermal environment”.
the sustainability development is to set up a good circulation between human society and natural environment. Only through this way can people keep and even create the natural living condition for themselves. Similarly, building designers can not just limit their work to ecological aspect. The diagram below (Figure 1-3) illustrates the linkage between sustainability concerns and classic architectural design principles. It is obvious that, today, a sustainable building should incorporate a balanced concern for the future preservation of three interdependent areas: community, economy, and ecology. In the next section, we will introduce the concept of socio-climatic design opposite to bio-climatic design and discuss the relationship of social activity and environment.

**Figure 1-3**
The linkage between sustainability and architecture design
Source: the National Council of Architectural Registration Boards
Socio-climatic design

Socio-climatic design is created by Bay (2004) as a concept furthering bio-climatic design, which focuses on the physical environment, such as biological behaviour, material ecological and energetic impact. Bay (2004) argues that “Jane Jacobs, in her criticism of the death of American city, reminds us of the imperative to consider social-culture aspects of people in order to have quality living, and in a sense sustain human values and civilization, for we are not merely part of the physical-biological food chain”. An important hypothesis of socio-climatic design is that the assessment of user preferences by design professionals can enhance the process of environmental optimization.

Socio-climatic design brings together two major concerns: social-culture and climatic-ecological issues. According to Bay (2004), it adds the consideration of place making, a sense of belonging and quality of living to bio-climatic design. It can help to enhance the quality of urban life, especially in the high-rise high-density living environment. So, it must be part of knowledge of sustainable design.

Human behaviour and living environment

Since 1960s, there have been many researches concerning the relationship between human behaviour and elements of the architectural and natural environment. Stokols (1978) summarised two converging lines of these research: ecological psychology and
environmental psychology. While ecological psychology emphasizes on the collective processes by which groups adapt to the physical and social resources available in the environment, environmental psychology focuses more upon intrapersonal processes, such as perception, cognition, and learning that mediate the impact of the environment on the individual. (Stokols 1978, 6)

Human behaviour is related to environmental conditions. Lewin (1935, 1936) emphasized the continual interaction of inner and outer forces, such as personal needs, values, and attitudes, as well as environmental conditions. In his point, behaviour is a joint function of personal factors and the perceived environment. In Murray’s analysis (1938), human behaviour is determined not only by personal traits and underlying needs but also by environmental presses that either satisfy or frustrate these needs. Bowers (1973) clearly and comprehensively stated the interactionist perspective that situations are as much a product of person as the person’s behaviour is function of the situation. (Stokols 1978, 15) Thus, in the designed living environment, there is a dynamic interchange between Man and the environment in which people affect, and are affected by their settings.

Human behaviour should be an indispensable element of sustainable design. Day (2003, 30) argues that “Sustainability isn’t just a euphemism for ecological. For something to be sustainable, it must continue. And, as nearly every stable ecosystem in today’s world is held in balance by a partnership of humanity and nature, this continuance depends upon people”. Hence, human value cannot be sidelined.

Designers should take into consideration of not only environmental strategies, but also the manners of making buildings more user responsive and more intelligent. The
two aspects should not be looked separately. They are two interrelated factors as a whole. An example will be the high-rise gardening.

**Figure 1-4**

*Interactions among building design, social activities, environment and energy*

*Source: Author*

Many architects like to have green space in their buildings because they think that plants can improve the indoor environment and make the building more ecological. But most of the high-rise gardens, which are costly to maintain, cannot be enjoyed by occupants. Since designer didn’t consider human behaviour and residents’ need, the
garden may be a place that lacks of privacy, or as hot as a greenhouse. As a result, no
one will like to stay there even if it looks beautiful. A high-rise garden will be
meaningless if it is no more than a decoration.

On the contrary, if architect designs a comfortable and convenient place for social
activities, high-rise garden will be a part of people’s daily life. Occupants will place
some plants in the space on their own initiative and maintain the garden themselves.
The diagram (Figure 1-4) shows the possible structure of the relationship of building
design, social activities and environment. In this way, high-rise garden will help not
only sustain the environment and community, but also save energy and minimize the
urban heat islands effect. In a summary, no ecological building will be sustainable
unless people want to live there, maintain them and imprint them with care.

**Ways of involving of human factor in architecture design**

There are different ways of integrating human factor in architecture design. It can be
before design process, or during design process. An example will be Day’s consensus
design, which is co-design (Day 2003). It involves design and construction
professionals, clients, users and anyone who might be affected by specific
environmental and architecture development. It reconnects people with place through
users’ attendance of design process. Day (2003, 32) argues that the buildings that
result from this process revere both people and place, the life of nature and of human
activities. However, co-design is not applicable to complicated sustainable design,
which requires knowledge of many disciplines. It is hard for architects to constantly spend time on explaining design ideas to clients and users, and discussing with them.

Development of socio-climatic design guideline is distinguished from other ways. It considers human factors before design process; therefore it is more convenient for architects. Guidelines, which predict environmental and social performance can help, in advance, deal with large amount of knowledge and information from building science researchers, civil engineers, environmental design coordinators and even users. In this thesis, we will study an approach to develop socio-climatic design guidelines.

The socio-climatic design guideline will be developed and presented in an architectural way. First of all, it is important to know how to frame and present the architectural knowledge in the guideline. Tzonis (1992) derived a framework for representing architectural knowledge with the interrelated concepts of performance, operation, and morphology in a context. This framework can be used to guide socio-climatic design because morphology, operation, performance and context clearly present the necessary elements in the design of environment and social culture, as well as their logical relationship. In the next chapter, chapter 2, we will discuss in details on Tzonis’s framework and its utilization in the design guidelines.
Precedent study on the socio-climatic design

Bay (2004) studied high-rise high-density semi-open spaces with the case of Bedok Court Condominium in tropical Singapore. They examined the quality of spaces in terms of community and environmental aspects. Bay (2004) proposed a socio-climatic sustainable cycle (Figure 1-5) and suggested a framework of environmental research on the dynamic synergy of socio-climatic qualities, beyond the bioclimatic model, for designing sustainable dense urban environment.

**Figure 1-5**

Socio-climatic sustainable cycle

Source: Bay 2004
This study will develop socio-climatic design guidelines based on Bay’s present study on tropical high-rise semi-open space. Objectives of carrying out study of specific building projects are:

i). Understanding the process of developing socio-climatic design guidelines, ways to collect data from case study, do simulation in between, and design various patterns in the guidelines;

ii). Ascertaining the feasibility of the guidelines and its success in the application;

iii). Finding out some real problems in the practice of developing the guidelines, and pointing out the limitation of the methods and possible improvement.

Bay’s study generally shows the relationship of thermal comfort and social activity on the case of high-rise semi-open space, but not further develops guidelines on the architecture design. Several questions are left in his study: i) How do the sizes and configurations of forecourts constrain the types of human activities? ii) What is the optimal size for various activities? and iii) Are there higher and lower limits for each activities? This research will answer these questions by investigation of the size of semi-open entrance spaces, as well as its relationship with thermal comfort and social activities.
CHAPTER 2

FRAMEWORK OF CONTEXT-MORPHOLOGY-OPERATION- PERFORMANCE AND DESIGN GUIDELINES²

Explanation of theoretical framework, and a distillation of the content and structure of available environmental design guidelines with a focus on an architecture design scale

Alexander Tzonis (1992) developed a framework for representation of architectural knowledge, which is discussed in more details in this chapter. It will be used as a theoretical foundation of socio-climatic design guidelines in this thesis. In this section, a critical review is done on the content and structure of the various types of environmental design guidelines. Tzonis’s framework is used to assess the elements that are included or missed in the guidelines. The aim is to understand what aspects these guidelines are talking about and in which mode they are presenting. The critical review is not only a compilation of the prevalent environmental design guidelines, but also a critical analysis of the methodologies of developing these guidelines.

² This section was published at 1st International Tropical Architectural Conference (Singapore 2004). Paper title: Environmental design guidelines for socio-climatic design of tropical region.
The design thinking of *Context-Morphology-Operation-Performance*

Elements in the framework

Based on analytical paradigm, a framework shaped by the views of Chermayeff and Alexander (1963), Alexander Tzonis developed a frame for representing architectural knowledge. The framework includes four elements: *Context, Morphology, Operation and Performance*. Tzonis argues that, ‘We consider form, operation, performance of a design product, in reference to the context within which the artifact is to be realized.’ (Tzonis 1992, 147)

*Context* refers to the boundary conditions such as climate, surrounding environment or culture atmosphere. Tzonis (1992, 148) argues that ‘Context enters in design reasoning by attaching conditions within which the principles or rules about relations between form-operation-performance apply.’ *Context* describes the background under which the architecture design happens, while *morphology, operation* and *performance* tell stories about architecture design itself. Bay (2001, 120-123) applies the three concepts to a tropical context and cites that:

- **Morphology**: refers to the formal aspects of a building or urban design
- **Operation**: refers to the processes of use of a building, and the role of forms in these processes.
- **Performance**: refers to the conditions a prospective building is interned to bring about, or the degree to which a scheme of a building brings these conditions about.
An indigenous traditional house in Malaysia is taken as an example (Figure 2-1). The Malay house is constructed in the countryside of a tropical region. That is the context of the building. To achieve cooling effect, the morphology of big roof is often used in Malay house. Performance is that the big roof reduces the indoor temperature by two Celsius degrees lower than outside. Operation explains the theory behind. Suppose the reduction of indoor temperature is caused by the shading effect of the big roof, and it is found that the big roof can reduce 70% of direct solar radiation. That is the corresponding operation of the big roof.

**Figure 2-1**

*Indigenous Traditional House in Malaysia*

Source: After Edward 1990
The relationship of the elements in the framework

Context, morphology, operation and performance are interrelated. Tzonis (1992, 147) argues that, ‘This interrelationship can be expressed in constraints that state which performance of a building may result from which operation and, in turn, which operation may result from which form, a rule chain whose links are neither deterministic nor closed.’ The interrelation of these elements is compatible with different reasoning processes of architecture design. Tzonis (1992, 148) explains some types of reasoning which designers use in practice expressing constraints linking form, operation, performance and context to each other. He said, ‘First, given the performance of a building they try to explain the aspects of operation and form - that may have influenced it, or given the operation of a building, which aspects of its form may have affected its operation (Davis and Hamscher, 1990) ……. A second type of reasoning process information the opposite direction. From form it predicts operation, and from operation performance. In design practice predictions are used in the evaluation of artifacts’.

The framework and socio-climatic design guideline

Context-Morphology-Operation-Performance framework can also analyze and explain social behaviour. Stokols (1978) summarises the various lines of research in environmental psychology and categorized them according to three basic kinds of human transactions with the environment: (1) orientation, (2) operation, and (3)

evaluation. He (Stokols 1978, 16) explains that ‘Orientation pertains to the processes by which people perceive where they are, predicts what will happen there, and decides what to do. Operation refers to the processes by which people act upon, and are affected by, their surroundings. And evaluation involves the assessment of how effective one’s actions in the environment have been in procuring certain goals and how adequate the environment is as a context for future activity and goal attainment.’

The concept of orientation, operation, and evaluation can be reflected correspondingly by the Context-Morphology-Operation-Performance framework. Orientation equals to Morphology, Operation equals to Operation, and Evaluation equals to Performance. In addition, both of the theories are discussed under certain context. So the Context-Morphology-Operation-Performance framework can be used to research on environmental design and social behaviour, or say socio-climatic design. In the next section, we will discuss the application of the Context-Morphology-Operation-Performance framework to design guidelines.

The design thinking of Context-Morphology-Operation-Performance can be used as a framework for representation design guidelines. It tells the story of environmental control by answering designer three interrelated questions: what method should to be taken under certain condition (Morphology and Context), what result can the design method lead to (Performance), and why certain method can reach the predicted performance (Operation). Design guidelines under the framework of Context-Morphology-Operation-Performance are in accordance with architectural design process and can help architects at different stages of design.
Absence of these elements in design guidelines will be problematic. The lack of statement of context will result in the totally misuse of the guidelines. If there is not adequate knowledge of morphology, the guidelines cannot be used by architects directly. Designers have to go to other references to search for design method. The missing of performance will make the guidelines inaccurate. Without operation, the guidelines are probably misused and that will lead to unexpected performance. The problems caused by absence of necessary elements will be explained in details with examples in the following sections.

Some aspects of environmental design guidelines

Socio-climatic design, which adds the factor of social activities to environmental design, is a new concept. There are no available design guidelines on this topic. So, we need to study environmental design guideline at first, which will give a clear clue to the development of socio-climatic design guidelines. Environmental design in this study refers to the design of various factors generated by, or related to climatic conditions, in order to satisfy the need of the physiological comfort of the occupant of a building.

Element factors of environmental design guidelines

Environmental design in a wider sense also refers to the design for sustainability in the long term. Hyde (2002, 46) argues that climate responsive design, using passive climate control systems rather than relying on active energy systems, is an internal part of the environmental framework that is being developed to reduce environmental impacts and provide for human being. We limit our discussion to only the aspects of environmental design that is related to environmental control for comfort and convenience of the occupant of a building. Based on the theoretical framework in last section, we will discuss the elements factors of environmental design guidelines.

Olgyay (1963) mentions six aspects which should be considered in climatic design: site selection, orientation, shading calculation, housing form, air movement and indoor temperature balance. Bay (2001) issues four aspects of environmental control: regional expressions, climatic comfort and convenience for social and culture need, materials and means of building, and thermal comfort. Among these element factors, thermal comfort is most important because it is related with physiological feeling of the occupant directly. Bay (2001, 18) summarizes the physical factors in relation to the tropical climate that need to be considered in the environmental control (identified by e.g. Fry and Drew 1982; Olgyay and Olgyay 1963; Lippsmeier 1980; Koenigsverger et al. 1974) as follows:

i. Solar radiation and sun path,

ii. Daylighting and glare,

iii. Temperature and temperature change
iv. Precipitation (rain),
v. Humidity,
vi. Ventilation, and
vii. Noise and air pollution.

These are the factors that are involved in environmental design guidelines. Various approaches include some or all of these factors. For example, Lam (1997) concentrates on guidelines of solar radiation in Singapore, and goes into details of sky luminance distribution and computational prediction of daylighting performance. Wong (2002) develops guidelines on natural ventilation of public housing in Singapore. Both of Lam and Wong, with many other similar guidelines, only concern one factors of environmental design, while Yeang (1999) discuss all factors of environmental impacts of skyscraper in The Green Skyscraper: the Basis for Designing Sustainable Intensive Buildings.

Modes of presentation of guidelines

The ways of how guidelines are presented have direct relationship with their effectiveness and efficiency because visual contact is important for the users. Six modes of presentation are summarized below from the available environmental design guidelines. They are descriptive statements, plan/sectional sketches with analysis, photos or 3-D Models, charts or tables, analytical diagrams, and computer programs.

Descriptive Statement
Descriptive Statements is a basic way of presenting guidelines. The descriptions can be a simple statement on general principles, or a detailed one on a particular aspect of environmental design. The ease of use depends on the way of description and organization of the statements.

**Plan /Sectional sketches with analysis**

Sectional sketches with details of components are used to help the eye judge and decide graphically. Examples of guidelines using such architecture languages are sketch map, plan, section or legend, which can be easily understood by architects. Hawkes’s (1996) analysis on the operation of a school building is an example of sectional sketches with analysis (Appendix A, Figure A-1). These guidelines are presented from the views of architects.

**Photos and 3-D Model**

Photos and 3-D model of a building is the most direct way of presentation. It is most correlated with reality, where no extra imagination is needed. The guidelines in this way are easy to read and will avoid the any misinterpretation of their meaning. They
are often used as qualitative, not quantitative analysis because their limitation of inaccuracy.

**Charts, Graphs and Tables**

Charts, graphs and tables are often used to present the quantitative factors of the guidelines. They can be used to illustrate a series of values or solutions under different conditions. It is easy to read and check. Users can search for items according to their needs. However, extra time and mental resource are needed to look through the data or to analyze the graphs.

**Analytical Diagrams**

Analytical diagrams are often used to show comparison or express ideas which are difficult to describe clearly in words. It is a convenient and relatively free way of presenting the guidelines. For example, Hawkes (1996) compares different building shapes through illustrated diagrams, to argue that successful design in architecture frequently rests upon the establishment on outset of an appropriate shape (Appendix A, Figure A-2, A-3). Diagrams are simply and far remote from real buildings, but they do establish a basic measure of the potential of a design approach.
Computer programs

Some computer programs are also applicable for environmental design guidelines. In this case, results from a particular research project are normally used as a database to develop the program. What the users need to do is to input some parameters according to the project, and specific results can be obtained from the program. For instance, Lam (1997) developed an excel-based software named SOLARIS, for predicting the performance of shading devices in Singapore. The user will be able to get two values on the effectiveness of shading direct and indirect solar radiation by inputting basic parameters such as the orientation of the buildings, the dimension of the window and the shape of the shading device. Computer program is a scientific and accurate way of presenting guidelines. However, although developers tried to make the program user friendly, the difficulty of using still limits its application.

Combination of presentation manners

The six modes of presentation discussed above are the fundamental ways of expression. In summary, each of them has their strong points and limitations. Table 2-1 shows the comparisons between the six modes.

In fact, several means of presentation are sometimes used together in one guideline. For example, Olgyay’s (1963) guideline on shading devices, which is based on shading marks for design purpose, is presented using descriptive statement,
sectional sketches, photos and diagrams (Appendix A, Figure A-4). Through the columns, the guidelines are able to show the views of various types of shading devices respectively, the analysis of the sun-path, the masks drawn by geometrical methods, and some real examples and descriptions of the characteristic.

Table 2-1
Comparison of the presenting manners
Source: Author

<table>
<thead>
<tr>
<th>Name</th>
<th>Good Points</th>
<th>Limitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Descriptive Statements</td>
<td>Easy to develop</td>
<td>Not facilitating fast thinking</td>
</tr>
<tr>
<td>Plan/Sectional sketches with analysis</td>
<td>Easy to understand</td>
<td>Inaccurate in application</td>
</tr>
<tr>
<td>Photos and 3-D Models</td>
<td>Visual friendly</td>
<td>Inaccurate in application</td>
</tr>
<tr>
<td></td>
<td>Direct following in design</td>
<td></td>
</tr>
<tr>
<td>Charts and Tables</td>
<td>Accurate in application</td>
<td>Data can not be used directly in design</td>
</tr>
<tr>
<td></td>
<td>Easy to check</td>
<td></td>
</tr>
<tr>
<td>Analytical Diagrams</td>
<td>Clear to show variation and comparison</td>
<td>Inadequate knowledge</td>
</tr>
<tr>
<td>Computer programs</td>
<td>Accurate</td>
<td>A lot of extra work in calculation or simulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Complicated tool can not be independently used by architects.</td>
</tr>
</tbody>
</table>

Suitable way of presenting socio-climatic design guideline

Socio-climatic design guideline is difficult to present clearly through a single mode. It involves multi-disciplinary knowledge and requires quantitative and qualitative analysis. Several modes should be combined in presentation to maximise the effectiveness and efficiency.
Chart with details is a good way to present the socio-climatic design guideline. Table can contain substantial information and are very easy to check. Therefore, it can be used as a basic structure of the guidelines. The contents of the table could relate to performance, operation or morphology under certain context. Sketches with analysis, photos, models and diagram could be used to fill in the contents of the tables. In this way, guidelines will be accurate to apply, easy to understand, fast to use and provide adequate knowledge.

A critical review of the available design guideline

The aim of this study is to provide architects with guidelines that can improve their practice. Therefore we need to gain more insight into the nature of environmental design guidelines. In order to improve guidelines, we have to understand them, and in order to understand, we must be able to describe them. First of all, we need to have a critical review of the types of existing environmental design guidelines, to see where and why problems occur. Bay (2001, 61) divides the guidelines into four types: rules and principles, typologies, examples, and quantitative analysis with calculation and simulation. Based on Bay’s categories, five types of environmental design guidelines are discussed in this section. They are regulations and codes, rules and principles, typologies, examples, and quantitative analysis with calculation and simulation. They are arranged in the order of degree of richness in knowledge of guidelines. The
framework of *Context-Morphology-Operation-Performance* is used to describe and evaluate the guidelines.

**Regulations and Codes**

Regulations, codes and standards are the simplest guidelines. They can be divided into code-based and performance-based guidelines.

**Code-based guidelines**

Code-based guidelines are descriptions of the morphology, which are the minimum requirements to satisfy the code. Examples are the minimum width of a wall or minimum distance between buildings. The guidelines can be found as a part of general planning scheme of a city, town or state. The whole scheme, which is used as a mandatory policy, often concerns many aspects of planning and design, from setbacks and site coverage to building height and silhouette, from streetscape amenity to landscaping, and from parking or traffic to service infrastructure and so on. Environmental design guidelines, as a section of the whole city design guide, normally summarize the basic requirement from the requests of local climatic design. The guidelines usually have the power of making architects take into consideration environmental problems, when sustainability would not be included the decision-
making process due to short of time, mental resource or financial aids. The code-based guidelines are easy to read and simple to follow. They provide exact values that can be used directly by architects.

Code-based guidelines do not relate to operation and performance. For example, in Singapore, it is suggested that the window size should not be less than 50% of the wall area to encourage natural ventilation. In fact, many factors have impact on the wind pattern. So, even though the window may occupy 90% of the wall area, there may still be no natural ventilation in the room. Hui (2002) argues that this kind of guidelines tends to limit development of new technologies and techniques, as well as the creativity of architects. The prescriptive codes are not able to consider the interactions between the building systems and measures that may optimize the combined performance.

**Performance-based guidelines**

Hui (2002) defined that performance-based guidelines refer to those giving the situation in which regulations are written in terms of the required outcome, rather than by prescribing the process by which the specified outcome can be achieved. They can help designers present a solution, together with appropriate predictive evidence of its future performance. For example, it is suggested in *Hugh L. Carey Battery Park City Authority Residential Environmental Guidelines* to provide humidity stabilization
through adjusting the temperature to 68°F and relative humidity to 30% in winter and to 76°F and 50% in summer, throughout the year for all occupied building spaces.

Performance-based guidelines give suggestions on what designers need to fulfill in order to reach the goal of sustainability, rather than advise the specific manners that can be used to achieve the goals. It only contains the performance and not about the suitable morphology. For example, the American Public Health Associate Committee on the Hygiene of Housing recommends that orientation and spacing of buildings should meet the following performance standard: “At the winter solstice, at least one-half of the habitable rooms of a dwelling should have a penetration of direct sunlight of one-half hour’s duration during the noon hours when the sun is at its maximum intensity.” Olgyay (1963, 62) criticized that “This standard, although commendable, does not define any orientation, being dependent on the plan and spacing of the buildings.”

Sometimes, designers need to do quantitative analysis, such as calculation with mathematical formulas or computer simulation. For example, in order to fulfill the requirement of 68°F 30% RH (relative humidity) in winter and 76°F 50% RH in summer, which is mentioned in previous paragraph, architects have to test his design through some mathematical or physical way. But in practice, most of architects would depend on air-conditions to achieve a comfortable temperature and relative humidity in their building, and not spend their time calculating, simulating and modifying their design to fit the sustainable standards. Even if the architects have enough technical support, they still need to put in lots of time and mental resources, especially in the early stage of design. Olgyay, who had illustrated the quantitative guidelines admitted:
‘in practice we cannot expect an architect or builder to go through all those elaborate calculations’ (1952, 23).

The inadequate knowledge of morphology limits the guidelines in helping the design practice because the guidelines cannot be used directly. Architects have to go to somewhere to look for the specific design methods elsewhere. Morphologies solve the problem of design thinking by translating the scientific language into an architectural one. Here, architects can be compared to computer users, and what the researchers developed is taken as computer programs. Media such as software is needed to translate the programming languages into something that can be easily used. The function of morphology is to transfer information from new technology to design practice, interpret environmental design theories, and present the guidelines in the way of architectural design.

Rules and Principles

Bay defines (2001, 49) rules as usually valid generalizations, and principles as comprehensive and fundamental law, doctrine, or assumption. In Book VI of Ten Books of Architecture, Vitruvious wrote, ‘In the north, houses should be entirely roofed over and sheltered as much as possible, not in the open, though having a warm exposure. But, on the other hand, where the force of the sun is great in the south countries that suffer from heat, houses must be built more in the open and with a northern or north-eastern exposure. Thus we may amend by art what nature, if left to
herself, would mar.’ The above description of houses for different regions, and the later discussion in Book VI on ‘the proper exposures of the different rooms’ can be taken as the first rules and principles of climate responsive design.

Rules and principles can be several lines of summary or pages of description with a lot of details. For instance, Powell (1996, 13) summarizes a simple checklist with ten items to judge the appropriateness of the design of a house in the humid tropics. Each item is described by one sentence, such as “be naturally ventilated with permeable walls facing prevailing breezes”. While Yeang (1999, 202-265) gives suggestions on the design of passive-mode system from eight aspects. Each aspect contains pages of description of the principles.

No matter how simple or complicated, most rules and principles describe morphologies. Operations are often missed out in the guidelines. We can take the Planning Scheme for the city of Yarra in Australia for an instance. The following is a part of the guidelines from Yarra Planning Scheme.

22.09-3.5 Guideline No. 4 Environmental Sustainability.

4.1 New development should be sited and orientated to maximise solar energy use, reduce winter heat loss and to protect occupants from harsh weather conditions and natural elements such as western sun and strong winds.

4.2 Weather protection devices which should be incorporated into new development include:

• Canopies over the main entrances;

• Verandahs along western and northern facades;
• **Sun shades over partial areas of communal open spaces;**

• **Solar protection of west facing windows; and**

• **An appropriate level of openable windows to allow effective natural ventilation of internal spaces.**

Through these guidelines, architects cannot make clear about the particular relationship between the orientation of the building and environmental sustainability. Even though designers following the guidelines will add verandas along some facades, design sun shades for the open spaces and open windows for natural ventilation, the design probably has nothing to do with climate, except looking like an environmental friendly one.

Inadequate knowledge of operation will result in the problem of architects obeying the guidelines but not achieving the expected performance. Bishan Institute of Technical Education (Bishan ITE) in Singapore is an example. Bishan ITE is an educational complex with two parallel blocks of accommodation separated by a strip of landscaped open-street (Appendix A, Figure A-5). A case study done by Bay (2001) shows that the performance, as described by the architect, is quite different from the reality.

The architect of Bishan ITE got the morphology of landscaped streets between building blocks from Kampong Bugis Design Guide Plan (DGP) proposal (Appendix A, Figure A-6). And he believed that high and narrow space with overhanging roofs could effectively give shade throughout the day and improve the natural cross ventilation. However, the users reported that the re-radiation level of the landscaped
street in between the buildings is very high, and expressed discomfort when staying there. The reason is that no operation in the guidelines explains to architects why the landscaped streets can achieve cooling effect and natural ventilation.

**Typologies**

Taxonomy is an important way of developing guidelines. In the early period of environmental design, Olgyay (1963) for instance, used simple taxonomy of building types relating to climate, making it possible to initiate the development of an appropriate design. There are two kinds of typologies: stereotype-based guidelines and function-based guidelines.

**Stereotype-based guidelines**

The term of stereotype is defined by Hawkes (1996, 46) as a generally held notion about the nature of a good solution to any recurrent building design problem, that frequently inspires the initial design hypothesis. The guidelines based on stereotype make reference not to a simple type, but to an accumulated store of solutions, making it more productive. Hawkes (1996) presents the stereotype of the British form of office building in the first past of the twentieth century (Appendix A, Figure A-7). It provides simple stereotypes of office building forms, and works as platform for creative design.
Normally, the stereotype-based guidelines are first used to establish morphology of architectural form; subsequently the tools of building science and other methods of analysis are used to make explanatory statements about the relationship between form and performance. The relationship of science and precedent in environmental design is argued by Hawkes (1996, 62), ‘Science has primarily help to explain why the precedents were successful rather than to define a fundamentally new basis for design, free from the traditional empirical constraints on form. With the assistance of science the evolutionary process has certainly accelerated, but it is still possible to indicate the formal antecedents of most design.’

The stereotype testified by science, in fact, provides a reasonable confident position for architects to begin the cycle of analysis and revision. Hyde (2002) designs Habitat Home as an ESD (ecological sustainable design) demonstration for the suburbs (Appendix A, Figure A-8). A notional ideal environmental brief was established and then used to develop the design of the prototype environmental house.

Another kind of stereotype is the comparison of different design approaches. These approaches are aim at a same aspect of design, such as the orientation of the service core in skyscraper, the dimension of the shading device or the configuration of a building. The conditions under which to do the comparison normally come from the difference in climate, such as the wind direction, azimuth of sun, or air temperature variation. The guidelines can be used widely because they provide approaches under different conditions. For instance, Yeang (1999, 207-208) develops guidelines on the service core of skyscraper (Appendix A, Figure A-9, A-10) by first simplifying
typical models of buildings. Comparison of the performance of stereotypes is then illustrated by changing the position and orientation of the service core.

The limitation of stereotype is argued by Hawkes (1996) that, in environmental design, the stereotype guidelines fail to acknowledge that the goal of good performance can be achieved in many ways, both in the terms of values attached to the design parameters and architectural and technological means. Another limitation is, analyzed by the Tzonis’s framework, that the stereotype-based guidelines tell architects certain relationship of methodology and performance, without allowance of different context and sometimes with no information of the operation.

**Function-based guidelines**

Function-based guidelines refer to those that are developed according to the function of the space, structure or other components of a building. They could be approaches in designing roof, internal or external wall, and floor, or they could also be suggestion on office room, rooftop garden or courtyard. For example, in Vitruvian’s guidelines, the expectation of the comfort in a room with different functions has been implicated when he speaks of the purpose of bedrooms and libraries requiring the morning light and, hence, an eastern exposure. Jeffrey E. Aronin (1953) gave the recommendation on room exposures based on the function of the rooms (Appendix A, Figure A-11). He suggested sun orientation for various rooms in residential buildings to be above 35° latitude by using illustration.
Another example is that, in *Climate Responsive Design: A Study of Buildings in Moderate and Hot Humid Climates*, Hyde (2000) discusses design strategies of five types of roofs:

i. skillions (mono-pitch), duo-pitch and vaults

ii. attics

iii. parasol and free-form roofs

iv. low-inclination and trafficable roofs (water cooled roofs and mass roofs, double roof, insulated and inverted roof)

v. shading roofs, surface-diffusers and surface reflectors

vi. roofing accessories (roof inclination and overhang, gutter and rainwater pipe design, edge gutters, box gutters)

Strategies are given on types of roof geometry (Appendix A, Figure A-12). Analysis and examples of six types of roofs are shown. Architects can choose and follow according to their need. It is convenient to put design method into practice. But there is seldom description of the performance. Absence of performance is caused by inadequate evaluation of the morphologies. It is often taken for granted that performance can be deducted from the operation, but in actual fact, performance is impacted by many factors. So, guidelines without performance cannot help designers present a design solution with appropriate predictive evidence of its future performance.
Examples

Bay (2001, 49) argues that, “A ‘case’, or an ‘example’ contains aspects of multifaceted decision processes as a holistic solution. It allows one to focus in detail and depth on the domain problem without losing applicability”. Learning from precedents is necessary for architects in practice because they can help to generate new solutions quickly and efficiently for the difficult design problems. Many environmental guidelines are developed from the exemplary buildings. Some examples may contain rules and principles, and therefore are more comprehensive and concrete than other types of guidelines. They contain some or all the elements of design guidelines. Although some examples concern complicated knowledge in many aspects of environmental design, they are easier to understand and use by architects than other types of guidelines. There are two sources of examples: one is traditional building-based; the other is modern building-based.

Traditional building-based guidelines

Traditionally designed buildings are always used as precedents because they can offer an understanding of the relationship between culture, climate and building form. Hyde (2000, 8) argues that these buildings encapsulate thousands of years of unconscious research into relationship between building and climate, and represent more holistic models for the development of a climate responsive architecture. This kind of
guidelines normally provides information on the architecture rather than a set of ready-made solutions.

In tropical area, Indigenous Malay house is often used as examples in guidelines (Appendix A, Figure A-13). Their large roof overhangs for solar protection, and porous facades for cross ventilation show the traditional way of designing climatic responsive buildings.

**Modern example-based guidelines**

Modern example-based guidelines tell a story of environmental design by analyzing in detail some projects with good performance. They often show the pictures of the existing buildings, diagrammatize typical approaches, elaborate the morphologies and analyze the operating system.

Although the guidelines in examples are vivid and suitable for architects to get useful information, they are probable to be misused by designers. This limitation comes from the variation of boundary condition of each building. For instance, in Architecture in a Climate of Change: A guide to sustainable design (Smith 2001), the author took the Contact Theatre (Appendix A, Figure A-14) in Manchester University as an example to tell about the unassisted natural ventilation. In the guides, the operating system based on stack effect is explained (Appendix A, Figure A-15). And the author particularly illustrated the design method used in rotary terminal (Appendix A, Figure A-16). Although the whole system based on stack effect can
work economically in UK, it is not suitable in Singapore, where the difference in temperature outside and inside is very small. So, if the architect copies the morphology from the example, he must fail in that design.

In addition, some guidelines mainly show the approaches to architects, but seldom tell about the theoretical basis. There is no way to access to other approaches when the boundary conditions are in between. The space left for deduction is too little, limiting the creativity of the designers.

Quantitative analysis with calculation and simulation

Quantitative analysis in environmental design is using the calculation or simulation tools to achieve the performance of the building. It makes the future performance of the designed building more reliable.

The quantitative analysis-based guidelines concern comprehensive aspects of environmental controls, including daylight consideration for lighting and flare, protection from rainstorm, building materials and constructional considerations, etc. The analytical system developed by Olgyay (1963) is a typical quantitative analysis-based guideline. Bioclimatic chart (Appendix A, Figure A-9-17) clearly establishes the relationship of climate to comfort for any given conditions. Olgyay’s schematic chart, Schematic Bioclimatic Index (Appendix A, Figure A-18), synthesizes architecture and building science effectively. Architects can easily plot prevailing climatic conditions on the chart and find out which corrective measures are needed to
restore comfort conditions. Quantitative-analysis based guidelines can effectively combine building science theories and architectural interpretations. It makes the future performance of the building more reliable.

Moreover, architects not only can get scientific suggestions on how to design with different environmental conditions, but are clear with why to design in this way. It allows designers to deduct the approaches in between. For example, Figure 2-2 shows the design guidelines on basic forms of houses with the explanation by Olgyay: “On the graph at the left the heat amount received by different building shapes are charted, the numerical values of the heat amount received by the square house both in winter and summer were considered as starting reference points, and therefore located on the zero line, the heat amounts received by other forms (see top) are charted from this line relative to it. The middle column illustrates the optimum and elasticity basic forms compared to the square area. At the right are architectural interpretations of the basic forms.” The illustration and description from the guidelines provides serious relationships between climate and building forms. Architect can develop his own approach with accurate estimation of the environmental performance.

With the development of more and more computer simulation programs for the assessment and prediction of design for environmental control, the tedious and complicated calculations can be automated and the task made easier. Computer simulation-based guidelines normally concentrated in a particular aspect of environmental control. They are easy to use software or instruction on how to use computer simulation to assist environmental design.
Quantitative analysis with calculation and simulation contains morphology and performance. The operation is normally mathematics formulas or computer program, which cannot be seen directly or understood easily. Quantitative analysis with calculation or simulation always needs the experts’ help and requires of a lot of time and mental resources. Hyde (2000, 59-61) argues that it is suitable for diagnosis of design effectiveness after the architect’s initial design stage, so as to demonstrate to the client the effectiveness of environmental design and to make minor detailed adjustments.
The guidelines compatible with architects’
design thinking process

The requirement of architects

The reason why so many guidelines do not contribute as much as expected in architecture design is that they are not developed or presented in architects’ way. In brief, by the terms of ‘in architect’s way’, it refers to ‘compatible with architects’ design thinking process. That means environmental design guidelines should keep in accordance with the sequence of a building design process and reflect the particular requirement of architects.

The difference in thinking manners between architects and engineers is that architects concern more about space for human activities while there is much more consideration of performance of physical environment in engineers’ minds. This difference comes from the special character of architecture design, a half intuitional process, and a half rational process. On the one hand, architecture design dose not belong to science-based (and/or technical rationality) category, and on the other hand, design has always been considered part of professional knowledge to distinguish it from fine art, i.e. painting. So, what architects need to obey in design practice is not only physical standard, but also human standard and aesthetic standard. The guidelines are purely based on scientific computation or on logical induction and deduction can not be well used by architects in sustainable building design.
Another requirement of architects is the flexibility of the guidelines. Just as no two leaves are totally same to each other, building design varies in different climate, under different cultural background and according to different design program. The guidelines must fit the variation in architecture design. That does not mean guidelines have to include every possible situation. The most important is that the guidelines can tell architects the reason behind and give them multi-choices. Only in this way can architects deduct their own solutions.

Last but not least, the guidelines should be an integrated system. A system approach helps in reaching decisions that are optimum for the system as a whole, through the division of complex systems into smaller and more manageable components that are logically linked to achieve defined objectives using logical and systematic procedures that can be explained and repeated (Al-Homoud 2001, 430).

Criteria of good guidelines for architects

Degree of richness of knowledge in environmental design guidelines is important. It affects the effectiveness and the efficiency in the use of the guidelines. Some guidelines are just simple rules; some are rules with details; and others are detailed examples. Insufficient richness of knowledge will make guidelines inaccurate and inadequate. On the other hand, overflow of the knowledge will slow down the thinking process of architects, making guidelines indigestible to users. Mahdjoubi (2001) pointed out that “Research indicated that the decision-making progress is
closely related to the level of detail. Information is more effective if the right data is presented at the right level of detail.”

Besides adequate knowledge, good guidelines should be accurate in application. Environmental design is not creating process which only deal with aesthetics or functional factors. It involves more scientific theories and technological consideration. No one can finish climatic responsive design depending only on his imagination. So, the accuracy of the guidelines is especially important, as it determines the effectiveness of the design.

Good guidelines also need to be developed in an architects’ way. That means the guidelines should be compatible with architects’ design thinking process and presented in architectural languages. The efficiency of the guidelines is determined by whether they are in the way of architects. Good guidelines are user friendly, which allow fast thinking, and are easy to use and understand.
CHAPTER 3

SEMI-OPEN SPACE DESIGN AND RESEARCH METHODOLOGY

Methodology to develop socio-climatic design guidelines of semi-open space with the case of tropical high-rise dwellings, and discussion on the application of parametric simulation tools to the preparation of pre-parametric design guidelines

In this chapter we will discuss an approach of developing a particular set of guidelines with interdisciplinary knowledge, namely, architecture design, social behaviour and climatic condition. The methodology will be explained based on the case of semi-open entrance space of tropical high-rise apartments in Singapore. The parametric tool is used to assist pre-parametric design thinking, where pre-parametric design thinking is a common heuristic used by designers in practice. Computer simulations will be discussed to generate extrapolations of bio-climatic conditions of semi-open spaces.
Environmental design and social behaviours of semi-open space

High-rise semi-open spaces

High-rise flats are erected and occupied the largest percentage of residential area in Singapore. More than 90 percent of the population in Singapore live in high-rise apartment, about 86 percent of which is staying in densely built up HDB (Housing Development Board) housing estate. This kind of public housing is designed in the form of skyscraper and passive cooling system, such as natural ventilation. As far as sustainable design in tropical areas is concerned, one of the key points is how to cool the buildings naturally. Researchers in the field are trying to find more efficient ways to improve the thermal comfort in high-rise residential buildings, utilizing shading, natural ventilation and vegetation etc. And architects are trying to create more green space in the sky.

Semi-open space, as a filter between inside and outside, plays an important role in environmental control, especially in the tropical regions. Yeang (1996) and Hyde (2000) have well discussed the advantages of the tropical semi-open space for providing shade and ventilation for thermal and reducing heat load on the main building.
Veranda is located in front of the entrance of each unit. It is private court yard.
(Photo is taken at Bedok Court Condominium)

Public corridor is located at each floor for public circulation.
(Photo is taken at Jurong West Public Housing Block 510)

Balcony is an extension of indoor space for private use.
(Photo is taken at Bedok Court Condominium)

Void deck is located at the ground floor of public housing for social activities.
(Photo is taken at Bukit Panjang Public Housing)
High-rise semi-open space provides an open-air space for activities and put off the extreme hot or rainy weather. In addition, it makes the nature and greenery more accessible for people living in the man-made urban environment. Chermayeff (1963, 61) argues that, “The little tree growing outside one’s own room is a more real tree than the largest Sequoia in the national park”. He also said that, “All this demands dwellings close to ground with easy access to outdoors, an organic whole in which indoors and outdoors are integrated in a single comprehensive shelter” (Chermayeff 1963, 62).

In the metropolis like Singapore, it is impossible to construct all dwellings close to the ground because of the big population and limited land resources. High-rise dwellings are popular and the situation will stay for a long period. In this case, semi-open space helps to relieve the discomfort of living far away from the ground and make the living environment more humane. In Singapore, there are four kinds of semi-open space in the high-rise dwellings: veranda, balcony, public corridor and void deck, which involve people’s daily life (Figure 3-1). To some extent, the semi-open spaces of the high rise are as important to the life of urban man as the building themselves.

**More choices for social activities**

High-rise semi-open space not only provides urban man an opportunity access to nature, but also more choices of various activities. These choices result from the diversity of environmental conditions. Chermayeff (1963, 110) argues that, “Designed environment will be successful only if they respond to the most crucial pressures of
our time”. The pressure of living in high-rise apartments may be caused by noise, lack of fresh air and day lighting, alienation of neighbours, or the far distance from the ground. Most of the factors are ‘invisible’, but they have the most serious implication for physical form. Semi-open space relieves the pressure by providing more choices of environmental conditions for various activities. For example, a person wants to read a book for recreation and he feels uncomfortable staying in the flats. There are several possible reasons: the day lighting in the room is too dim, it is too quiet in the room, there is no natural ventilation or fresh air, or it is too hot in the room. Whatever the reason is, the person has the pressure and needs to find a new place. Semi-open space is a good choice because it can fulfil the requirements and it is close to home.

High-rise semi-open space makes the diversity of environment possible. But whether it can really relieve the pressure depends on the form of semi-open space design. Chermayeff (1963, 108) argues that, “Form is the ordered expression of a need; the end product of a process of response to pressure. Sometimes the interaction between need, or pressures, and the end product, or form, is direct, immediately clear, and involves relatively simple technology. Under such conditions, every form reflects the pressures that are responsible for its existence, and the appropriateness of the form, in terms of its structure and function, may be apprehended accordingly.” The direct relationship between the need/pressure and the end product/form can be found from observation and survey of activities of people’s daily life in the sky, as well as their feelings and requirements for the environment. Take the example in the last paragraph, the semi-open space attached to the person’s room should be designed suitable for
reading: it needs enough daylight, it is naturally ventilated, it prevents solar radiation and it is big enough for a chair and even a table.

Guidelines help architect to create order, to organize conflicting material and to make a form. In order to bring the semi-open space into play, the socio-climatic design guidelines need to involve an explicit statement of the pressure pattern that the form is to reflect. The pressure pattern explains to designers why the form is in this way. It enables architects to do their own revision on the basic forms from the guidelines.

Pre-parametric design thinking and parametric design tool

Pre-parametric design thinking

Pre-parametric design thinking is a common heuristic used by designers in practice. Bay (2001, 53) explains that heuristics are in the sense referred to by Tversky and Kahneman (1982) and Schon (1983) as “thinking relying on the use of intuition, human feeling, experience, rules-of-thumb, examples by analogy for judgement and decision making in real life conditions, without normative analysis based on mathematical representations.” Schon (1983) argues that architects often employ

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3 This section was published at the 21th Conference on Passive and Low Energy (Eindhoven, the Netherlands. 2004). Paper title: Parametric simulation and pre-parametric design thinking: Guidelines for socio-climatic design of high-rise semi-open space.
heuristics as shortcuts without quantititative calculation when facing with complicated design problems, which are ‘uncertainty, instability, uniqueness and value conflict’ (Shone 1983, 49-50). In this paradigm, the basic elements of design activities are actions, and the kernel of design ability is to make intelligent decisions about those actions (Valkenburg 1998, 251). We can see that most of the guidelines criticized in Chapter 2 are developed based on the parametric design thinking. It is analogical means. Architects turn to precedents, no matter from his experience or from guidelines, when making movement towards solutions.

The design of Bedok Court Condominium (Bedok), a modern milti-storey condominium in Singapore, is an example of the parametric design thinking. Bay (Bay and Lam 2004) studied the building and interviewed the architect, Cheng Jian Fenn of Design Link Architects, Singapore. He found that the architecture of Bedok made references to the traditional Maylay Kampong (village) verandah and community, as well as the front entrance garden of the typical low-rise dwellings. Kampong is tropical vernacular village (Figure 3-2). It has evolved as Equilibrium systems between social-cultural and climatic-ecological needs. The architect got the idea of large open entrance terraced courtyard from Kampong. He successfully re-adapted and re-invented the salient characteristics of the traditional village to high-rise context (Figure 3-3).
3. Semi-open Space Design and Research Methodology

Figure 3-2
Traditional Malay Kampong
Source: Bay 2004

Figure 3-3
High-rise veranda of Bedok Court Condominium
Source: Bay 2004
Gathering of social and environmental data from specific cases

As discussed in last section, architects think in a pre-parametric manner. Design guidelines should restructure precedent knowledge. The precedent knowledge can be obtained from case study\(^4\), where both qualitative and parametric data are collected and organized.

In this study, selected data and information are from Bay’s research project (Bay 2004) on semi-open spaces in high-rise residential development. In his project, two cases are selected so that they produce contrasting results but predictable reasons (a theoretical replication). Through multiple source data collection, such as field measurement, observation and direct interview, specific morphologies and performance are found out. The validity and accuracy of the performance associated with the design morphologies of the two cases are discussed and proved in Bay’s study. So the two cases are used directly as precedent knowledge without further validation.

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\(^4\) Case study is one of several ways of doing social research. (Other ways include experiments, surveys, histories, and the analysis of archival information.) Generalizing results from case are different from statistical generalization because cases are not ‘sampling units’ and should not be chosen for this reason. Yin (1994, 28) argues that “individual case studies are to be selected as a laboratory investigator selects the topics of a new experiment. Multiple cases, in this sense, should be considered like multiple experiments. Under these circumstances, the method of generalization is analytic generalization, in which previously developed theory is used as a template with which to compare the empirical results of the case study”. He emphasises that we should avoid thinking in such confusing terms as ‘the sample of cases’ or the ‘small sample size of cases’, as if a single case study were like a single respondent in a survey or a single subject in an experiment. So the case study in this study can represent certain pattern of physical performance and social activities of semi-open spaces in the high-rise tropical dwellings.
Further survey and measurement, which are done by the author, supplement the data and information from Bay’s project. It is specific to this methodology to produce the guidelines.

**Parametric simulation tools**

The parametric tool based on building simulation can assist pre-parametric design thinking depending on its quantitative property. Simulation techniques are crucial for environmental design decision-making process because they represent environmental reality and predict real-life situation. Hong (2000) pointed out that “the demand for green buildings has made the application of building simulation a must, rather than a nee.” Simulation foretells the performance and ensures the accuracy of design morphology. According to McKechnie (1978, 169), environmental simulations refers to the family of techniques utilized for replicating—or, more precisely, previewing or otherwise anticipating—in the laboratory everyday environments that have not yet been built, modified, or otherwise actualized. Simulations tools are categorized by *concrete perceptual* and *abstract conceptual*, according to the degree of which they emphasize on information. They can also be classified in terms of the extent to which the information they provide is *static* and *unchanging* versus *dynamic* and *variable*\(^5\).

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\(^5\) Conceptual simulation represents the processes underlying man-environment interactions and transformations through formal, abstract analysis. Perceptual emulation attempts to provide tangible, concrete replicas or isomorphs of environments—often future environments—that can be displayed to observers for their evaluation or other response, dynamic simulations provide a recursive or interactive capability, such that often unanticipated new information is generated from the multiple, complex parts of the system. Static simulations lack this interactive capability and instead merely extract known aspects of the environment. (McKechnie 1978, 174)
In this study, the simulations will be discussed at two aspects: one is simulation of thermal comfort; the other is simulation of ergonomics. The former simulation depends on computer-aided system, which uses the computer program to create representation or to predict the performance of buildings. While the later one needs manual calculation or design. Both of them are necessary for developing passive-mode building design guidelines.

**Computer-aided simulation for design guideline**

Computer-aided simulation has become an important tool in environmental design. It is widely used to evaluate the existing building or to predict the performance of design proposals. Hyde (2000, 59-61) argues that “simulation is suitable for diagnosis of design effectiveness after the architect’s initial design stage, so as to demonstrate to the client the effectiveness of environmental design and to make minor detailed adjustments.”

However, the potential of computer-aided simulation in generating design guidelines has not been fully brought into play. Simulation can help to ensure the accuracy of the guidelines. It can effectively help designers modify the climate by proper selection and integration of the building’s physical components. The impact of decisions on the thermal performance of a building diminishes along different stages of its life as illustrated in the generic curves of Figure 3-4. Design decisions made during earlier phases of the design process cost less and have a more significant impact on the performance of the building (Al-Homoud 2001).
Figure 3-4
Decision costs and their impact on the performance of a building through the various stages of its life
Source: Al-Homoud 2001

Donn (2001) did a study on the quality control of simulation. It shows problems that reduce the clarity of the relationship between prediction and reality. Those problems fall into the following classes:

i. model preparation time limits;

ii. no clear guidance as to the important features of a building that should be modelled well, and the features whose effect on predicted performance is insignificant,

iii. minimal quality assurance systems that allow the simulation user to ensure the relevance and accuracy of their recommendations,
iv. lack of performance guidelines for buildings that provide a basis for understanding the recommendations from the simulation.

v. lack of tools for summarising and detecting patterns within the information overload that well-applied simulation can produce when exploring design scenarios.

Involving building simulation in social-climatic design guidelines can solve most of the above problems. First of all, it saves the time of doing extra simulation during the design process. Time is the most significant aspect because no client would apparently pay for extra analysis time. Furthermore, different from simulating the existing building or detailed design proposal, developing guidelines does not need to set up complicated model in the program. Computer-aided simulation is mainly used to find out the threshold of a good performance by varying different parameters. Decisions made at the early stages of the design process are of paramount importance and can strongly affect later stages. A clear threshold in the guidelines can help architect start from a right point. At the same time, simulation included in guidelines tells the connection between ‘Rules of thumb’ and calculations. ‘Rules of thumb’ typically specify what size a building feature should be but they usually do not specify why. Guidelines can explain the theory behind through comparison of a series of models.

Computer-aided simulation generates various visual representations of the reality under different circumstances. At the early stage of design process, flexibility and adaptability is more important. Mahdjoubi (2001) cites from Kaplan and Kaplan (1983, 202) that “A simplified model of the environment is more likely to parallel
people’s cognitive structure. Hence the very simplicity of the model may encourage its use. A simplified model also encourages generality; details make things particular, thus narrowing their range of appropriateness. Finally, simplification reduces the total load to one’s processing.” Using simplified models with predicted performance in the guidelines allows fast processing of data and decision making. Moreover, low level of detail simulations makes the simulation work easy to grasp and follow.

In the study, building simulation is used to find out the operations, such as the shading effect of semi-open space. It can help to explain why certain morphology leads to certain environmental or social performance.

SOLARIS are chosen in this case to simulate the physical environment. The climate data of 2:00 pm on June 21st is chosen because it has the worst climatic conditions. Series of simple models of semi-open space are set up by changing the depth of semi-open space from 0 to 7 meters (Fig. 3-5). The depth of around 7 meters is as large as the case of Bedok Court Condominium (case B in Figure 3-5), while around 1 meter is as small as the case of Jurong West Public Housing 510 (case S in Figure 3-5). Both of the cases are from Bay (2004). The two presidential cases are used to set up standard models and validate the simulation results of other depths in-between.

Besides simulating the two extreme cases, further simulation will be done by varying the depth of semi-open space in between case B and case S. Series of performance and operation can be gotten from further simulation. They will be used as design approaches of semi-open space in the guidelines. Keeping the same
boundary conditions, it is proposed to find a threshold of good performance when the depth reaches a certain value, which is case T in Figure 3-5.

**Figure 3-5**
**Computer-aided simulation from large size to small size**
*Source: Author*

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**Simulation of ergonomics**

Sometimes software fails to improve architecture design, mainly because of its neglect on social and professional characteristic of the decision-makers. Manual simulation can make up the deficiency by taking social factors into account. The concept of manual simulation here is different from the conventional manual calculation which uses pre-selected design conditions and often resorts to the ‘rule-of-thumb’ method. It is concerned with the problem of anticipating human response to future environments, which are being planned now but not a reality yet. It selects parameters, which affects human behaviour, and satisfies multiple criteria through calculation.
Donn’s research interviews of architects (Donn 2001) showed that in most situations architects do not use environmental design tools (Computer-aided simulation).

“Even when architects seek the predictions of those tools, they apply them at a stage in design when practical improvement in building performance is nearly impossible. There is a mismatch between building performance design tool input/output (i/o) and architects’ expectations of their role in that i/o. An associated problem is that the current generation of environmental design tools cannot provide design information in the form that architects would like at these early stages of design. ......However, it still seems questionable whether these programs will ever produce the answers to questions that architects want answered at the earliest phases of the design process.” (Donn 2001, 677)

At the earliest phases, the building description is vague. Manual simulation can describe the building in everyday language. For example, the language of comparison can use real concepts like ‘warm’ or ‘cold’, instead of 32° C or 25° C; or ‘good for reading’, instead of ‘400 lux’.

In this study, manual simulation will focus on the simulation of ergonomics. It further develops the social-climatic design guidelines into comprehensive ones full of details of social activities. Limited spaces for different activities will be calculated. Ergonomics and human psychology will be taken into consideration.

Simulation of ergonomics calculates the minimum area required for social activities at the semi-open space. Time-saver standards (Chiara et al. 1995) and Neufert Architects’ data (Baiche 2000) are used as references to the elemental activities and furniture sizes. For example, Figure 3-6 shows that the suitable width for the traffic at the corridor is from 1.3 to 1.4 m.
3. Semi-open Space Design and Research Methodology

The users’ behavioural patterns are based on the way how Singaporeans normally use their semi-open space during the whole year. The main objects of simulation of ergonomics are the popular social activities obtained from the questionnaire in the case study. Examples are gardening, receiving guests and sitting/watching. Figure 3-7 shows that the minimum width for gardening is 1.65 m. If traffic is taken into consideration, the depth of semi-open space should be at least be 2.95 m.

Figure 3-6
Doors on one side and wide enough for two people to pass one another unhindered. Width 1.30 to 1.40 m
Source: Sketch by author, after Neufer Architects’ data (Baiche 2000)

Figure 3-7
Minimum space for gardening
Source: Sketch by author, after Neufer Architects’ data (Baiche 2000)
Combination of pre-parametric design thinking and parametric design tool

The Context-Morphology-Operation-Performance framework can employ both pre-parametric design thinking and parametric tools to make the guidelines not only compatible with architects’ design thinking process, but also accurate and reliable enough for sustainable design. It reflects architects’ need for precedent knowledge through the element of morphology. At the same time, parametric tools are used to satisfy the requirement of accuracy. The precedent knowledge is re-generated through simulation, calculation and scientific analysis. The results will be shown through the elements of operation and performance. In this way, the guidelines will not only help architects make movement, but also ensure the effectiveness of design.

Guideline design in this study will comprehend the results of both simulation of thermal comfort and simulation of ergonomics. Patterns of social activities will be given for each semi-open space’s size. The meaning of pattern here is different from Christopher Alexander’s pattern (Christopher 1973), who thinks that certain activity will happen when proper space is provided. This study thinks that social activity might happen, but not a certainty. Based on the existing pattern of social activity of the two cases, designed plans are given as a recommendation. The recommended pattern of social activities will help architects design such a semi-open space which can improve the sustainable community.

It is found in this study that one of the links that bind the problem of socio-climatic design of semi-open space is its size, which has implications for plan. In the
third step of this study, guideline design, design recommendations attempt to reveal the full implications of the size for the plan of the semi-open space.

The guidelines are organized as visual charts, which show correlations of expected social patterns, predicted bio-climatic behaviours, and sizes. According to Tzonis’s framework (Tzonis 1992), all information is classified into four groups: morphology, operation, environmental performance and social performance. Analysis and comparison of the cases will show the key points of socio-climatic design. Each element of interdisciplinary knowledge, their relationship and structure are explicitly mapped out in these charts for clear communication. Users can go through and use the guidelines more quickly and flexibly according to their design needs. Also, architecture language, such as plan/sectional sketch, is used to present the guideline for easier understanding and to judge and decide graphically.

Methodology of developing the socio-climatic design guidelines

The guidelines in this paper are created to guide socio-climatic design of high-rise semi-open entrance space. Thermal comfort condition, space design and social activities are three factors affecting the living condition of high-rise dwellings. The assumptions invoked in studying these three interacting parameters in the case of the Singapore climate, dwellings and people will be discussed in Chapter 4.
In a summary, the method of developing socio-climatic design guidelines includes three steps: case study, building simulation and guideline design. This methodology evolves two aspects of building design: one is user, the other is architect. Case study, which deals with the aspect of user, collects information from the precedents. Guideline design, which deals with the aspect of architect, is focused on design recommendation in the framework of context-morphology-operation-performance. Building simulation, which employs parametric tools, connects the two aspects by analyzing and simulating the data from case study.

The technique used for investigation is to establish thermal comfort zone and the pattern of social activities based on the case study first. After this, the effects of various design options (such as shape, orientation and size of openings) will be tested. They are established by computer simulation technique which will predict the thermal conditions. The simulation of thermal comfort will take broad look at the most important variables to establish the basic parameters of thermally efficient design, while simulation of ergonomics rigorously will investigate the detailed design features. The criterion of selecting the effective design feature is surveying real cases. Finally, the results of both simulations are organized in charts and developed into guidelines. Figure 3-5 illustrates the research methodology.
3. Semi-open Space Design and Research Methodology

Figure 3-8
Research Methodology
Source: Author

<table>
<thead>
<tr>
<th>User/Precedent</th>
<th>Case Study (Multiple sources of data collection)</th>
<th>Parametric Tools</th>
<th>Architect/Guideline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Survey: Social activities</td>
<td>Predicated solar radiation</td>
<td>Performance (Environmental and Social)</td>
</tr>
<tr>
<td></td>
<td>Observation: Arrangement of furniture</td>
<td>Possible social activities</td>
<td>Operation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recommendation of arrangement</td>
<td>Morphology</td>
</tr>
</tbody>
</table>
CHAPTER 4

CASE STUDY OF SPECIFIC BUILDING PROJECTS

*Method to obtain and deal with the information and knowledge from two dwellings in Singapore and preparation of data for simulation*

In this chapter we will apply the method of developing socio-climatic design guidelines to the case of the semi-open entrance space of high-rise apartment in Singapore. The two building projects are chosen from the Bay’s socio-climate studies of high-rise high-density buildings (Bay 2004). An understanding of the design thinking and the method in this urban context and climatic environment is relevant to understanding similar design problem.
Bay’s precedent study on high-rise semi-open space

In this section, we will introduce Bay’s precedent study on high-rise semi-open space. We will describe the two case buildings, his method of data collection and some of his analysis and conclusions. It will give a clue to the way to collect information and precedent knowledge from case buildings. An understanding of Bay’s method of case study is relevant to understanding the method of preparing for design guidelines based on pre-parametric design thinking. Moreover, some of the data from Bay’s study will be used as database for the building simulation. For example, the measured temperature (air temperature and global temperature), relative humidity, and wind speed, help set boundary conditions in the simulation program, and validate the simulation results.

Descriptions of the building projects

Two tropical high-rise dwellings in Singapore are selected by Bay (2004). One is Jurong West Public Housing Block 510 (Jurong), located at the west part of Singapore. The other is Bedok Court Condominium (Bedok) at east (Please refer to Appendix B for the pictures and drawings of both buildings). Both cases were built in 1980s within the same social context. They are both high-rise residential buildings: Bedok is 17 to 20 floors high with 134 units and Jurong is 14 to 16 floors high with 162 units. Both buildings are facing north. Both have car parks, central playground,
community centre, lift lobbies, corridors and balcony. Typical morphologies for tropical environmental design, such as shading device and opening for cross ventilation, are used for both of the cases.

**Figure 4-1**  
Semi-open space of Bedok Court Condominium (Left: from veranda; Right: from walkway)  
Source: Bay 2004

**Figure 4-2**  
Semi-open space of Jurong West Public Housing Block 510  
Source: Author
Bedok has a semi-open forecourt of around 30 square meters in front of each apartment, which serves as a transiting space from public to private space (Figure 4-1). The forecourts are called verandas in Bay’s study. They are connected by a walkway. While in Jurong, the semi-open space is public corridor, 1.5 meter width, in front of each unit (Figure 4-2).

The two cases are comparable because Bay’s study shows that the residents of both cases have similar social activities, such as gardening, chatting, children playing or doing household work. It also shows that there are correlations between human activities and thermal comfort condition. Survey in the both buildings also shows that the backgrounds of the residents are similar. The ratio of the genders, age distribution, race comparison and ownerships of habitants in Bedok and Jurong are similar to each other. Hence it can be assumed that the objects of the case study are the same, and comparison can be done between both cases.

**Multiple sources of data collection**

*Field Measure*

High-rise dwellings in both locations were monitored for a week in hot-dry season and another week in cool-wet season. Equipments were positioned at the low, medium and high level of the both buildings to measure the temperature, wind and relative humidity of the semi-open spaces to investigate different climatic conditions. Measurement on both cases investigated on the typical design methods of tropical
building, such as dimension of semi-open spaces, design of shading devices and natural ventilation.

Interview

120 interviews were conducted with the residents of each building for two Singapore high-rise buildings. Interviews were done during the same time of field measurement. Forty questions were asked covering different areas such as their feeling of thermal comfort of the semi-open space, their social activities in the semi-open space, and their preference of the design of high-rise semi-open space.

Observation

The numbers and arrangement of furniture in front of each unit are recorded. They are used to detect the residents’ utilization of the space in front of their home. By comparing the available arrangement, possibility of people’s preference to certain activities can be found.

Correlations between size of space, intensity of activities and thermal comfort

Bay’s study shows that different design of semi-open spaces of Bedok and Jurong leads to different socio-climatic performances. The residents in Bedok have a stronger feeling of belongings and can get to know each other in a shorter time, than those in
Jurong. Also, more social activities take place at the semi-open space of Bedok than Jurong. The correlations of space, social activity and thermal comfort are as follows.

\textit{Correlation of size of space and intensity of activities}

The size of semi-open space had direct impact on the social activities because by sheer ergonomics it constrained the possibility of various activities. The corridor spaces of the Jurong case were very narrow (7m length x 1.5m width). After allowing for the passageway, only a narrow strip of spaces is left for potted plants, small tables and chairs, etc. Whereas in the forecourt of the Bedok case were large (typical size of 5m x 7m) spaces adjacent to unobstructed corridors. Ergonomically, this allows for a lot more permutations of activities and layout of furniture, plants, etc.

Seventeen typical daily activities were observed from the Bedok forecourts. This list was used in the survey as a checklist for both cases to compare the relative intensity of each activity. Figure 4-3 shows the percentage of respondents having daily activities in the semi-open spaces studied. It is obvious that much of the interesting activities that were happening at the Bedok forecourts were not happening in the Jurong corridor spaces, because of the lack of space.
Correlation of space and thermal comfort

It is a common argument that the design of spaces with proper dimension and shading affects the thermal comfort conditions. In the case of Jurong corridor spaces, the
amount of shade was very small compared to that of the case of Bedok forecourts. The measurements showed that the average temperature (DBT) of the Jurong case was around 2°C higher than that of the Bedok case. Also, the air velocity at the veranda of Bedok was generally higher than that at the corridor of Jurong. The survey recorded human votes for thermal comfort levels also correspond to the differences of the spaces of the two cases that allow different shading and ventilation.

**Correlation of thermal comfort and intensity of activities**

In the analyses and summary above, it was noted that respondents used the Bedok forecourt/courtyard more often in December (90%) than in June (76%). This correspond with the fact that the thermal comfort condition in December is better than in June for the same configuration and size of architectural spaces.

This correlates the changes of thermal comfort and intensity of activities without the factor of size. This also applies to the case of Jurong with the use of the corridor spaces in front of the apartments, where with the same space, there were noticeable changes in intensity of activities corresponding to changes in thermal comfort conditions.
Further investigation on design of semi-open space

Bay’s precedent study on semi-open space set up a foundation for the socio-climatic design guideline. It proves that well designed semi-open space provides a thermal environment, and good thermal comfort condition improves social activity. Also, good design provides enough space for social behaviors, which encourages people’s communication. To develop a design guideline based on Bedok, which is a precedent case, further investigation was done focus on the design of the semi-open space, such as its location and dimension.

Location of high-rise semi-open space

Besides area and thermal comfort condition of high-rise semi-open space, its location also affects people’s social activity. At Jurong, six three-volume high semi-open spaces are designed at different levels for public using. The area is spacious enough for most activities. However, observation shows that those semi-open spaces are not utilized. Some of them are totally empty, while others are used by some residents for storage (Figure 4-4). They do not improve interaction among residents.

On the contrary, people in Jurong like to have activities in front of their homes although the spaces are quite small. One reason is that the space by the door is very convenient for activities. People can go in and out freely. The other reason is that
people have feeling of ownership of the space in front of their home. The space is familiar and safe to them.

The semi-open space in front of each door improves the interaction among residents since people like to have activities there. When the residents were asked about the preferred place to see neighbours often, more than half of them vote for corridor of Jurong and veranda of Bedok. (Table 4-1)

**Figure 4-4**
Public semi-open spaces are empty or used by someone for storage at Jurong
Source: Author

<table>
<thead>
<tr>
<th></th>
<th>Interior</th>
<th>Balcony</th>
<th>Courtyard</th>
<th>Corridor</th>
<th>Lift lobby</th>
<th>Car Park</th>
<th>Park</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bedok</strong></td>
<td>1.7%</td>
<td>14.7%</td>
<td>62.1%</td>
<td>27.6%</td>
<td>31.0%</td>
<td>19.8%</td>
<td>15.5%</td>
</tr>
<tr>
<td><strong>Jurong</strong></td>
<td>0.0%</td>
<td>0.0%</td>
<td>2.0%</td>
<td>67.6%</td>
<td>39.2%</td>
<td>5.9%</td>
<td>7.8%</td>
</tr>
</tbody>
</table>
Depth of semi-open space and solar radiation

Further investigation on Bedok and Jurong shows that solar radiation has a great impact on thermal comfort. In June, during the hot and dry season, direct solar radiation can reach the floor of semi-open space through the openings, which increases the mean radiant temperature and makes people feel hot.

Figure 4-5 shows the condition of Bedok and Jurong under direct solar radiation at around 10 o’clock in the morning. It happens again at 3 o’clock in the afternoon. At Jurong, although shading devices and some plants help to protect the corridor from the solar radiation, the sun shines on the floor and the wall during some part of a day. The concrete material absorbs the heat and increase the temperature greatly. People feel hot and uncomfortable in this environment. While at Bedok, the similar incoming direct solar radiation does not affect the veranda much, as the depth of veranda is big enough. The walkway on the outer side of the veranda works as a buffer against heat. Acting is still possible in a relative cool environment during a sunny and hot time.

Measurement of solar radiation was done at two typical verandas of Bedok to show their shading effect. With the building simulation in the next step, it examines the variation of solar radiation with the difference in depth of verandas. The relationship of solar radiation and depth of semi-open space is the focus of this study. It will be discussed in detail in the next chapter.
Figure 4-5
Direct solar radiation on the semi-open space of Bedok and Jurong
Source: Author

Bedok: Direct solar radiation on walkway
Bedok: Varand is totally shaded.

Jurong: Direct solar radiation on corridor.
Arrangement of semi-open space

The stuff which is placed and used at the semi-open spaces is listed below (Table 4-2). And the numbers are counted. Table 4-2 shows the percentage of each item occupied by the residents. It is obvious that the residents at Bedok place and more furniture and plants at the semi-open space than those at Jurong do. On the average, the numbers of units in Bedok which have furniture is around 4 times more than Jurong. For some items like chairs and tables, Bedok exceeds 10 times more than Jurong. The reason lies in the area of semi-open space of Bedok which can hold more furniture. The possibility of arranging more furniture at the semi-open space provides more opportunities for various activities.

Table 4-2
Percentage of furniture at semi-open space
Source: Author

<table>
<thead>
<tr>
<th>Item</th>
<th>Jurong (162 units)</th>
<th>Bedok (139 units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant</td>
<td>35.80%</td>
<td>79.86%</td>
</tr>
<tr>
<td>Chair</td>
<td>6.79%</td>
<td>76.98%</td>
</tr>
<tr>
<td>Table</td>
<td>2.47%</td>
<td>74.82%</td>
</tr>
<tr>
<td>Cabinet</td>
<td>14.81%</td>
<td>65.47%</td>
</tr>
<tr>
<td>Shoe Rack</td>
<td>14.81%</td>
<td>38.13%</td>
</tr>
<tr>
<td>Exercise Equipment</td>
<td>4.32%</td>
<td>23.02%</td>
</tr>
<tr>
<td>Recreational Equipments (like Children’s playing facilities, TV, etc)</td>
<td>1.23%</td>
<td>16.55%</td>
</tr>
<tr>
<td>Additional Construction</td>
<td>3.09%</td>
<td>7.19%</td>
</tr>
<tr>
<td>Others (Grass patch, clothe lines, fridges, swing, laundry rack, storage shelf, adder, pail, box, baby trolley etc.)</td>
<td>20.37%</td>
<td>55.40%</td>
</tr>
</tbody>
</table>
4. Case Study of Specific Building Projects

Figure 4-6 is a graphical section of the two buildings with the layout of the units. A grey colour of 10 percent transparency is given to each unit if it has one kind of furniture stated in Table 4-2 (Please refer to Appendix C for the details of each unit corresponding to each item). Each unit shows different brightness as the overlap of grey colours. Through this way, the conditions of arrangement of each unit can be illustrated directly. As discussed, suppose the amount of furniture can represent the frequency of social activities there, the activity condition can also be judged according to the color of each unit. From the graphic section, we can see that there is much more activities being carried out at the semi-open spaces.

Further analysis is done about the percentage of different kind of furniture in Bedok. Figure 4-7 shows the comparison of each item. First of all, it shows that almost 80% of the residents have plants in their verandas. Compared with the 35% occupation of plants at Jurong, it shows that more people would like to have access to natural environment if there is enough space for plants. So, space for plants should be included in design and the activity of gardening should also be considered by architect in order to set up a good circle around human being and natural environment.

The items placed at the verandas are mostly chairs, tables and shoe rack. Shoe rack is due to the habits of people living in the tropical regions where they are accustomed to leaving their shoes outside their residence. Tables and chairs are fundamental furniture for most activities, such as sitting, watching, reading, or chatting etc. The spaces designed for different sizes of tables also decide the possibility of different activities.
4. Case Study of Specific Building Projects

Figure 4-6
Graphic section showing arrangement conditions
Source: Author

Bedok Court Condominium
The distribution of grey colors shows that almost all of the residents have facilities or furniture at the semi-open space. The dark grey colors show that most of the residents have more than one kind of facility or furniture. That means colorful social activities happen at Bedok.

Jurong West Public Housing Block 510
White colors show that many of the residents have no facility or furniture at the semi-open space. The light grey colors show that the kinds of facilities or furniture are limited. That means the semi-open space is seldom used for social activities at Jurong.
Some people place cabinet, exercise equipments and recreation equipments at the semi-open space. So, some simple exercises like those that take place in small gymnasium and Children’s playing activities should be a part of designers’ consideration.

There are some other furniture or equipments at the semi-open space of Bedok. The stuffs with occupational rate of less than 5% are classed under the item of Others. They include grass patch, clothes lines, fridges, swing, laundry rack, storage shelf, adder, pail, box, baby trolley etc. In the process of designing, they can be looked as auxiliary factors which are not necessary and can be designed together with the main factors.

Summarized from the above discussion, four principles will guide the semi-open space design as follows,
i). *Space for plants and gardening*;

ii). *Space for different sizes of tables and chairs*;

iii). *Space for adult exercise and children’s playing*;

iv). *And space for auxiliary furniture*.

**Figure 4-8**  
**Typical arrangements of semi-open space for activities**  
*Source: bay 2004 and Author*

Figure 4-8 shows typical arrangements of semi-open space for activities. Most people like to put the table in the centre and arrange the plants and cabinets around.
Other people prefer to leave the center empty for drying clothes or children’s playing. It reflects the habits of the residents and can also guide the design in the later steps of the study.
CHAPTER 5

FINDING THE OPTIMAL THERMAL COMFORT RANGE

Investigation of the relationship of depth of semi-open space and its shading effect against solar radiation through building simulation

In this chapter, we will discuss the thermal impact of solar radiation on tropical semi-open space. Computer-aided building simulation will be used to investigate the relationship of depth of semi-open space and its shading effect against solar radiation. We are trying to find the optimal thermal comfort range and a threshold which leads to good performance. Computer-aided simulation tools will also be used to visualized the research results for the design guideline.
Solar radiation

Control of humidity and wind speed

There are three factors which have impact on thermal comfort condition of semi-open space. They are humidity, wind speed and solar radiation. In this study, humidity and wind speed are not taken into consideration as they do not have direct relationship with depth of semi-open space. Bay’s study (Bay 2004) shows that the humidity in Bedok and Jurong are in the same range and design will not change the value of humidity.

Measurement in semi-open space of Bedok shows that wind does not change much with the change of the distance from outside. More wind in Bedok is due to the building being designed like strips. Wind can go through the semi-open space of Bedok, while it is blocked by the continuous facade of Jurong. Moreover, the wind is not constant in both buildings. Although the wind speed is higher in Bedok, it does not have strong wind all the time.

In this study, simulation will focus on solar radiation, which has direct relationship with thermal comfort condition and design of semi-open space. Survey shows that people feel uncomfortable when solar radiation is high, even if there is strong wind. So, we can say that solar radiation decides the thermal comfort by affecting the thermal load. The study based on Bedok and Jurong is applicable to other buildings.
Solar radiation in Singapore

The global solar radiation on a surface contains direct solar radiation and diffuse solar radiation. Direct solar radiation refers to incident sun beam that falls on the surface directly. As incident solar radiations passes through the atmosphere, a fraction of the direct radiation that is initially lost through scattering eventually reaches the earth. This is diffuse sky radiation. The intensity of the diffuse component of the solar radiation is the sum of sky radiation component and the terrestrial reflection component. So, in calculation, the global solar radiation on the surface can be obtained by adding the value of the direct solar radiation and that of the diffuse one.

An important clue in designing efficient shading devices is the knowledge about the distribution of solar radiation due to orientation. Figure 5-1 shows monthly direct and diffuse solar radiation in Singapore. It is obvious that the distribution of the diffuse radiation is almost identical at all orientations. So the direct radiation makes the difference. Due to the proximity to the equator, a slightly stronger radiation (around 10% more on east/west, compared with south) can be observed on east and west facades. The reason for this phenomenon lies in the low altitude of the sun on east and west, and therefore stronger impact and duration of the solar radiation. So in Singapore, most residential buildings face south and north in orientation.

In this study, we will focus on the north orientated semi-open space in June, which is the worst case of the whole year and all orientation. In Singapore, June is hot and dry season. The temperature in June is higher comparing to those in other months. It is obvious from Figure 5-1 that the north orientation has the strongest direct solar
radiation. Therefore, study on north orientation will show the performance of the semi-open space under worst thermal comfort condition.

Figure 5-1
Monthly direct and diffuse solar radiation in Singapore
Source: Grimme 2003

Singapore is so close to the equator, so the variation of solar radiation of the south orientation is probably similar to the north. The direct solar radiation of south orientation reaches peak during December and January, which is the cool and wet season. Bay’s study of semi-open space in June and December shows that the thermal environment is more favourable most of the time of the day for the cooler season compared to the hot season (Bay 2004, 3-24). Therefore, the performance of the south orientated semi-open space can be generally deduced from the study on north orientation: similar trend and slight improvement.

In this case study, there is no semi-open space facing east/west orientation. As the distribution of solar radiation of east/west orientation is different from that of
north/south, the social behaviors may be different. Moreover, most of the buildings in Singapore face north/south. So, east/west orientated semi-open space is not in this study.

Simulation on solar radiation using SOL-ARIS

Introduction

SOL-ARIS is a computational tool for the prediction of irradiance developed by Lam and Mahdavi (2000). It is an Excel-based software that can calculate the percentage of shading effect by inputting the angle and dimension of the shading. In this study, SOL-ARIS is used to predict the variations in shading effect with the increase of depth of semi-open space.

Assumptions

It is decided to carry out the investigation on the depth of semi-open space because of the large number of variables affecting thermal conditions, and the impracticality of testing separately a range of options for each variable in combination with options of all the other variables. It is assumed that the width of each semi-open space is fixed because the spatial layout of the unit will not have much change. Computer-aided simulation is used to predict bio-climatic conditions of the semi-open spaces of varying sizes between the large and small sizes of Bay (2004). This will be matched
with the social activities possible in varying sizes of semi-open spaces in front of the apartments, so as to find various thresholds of desirable correlations between social patterns and thermal comfort levels.

It is assumed that the wind speed at the both locations are similar. Comparison is done with a limitation of wind speed, which is within the comfortable range of semi-open space.

# SOL-ARIS simulation and validation

## Findings and analysis of SOL-ARIS simulation

In the SOL-ARIS simulation, the orientation of the building is set north, keeping in accordance with the case project. The depth of semi-open space increases from 0 to 7 meters with the pace of 0.1 meter. Figure 5-2 shows reduction of solar radiation with the increase of the depth of semi-open space. It is obvious that the direct solar radiation diminish with the increase in depth of space. The variation of the curve can be divided into three phases. Firstly, the percentage of non-shaded area drops sharply from 100 to around 45% when the depth of semi-open space increases only 0.1 meter and followed by another 35% drops when the depth extends to 1.2 meters. (Zone 1 in Figure 5-2). Secondly, the percentage gradually reduces from 12 to 0% with the depth changes from 1.2 to 4.5 meters. (Zone 2 in Figure 5-2). Finally, the line becomes

---

6 Comfortable wind speed of semi-open space is 1m/s-2m/s, while solar radiation is under 700W/m². (Liang 2005)
horizontal at 0% when the depth goes beyond 4.5 meters, which means that the direct solar radiation has no effect on the semi-open space (Zone 3 in Figure 5-2).

Figure 5-2
Percentage of inefficiency in shading of June
Source: Author

Another important aspect of solar radiation is the ratio of diffuse and direct radiation. While direct radiation can – more or less easily – be blocked out by shading
devices, diffuse radiation is in some way more difficult to handle, especially if one works with passive systems. Depending on the location, diffuse radiation may have a more important impact on the architectural layout than direct radiation. Especially for locations in the hot-humid tropics close to the equator, face a very high degree of diffuse radiation. In Singapore, the ratio of direct and diffuse radiation might reach 1:4, which manifests a strong predominance of diffuse radiation.

Average year percentage of diffuse and direct solar radiation can be calculated using SOL-ARIS (Figure 5-3). In order to compare with graph of direct radiation in June, percentage of shading effect is converted into percentage of the effect of solar radiation, which is the non-shaded area in Figure 5-4. In comparison, the percentage of shading effect against diffuse solar radiation varies more sharply with the depth of semi-open space than against direct radiation. It means diffuse solar radiation is more sensitive to the variation of the depth.

![Figure 5-3](image)

**Figure 5-3**

Average year percentage of the shading effect against the direct and diffuse solar radiation

Source: Author

The diminishment of diffuse radiation with the depth of semi-open space is not a linear, but a gradual process. The rate of change in the percentage with respect to
5. Finding the Optimal Thermal Comfort Range

depth is evenly decelerated. It is about 0.1% with the pace of 0.1 meter deep. Although there is no clear threshold, it is really obvious that the diffuse radiation decreases quite a lot in the corridor, from 100% to 44.2%.

**Figure 5-4**

Average year percentage of inefficiency in shading  
Source: Author

Liang’s study shows people’s feeling of thermal comfort and solar radiation (Liang 2005). He did a survey among the residents in Bedok. The interviewees were requested to stay in the middle of corridor and the middle of veranda for five minutes
5. Finding the Optimal Thermal Comfort Range

separately. Then they rated the comfort condition from -3 to +3 (see Table 5-1) based on their feelings during that time. The results show that the average vote value for the corridor is 0.56, while that for veranda is -0.78. It means people feel cooler in veranda than in corridor. More than 60% of the respondents feel warm in corridor and require more shading; while 96.7% of the respondents think the environment of veranda is within comfort range.

Table 5-1
Questionnaire about thermal comfort
Source: Bay 2004

<table>
<thead>
<tr>
<th>Vote</th>
<th>-3</th>
<th>-2</th>
<th>-1</th>
<th>0</th>
<th>+1</th>
<th>+2</th>
<th>+3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal comfort feeling</td>
<td>Too much cool</td>
<td>A little cool</td>
<td>Comfortable cool</td>
<td>Comfortable</td>
<td>Comfortable warm</td>
<td>A little warm</td>
<td>Too much warm</td>
</tr>
</tbody>
</table>

To further investigate the impact of diminishment of solar radiation on people’s thermal comfort, we analyze Liang’s study results by using percentage of non-shaded area in Figure 5-4. In that graph, the two red lines show the two points of taking interview. The corresponding values of two points at y-axis show the effect of diffuse radiation at the middle of corridor is 63.8%. In the corridor, the range of the effect of diffuse solar radiation is from 100% to 44.2%. So it can be deduced that in this range, people feel uncomfortable. On the other hand, the diffuse radiation at the middle of veranda is 19.3%. People feel comfortable when the solar radiation is reduced to around this value. At the depth of 1.5m to 2.5m, the effect of solar radiation is in the
range of 42% to 28%. Although there is no mean vote for this range, observation shows that people prefer to put plants or furniture at these spaces, and few activities take place here. It can be looked as a buffer zone. In fact, the plant in this space reduces the solar radiation and makes the veranda more comfortable.

Summarising from the above analysis of direct and diffuse solar radiation, Figure 5-5 shows the relationship of the depth and solar radiation. At the depth of 0 to 1.2m, the direct radiation diminishes rapidly; at the depth of 1.2m to 4.5m, it reduces gradually; and after 4.5m, there is no direct radiation. As for the diffuse solar radiation, it diminishes rapidly from the depth of 0 to 1.5m, and people feel uncomfortable when the effect of diffuse radiation is higher than around 44%. The diffuse radiation continues to reduce from the depth of 1.5m to 2.5m and it is in a transitional area. At the depth after 2.5m, the diffuse radiation is below 28%, and it is comfortable for activities.

As for architecture design concerned, at the depth of 0 to 1.5 m, design for any social activities should be avoided. At the depth of 1.5m to 2.5m, it is recommended to be designed as a buffer zone, where plants, furniture or shading devised may be best installed. At the depth of 2.5m to 4.5m, thermal comfort condition allows social activities. Global radiation does not affect human activities too much. And from 4.5m to 7 m, the thermal comfort condition is ideal for all kinds of activities because there is no direct solar radiation and the diffuse radiation is very low. (See Figure 5-6)
5. Finding the Optimal Thermal Comfort Range

Figure 5-5
Solar radiation and depth of semi-open space
Source: Author

Figure 5-6
Design recommendation on depth of semi-open space
Source: Author

<table>
<thead>
<tr>
<th>Depth</th>
<th>Direct Radiation</th>
<th>Diffuse Radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (0-1.5m)</td>
<td>28.6%</td>
<td>68.2%</td>
</tr>
<tr>
<td>2 (1.5-2.5m)</td>
<td>4.9%</td>
<td>35.3%</td>
</tr>
<tr>
<td>3 (2.5-4.5m)</td>
<td>1.5%</td>
<td>22.3%</td>
</tr>
<tr>
<td>4 (4.5-7m)</td>
<td>0.0%</td>
<td>14.0%</td>
</tr>
</tbody>
</table>

Design recommendation:
- 1 (0-1.5m): It is too hot for social activities.
- 2 (1.5-2.5m): It is better to design it as a buffer zone for gardening.
- 3 (2.5-4.5m): It is comfortable for activities.
- 4 (4.5-7m): It is ideal for most activities.
Validation of the simulation on the case

To validate the simulation result of the solar radiation, field measurement was done at Bedok. Two typical verandas with similar position and area were chosen. One is without plants and furniture, the other is with flushed plants and furniture. At each veranda, solar radiation is measured at eight different points in one line (Figure 5-7).

![Figure 5-7](image)

Figure 5-7
Measurement of solar radiation at veranda
Source: Author

The result shows that the solar radiation reduces with the increase of depth (Figure 5-8). All of the curves go down quickly from 0 to around 1m, and then they drop slowly from around 1 m to 2m. After the depth reaches around 2m, the solar radiation is very low. It means the veranda, plus the corridor, can protect residents from solar radiation effectively. It provides a thermal comfort environment and makes sure the possibility of having activities outside in a tropical climate.

There is no significant difference between the veranda with or without plant and furniture. The only difference is that, after 2m deep, the solar radiation of the veranda
with plants and furniture is lower than the empty one. It proves stuff arranged at the boundary of the veranda, especially plants, will make the veranda more comfortable.

Figure 5-8
Reduction of solar radiation with the depth of semi-open space
Source: Author
5. Finding the Optimal Thermal Comfort Range

Summary of the Findings

In summary, the measurement shows similar relationship of the solar radiation and the depth: temperature decreases with the increases of depth of semi-open spaces. Hence, the SOL-ARIS simulation is validated. It can be used to develop the design guideline.

It can be summarized that the thermal performance of the semi-open space is poor when the depth is below 1.5m. The threshold from poor to good performance is between 1.5m to 2.5 m. After that, the environment becomes comfortable for activities. When the depth is beyond 4.5 m, the solar radiation will not have great impact on the temperature. The thermal comfort condition is ideal for most social activities.
CHAPTER 6

FINDING THE MINIMAL SIZE FOR OPTIMAL SOCIAL ACTIVITIES

*Calculation of the limited space for different social activities and combination of thermal comfort condition with social behaviour*

In this chapter, we will calculate the limited space for different social activities. We will find the optimal size for social behaviors, and it will be combined with the optimal size for thermal comfort, which is the simulation result from Chapter 5. In this way, we will find the threshold of good performance both on the aspect of environment and community. A diagram about socio-climatic design and depth of semi-open space will be presented.
Ergonomics and spatial dimension

Manual simulation of alternatives of usage

Manual simulation is used to calculate the limited area for possible activities at the semi-open spaces. It is as important as the computer-based simulation because it also decides the possibility of having social behaviours. For example, if one would like to sit in an armchair in front of his unit, the required area is 1.8 m x 1.0 m. If a coffee table is added, the minimum area is 2.25 m x 1.0 m (Figure 6-1). So a semi-open space of 3.1 m to 3.55 m deep can provide a good place for a person to enjoy his leisure time. Similarly, 2.4 m x 2.4 m area can allow two to four persons to stay around a table, for eating or chatting (Figure 6-2). If the total depth is less than 3.7 m (2.4 m plus 1.3 m for traffic), the chance of communication among neighbours will be reduced.

Figure 6-1
Minimum space for sitting in armchair with a coffee table
Source: Sketch by author, after Neufer Architects’ data (Baiche200)
Limited space for various activities

The designed activities are based on the case study of Bedok. Observations and questionnaires show that people often have the following activities at the semi-open spaces:

i. *Sitting and watching,*

ii. *Reading and learning,*

iii. *Chatting with friends,*

iv. *Eating*

v. *Gardening,*

vi. *Exercising,*

vii. *Children’s playing,*

viii. *Drying clothes,*

ix. *and Having party.*
According to the information above, the social activities are divided into six groups for space calculation: circulation, family relaxation, house work, exercise & recreation, children’s playing and communication. In each group, number of persons involved varies from 1 to 8 persons according to the requirement of daily life. To keep in accordance with the possible interior design for each activity, the required width of the attached semi-open space is restricted to 4.5 meters, while the depth is restricted to 6 meters.

For instance, Figure 6-3 shows the minimum space for four people’s communication. The dimension of semi-open space is 2.9m x 3.3m. It has the capacity of a table and four chairs. Space for four people’s circulation is also taken into consideration. Appendix D shows the details of spaces for various activities.

Figure 6-3
Minimum space for 4 persons sitting around table
Source: Sketch by author, after Neufer Architects’ data (Baiche200)
Thresholds of environmental performance and social performance

Threshold of good performance

In order to indicate the architectural design of semi-open space, the results of the simulations of thermal comfort and human activities should be combined together. For example, 2.8m depth of semi-open space allows circulation and sitting outside (Figure 6-4). But the physical performance of 1.5 m depth is quite poor, and the average temperature from 1.5m depth to 2.8m depth is still a little high for activities. Design in this way will result in no activities at the semi-open space.

Figure 6-4
Semi-open space of 2.8m deep and social activities
Source: Author
As a result, a clear threshold considering both thermal comfort and human activities is very important. Through calculation, 3.4m is the minimum depth required for a good environmental and social performance (Figure 6-5). Within the 1400mm distance from outside, the environmental performance is very poor. Both diffuse and direct solar radiations are strong. It is not suitable for human activities other than for thoroughfare. The residents are not expected to linger in that space. From 1400mm depth towards inside, the effect of direct solar radiation becomes disappear, and the thermal comfort condition improves gradually. As there is not such a point where the temperature reduces sharply, the zone next to the 1400mm depth is suggested to use as a buffer zone, where plants and shading devices may be best installed. Normally, plants will occupy 750mm depth. They can help to provide more shads and reduce the temperature. After the circulation and buffer zone (plus 50mm fence in between, 2200mm depth altogether), the space is for social activities. According to Neufer Architects’ data (Baiche200), 1200mm is the minimum requirement for social activities. It allows a 2-person table or a single sofa. Users can do gardening and take some activities which do not require much space.

Designed in the pattern of circulation-plants-activities, the depth of semi-open space should better not smaller than 3.4m. 3.4m depth of semi-open space can provide the users a platform for social lives and ensure all the social activities can take place in the good environmental performance zone. The deeper the semi-open spaces are, the more activities are allowed in a comfortable environment. Designed in this way, semi-open spaces will have good environmental performance, as well as social one.
Figure 6-5
Semi-open space of 3.4m deep and social activities
Source: Author
Combination of thermal comfort and human activities

The threshold of 3.4m and the design as pattern of circulation-plants-activities are one of the applicable ways to achieve the sustainable environment and community. The guidelines in the next chapter are developed in this design pattern. Moreover, the designers can develop their own approach base on the relationships of the depths and their performances, which include physical performance and social performance. The graph shown in Figure 6-6 is the combination of the results from the simulation of thermal comfort and human activities.

The vertical lines represent the limited depths of different activities. The chart below shows the details of each line. For example, line C indicates 3100mm, which means that people can do gardening at the semi-open space (Example 1 in Figure 6-6); while line F represents that the depth of 4100mm allows exercising (Example 2 in Figure 6-6). 1400mm of circulated space is added into each depth. So the figures shown in the graph and chart are depths for both circulation and social activities.

Based on the discussion of the threshold of good performance and the pattern of circulation-plant-activities, the depths of semi-open space are divided into four zones. They are poor, threshold, good and generous. They are defined according to the environmental performance and social one (Table 6-1). They are also illustrated by red colours in Figure 6-6, which fade from dark to light.
### Table 6-1
Four zones of depths of semi-open spaces
Source: Author

<table>
<thead>
<tr>
<th>Depth of veranda from a corridor of 1.4m</th>
<th>Poor</th>
<th>Threshold</th>
<th>good 2.1—3.1m</th>
<th>Generous After 3.1m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct solar radiation</td>
<td>Strong</td>
<td>Moderate</td>
<td>Almost none</td>
<td>None</td>
</tr>
<tr>
<td>Diffuse solar radiation</td>
<td>Strong</td>
<td>Moderate</td>
<td>Mild</td>
<td>Almost none</td>
</tr>
<tr>
<td>Social activities</td>
<td>N.A</td>
<td>Gardening, Laundry, 2 person’s communication and relaxation</td>
<td>Children’s playing, Exercise, House work, 4 person’s recreation</td>
<td>A lot of social activities which require more space, e.g. party, pool, table tennis</td>
</tr>
</tbody>
</table>

The graph can be flexibly used to direct the design of semi-open spaces. For example, someone designing a semi-open space of 4 meters deep can first ensure that the predicted physical performance is satisfactory. The illustration will show that eight kinds of activities, numbered A to E in the charts, can take place in the designed area. He will also find that if 0.1m more depth is given, people can do exercise. And another 0.1m will allow house work. The social performance of semi-open space will be improved. In another case, if the designer proposes that the future users can hold family parties in the semi-open space, he will find in the illustration that the minimum depth is 4.6m where the physical performance will be accepted.
Figure 6-6
Illustration of depths for physical performance and limited area of activities
Source: Author

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Activities</th>
<th>Depth (mm)</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 1400</td>
<td>Circulation</td>
<td>H 2300 = 1400 = 4300</td>
<td>4 persons' recreation</td>
</tr>
<tr>
<td>B 1600 = 1400 = 3000</td>
<td>2 persons' communication</td>
<td>I 3100 = 1400 = 4500</td>
<td>2-3 children's playing and</td>
</tr>
<tr>
<td>C 1700 = 1400 = 3100</td>
<td>Gardening and laundry</td>
<td>J 3200 = 1400 = 4600</td>
<td>Family relaxation</td>
</tr>
<tr>
<td>D 1900 = 1400 = 3300</td>
<td>2 persons' relaxation</td>
<td>K 3000 = 1400 = 5000</td>
<td>Recreation like pool</td>
</tr>
<tr>
<td>E 2200 = 1400 = 3600</td>
<td>1 child's playing</td>
<td>L 3000 = 1400 = 5200</td>
<td>Porch</td>
</tr>
<tr>
<td>F 2700 = 1400 = 4100</td>
<td>Individual Exercise</td>
<td>M 5000 = 1400 = 7000</td>
<td>Games like table tennis</td>
</tr>
<tr>
<td>G 2800 = 1400 = 4200</td>
<td>House work</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER 7

ORGANIZATION AND PRESENTATION OF GUIDELINES

Structuring knowledge from case study and simulation and presenting socio-climatic design guideline

In this chapter, the knowledge and information from case study and simulation in previous chapters will be structured in the framework of Context-Morphology-Operation-Performance. FLUENT will be used to visualize the data. The guidelines will be organized and presented in a visual chart. A sample of the socio-climatic design guideline will be shown and explained in details.
Representation of precedent knowledge using FLUENT software

FLUENT\(^7\) software is used as an approach of representation in this study. It will help illustrate the environment performance the semi-open space for clearer understanding. This graphic tool is used to visualize the heat transfer between solar radiation and semi-open space when the depth of semi-open space increases from 1.5 meter to 6.5 meters.

Semi-open space is simplified to hollow cuboids with opening at three sides (Figure 7-1). Twelve models are set up using GAMBIT. The width of each is the same and the depth varies from 1 meter to 6.5 meters with the pace of 0.5 meters. The models are simulated in the same domain with same boundary conditions. Similar to the case buildings, the models are oriented to the north direction, which has less direct solar radiation in the hot season. Two o’clock pm on June 21st is chosen as a typical time. The simulation is done based on the solar radiation condition at that time. The average air temperature is set at 304K (30 °C). It is emphasized here that the simulation is not to predict the thermal comfort condition accurately, but to show the variation of temperature under different design and generate graphic results for the

\(^7\) FLUENT is one of the most popular CFD (Computational Fluid Dynamics) tools. It is a state-of-the-art computer program for modelling fluid flow and heat transfer in complex geometries. FLUENT is an engineering design and analysis tool for fluid flow, heat transfer, chemical reactions and combustion problems, etc. FLUENT is ideally suited for incompressible and mildly compressible flows. Utilising a pressure-based segregated method solver, FLUENT contains physical models for a wide range of applications including turbulent flows, heat transfer, reacting flows, chemical mixing, combustion and multiphase flows. The software is capable of predicting the external/internal aerodynamics performance of an aircraft or automobile, ship hull resistance, hydrodynamic performance of water-jet propulsion system, fire and smoke movement in a building enclosure, mixing and combustion processes, thermal management of electronics system, components or packages, among others.
visual friendly guidelines. So, in this study, comparisons of results are much more important than the exact values.

Figure 7-1
Models for FLUENT simulation
Source: Author

Figure 7-2
A sample of the colourful graphs generated by FLUENT
Source: Author

Figure 7-2 shows a sample of the colourful graphs generated by FLUENT (All graphs are shown in Appendix E). They are the plans of semi-open spaces showing the temperature variation. The extreme high temperature, represented by red colour in the graphs, is caused by the direct solar radiation. It is obvious that when the depth
increases, the red colour becomes diminish. It means the average temperature decreases with the variation of depth, which is same as the simulation result from SOL-ARIS. Another important point is that the proportion of hot area to cold area becomes larger when the semi-open space turns narrow. It means there is less comfort space for outdoor activities. When the depth is 2.5 meters, hot and cold area each occupy fifty percent.

**Framework of the guidelines**

The last step of study is to comprehend and organize all the information from case study and simulation as a user friendly guideline. The guidelines are organized as visual charts for clear communication. Tzonis’s design thinking about morphology, operation and performance is used as a framework to organize the guidelines. All information is distributed into four groups under the items of morphology, operation, environmental performance and social performance (Table 7-1).

**Table 7-1**

*Framework of the guideline*

*Source: Author*

<table>
<thead>
<tr>
<th>Depth</th>
<th>Morphology</th>
<th>Operation</th>
<th>Environmental Performance</th>
<th>Social Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5m</td>
<td>Variations of configuration</td>
<td>Analysis of the theory behind</td>
<td>Colourful graph of the predicted temperature</td>
<td>Possible activities and the predicted communication</td>
</tr>
<tr>
<td>4.0m</td>
<td>......</td>
<td>......</td>
<td>......</td>
<td>......</td>
</tr>
<tr>
<td>4.5m</td>
<td>......</td>
<td>......</td>
<td>......</td>
<td>......</td>
</tr>
<tr>
<td>5.0m</td>
<td>......</td>
<td>......</td>
<td>......</td>
<td>......</td>
</tr>
<tr>
<td>......</td>
<td>......</td>
<td>......</td>
<td>......</td>
<td>......</td>
</tr>
</tbody>
</table>
There are variations of configuration in the column of Morphology. Under the item of Operation, there are explanation and analysis of the theory behind. Colourful graph of the predicted temperature will be shown in the column of Environmental Performance. And the Social Performance will indicate the possible activities and predict the communication. This framework will show the correlations of expected social patterns, predicted bio-climatic behaviours and sizes. Each element of interdisciplinary knowledge, their relationship and structure are explicitly mapped out in these charts for clearer communication. Users can read through quickly and use the guidelines flexibly according to their design requirement. Moreover, architectural language such as plan/sectional sketch is used to present the guideline in order to help the eye to judge and decide graphically.

Instruction for using the guidelines

The constant and variable parameters

The guideline will be created based on the standard plan shown in Figure 7-3, which is simplified from the plan of Bedok. The semi-open space is made up of two parts: public corridor (1300mm deep) and veranda. The width of the semi-open space is kept unchanged, 5000mm, while the depths vary from small to large. Table 7-2 shows the constant and variable parameters of the guidelines, making comparison clearer and easier.
Figure 7-3
Standard Plan
Source: Author

Table 7-2
Constant and variable parameters
Source: Author

<table>
<thead>
<tr>
<th>Constant parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Context</strong></td>
</tr>
<tr>
<td>High-rise dwellings, urban, tropical region</td>
</tr>
<tr>
<td><strong>Orientation</strong></td>
</tr>
<tr>
<td>North</td>
</tr>
<tr>
<td><strong>Location</strong></td>
</tr>
<tr>
<td>The entrance of each unit</td>
</tr>
<tr>
<td><strong>With</strong></td>
</tr>
<tr>
<td>5000mm</td>
</tr>
<tr>
<td><strong>Wind direction</strong></td>
</tr>
<tr>
<td>North-south</td>
</tr>
<tr>
<td><strong>Lighting</strong></td>
</tr>
<tr>
<td>Similar comfortable condition</td>
</tr>
<tr>
<td><strong>Acoustic</strong></td>
</tr>
<tr>
<td>Similar comfortable condition</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of the semi-open space</td>
</tr>
<tr>
<td>The arrangement of the semi-open space</td>
</tr>
</tbody>
</table>
Presentation of the guideline

The guidelines developed in this study are shown in Figure 7-4. On the left of the chart, poor zone does not work for ergonomics and environmental aspects. On the right, it shows the good zone starting from threshold point: 2 meters depth of veranda. Beyond that point, the semi-open space provides more shaded space and allows more activities.

Figure 7-4
Summary of the guideline
Source: Author

<table>
<thead>
<tr>
<th>Unacceptable design size</th>
<th>Acceptable design size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>Threshold</td>
</tr>
</tbody>
</table>

Possible design configuration (Morphology)

<table>
<thead>
<tr>
<th>Poor design</th>
<th>Threshold design</th>
<th>Good design</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2m depth of veranda from 1.4m corridor</td>
<td>2m depth of veranda from 1.4m corridor</td>
<td>Bigger than 2m depth of veranda from 1.4m corridor</td>
</tr>
</tbody>
</table>

Social aspect

Possible social activities (Social Performance)

<table>
<thead>
<tr>
<th>Poor design</th>
<th>Threshold design</th>
<th>Good design</th>
</tr>
</thead>
<tbody>
<tr>
<td>-Saying hello to neighbours</td>
<td>-Saying hello to neighbours</td>
<td>-Saying hello to neighbours</td>
</tr>
<tr>
<td>-Gardening</td>
<td>-Gardening</td>
<td>-Gardening</td>
</tr>
<tr>
<td>-Sitting</td>
<td>-Reading</td>
<td>-Chatting</td>
</tr>
<tr>
<td>-Reading</td>
<td>-Chatting</td>
<td>-Children’s playing</td>
</tr>
<tr>
<td>-Chatting</td>
<td>-Exercising</td>
<td>-Children’s playing</td>
</tr>
<tr>
<td>-Children’s playing</td>
<td>-Housework</td>
<td>-Exercising</td>
</tr>
<tr>
<td>-Exercising</td>
<td>-Taking party etc.</td>
<td>-Housework</td>
</tr>
<tr>
<td>-Taking party etc.</td>
<td></td>
<td>-Taking party etc.</td>
</tr>
</tbody>
</table>

How it works (Operation)

<table>
<thead>
<tr>
<th>Poor design</th>
<th>Threshold design</th>
<th>Good design</th>
</tr>
</thead>
<tbody>
<tr>
<td>-Only several pots of plants can be placed at the corridor. And they will make the semi-open space more crowded.</td>
<td>-The maximum number of persons allowed having activities at the veranda at the same time is two.</td>
<td>-The number of persons allowed having activities at the veranda at the same time is more than 2.</td>
</tr>
<tr>
<td>-Residents have little chance to communicate with their neighbours at the semi-open space.</td>
<td>-Residents have some chances to see and communicate with their neighbours at the veranda.</td>
<td>-Residents have many chances to see, say hello to or communicate with their neighbors at the veranda.</td>
</tr>
</tbody>
</table>
7. Organization and Presentation Of Guidelines

Environmental aspect

<table>
<thead>
<tr>
<th>Desired environmental effect (Environmental Performance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>· semi-open space is totally exposed to solar radiation.</td>
</tr>
<tr>
<td>· Temperature is high for outdoor activities.</td>
</tr>
<tr>
<td>· 57.1% of the veranda is shaded even without plants.</td>
</tr>
<tr>
<td>· Plants can be arranged between the corridor and veranda. They help block the solar radiation and reduce the temperature of the veranda.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>How it works (Operation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>· more than 57.1% of the veranda is shaded even without plants.</td>
</tr>
<tr>
<td>· Plants can be arranged between the corridor and veranda. They help block the solar radiation and reduce the temperature of the veranda.</td>
</tr>
</tbody>
</table>
More characteristic of semi-open spaces after the threshold point is presented in Figure 7-5. It shows the morphology, operation and performance of the semi-open space from narrow to wide.

Four variations of configuration are shown under the item of Morphology. It provides designer four approaches to arrange the semi-open space.

Under the item of Operation, sections are used to explain why the semi-open space is designed in the order of corridor, plants and space for human activities. The thermal comfort condition of each zone is analyzed. The poor environmental performance zone can be used as circulation. Plants can be arranged in the corridor to reduce the temperature of the buffer zone and leave more space for human activities (if there is not much requirement of circulation). Plants in the veranda also make the environment more comfortable. Most of the space for human activities is totally shaded. Operation tells designers the theory behind the design. The designers can also derive their own approaches according to the explanation and analysis.

Under the item of Environmental Performance, a colorful graph of the predicted temperature is shown. It also shows the distribution of the relative high temperature and low temperature in a visually friendly way.

Under the item of Social Performance, possible activities allowed at the veranda are stated. They also tell how these activities can promote the community and predict the future communication condition.

Organizing and presenting the guidelines in this way make the design instruction more practical, architectural, and user friendly. The designers can start at any point of the guideline according to the design requirement. They can also deduct their own
approach because the guidelines not only tell how to design the semi-open space, but also explain how it works.

**Figure 7-5**

**Summary of characteristic of the space**

Source: Author

<table>
<thead>
<tr>
<th>Morphology</th>
<th>Operation</th>
<th>Environmental Performance</th>
<th>Social Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variation of Configuration</td>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
<tr>
<td>1</td>
<td>• The poor environmental performance zone (1500mm) is used as corridor (1450mm) for circulation.</td>
<td></td>
<td>• The maximum number of persons allowed having activities at the veranda at the same time is two.</td>
</tr>
<tr>
<td></td>
<td>• Plants (750mm) can be arranged in the corridor. The left space allows one person passing. Plants in the poor environmental performance zone help block the solar radiation and reduce the temperature of the buffer zone.</td>
<td></td>
<td>• 1 child can play there.</td>
</tr>
<tr>
<td></td>
<td>• 57.1% of the veranda is shaded even without plants.</td>
<td></td>
<td>There are spaces for some plants. But it will be crowded for gardening.</td>
</tr>
<tr>
<td>Variation of Configuration 3</td>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
<tr>
<td>4</td>
<td>• The poor environmental performance zone (1500mm) is used as corridor (1450mm) for circulation.</td>
<td></td>
<td>• The veranda allowed simple social activates such as sitting, reading, and chatting</td>
</tr>
<tr>
<td></td>
<td>• Plants (750mm) can be arranged in the buffer zone of the veranda. Plants help block the solar radiation and reduce the temperature of the veranda.</td>
<td></td>
<td>• Residents have some chances to see, or say hello to their neighbors at the veranda.</td>
</tr>
<tr>
<td></td>
<td>• 57.1% of the veranda is shaded even without plants.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Depth: 2.1m depth of veranda from 1.4m corridor *(Context: tropical region, urban)*
### Depth: 2.6m depth of veranda from 1.4m corridor (Context: tropical region, urban)

<table>
<thead>
<tr>
<th>Morphology (Variation of Configuration)</th>
<th>Operation</th>
<th>Environmental Performance</th>
<th>Social Performance</th>
</tr>
</thead>
</table>
| 1                                      | ![Diagram 1] | ![Diagram 2] | `- The maximum number of persons allowed having activities at the veranda at the same time is 3. 
- 2 Children can play there. 
- There are spaces for some plants and gardening 
- The veranda allowed simple social activates and entertainment such as sitting, reading, chatting, exercising, and painting 
- Residents have some chances to see, say hello to or communicate with their neighbors at the veranda.` |
| 2                                      | ![Diagram 3] | ![Diagram 4] | |
| 3                                      | ![Diagram 5] | ![Diagram 6] | |
| 4                                      | ![Diagram 7] | ![Diagram 8] | |

- The poor environmental performance zone (1500mm) is used as corridor (1450mm) for circulation.
- Plants (750mm) can be arranged in the corridor. The left space allows one person passing. Plants in the poor environmental performance zone help block the solar radiation and reduce the temperature of the buffer zone.
- 62.5% of the veranda is shaded even without plants.
- The maximum number of persons allowed having activities at the veranda at the same time is 3.
- 2 Children can play there.
- There are spaces for some plants and gardening
- The veranda allowed simple social activates and entertainment such as sitting, reading, chatting, exercising, and painting
- Residents have some chances to see, say hello to or communicate with their neighbors at the veranda.
# 7. Organization and Presentation Of Guidelines

## Depth: 3.1m depth of veranda from 1.4m corridor m (Context: tropical region, urban)

<table>
<thead>
<tr>
<th>Morphology (Variation of Configuration)</th>
<th>Operation</th>
<th>Environmental Performance</th>
<th>Social Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Diagram 1" /></td>
<td><img src="image2.png" alt="Diagram 2" /></td>
<td><img src="image3.png" alt="Diagram 3" /></td>
<td><img src="image4.png" alt="Diagram 4" /></td>
</tr>
</tbody>
</table>
| 1 | - The poor environmental performance zone (1500mm) is used as corridor (1450mm) for circulation.  
- Plants (750mm) can be arranged in the corridor. The left space allows one person passing. Plants in the poor environmental performance zone help block the solar radiation and reduce the temperature of the buffer zone.  
- 66.7% of the veranda is shaded even without plants. | - The maximum number of persons allowed having activities at the veranda at the same time is 4.  
- 3 Children can play there. There are spaces for some plants and gardening.  
- The veranda allowed some social activates, housework and entertainment such as sitting, reading, chatting, exercising, painting, having dinner and laundry  
- Residents have many chances to see, say hello to or communicate with their neighbors at the veranda. | |
| 2 | ![Diagram 5](image5.png) | ![Diagram 6](image6.png) | |
| 3 | ![Diagram 7](image7.png) | ![Diagram 8](image8.png) | |
| 4 | ![Diagram 9](image9.png) | ![Diagram 10](image10.png) | |
7. Organization and Presentation Of Guidelines

| Depth: 3.6m depth of veranda from 1.4m corridor (Context: tropical region, urban) |
|---|---|---|
| **Morphology**<br>(Variation of Configuration) | **Operation** | **Environmental Performance** |
| 1 | ![Diagram 1](image1) | ![Diagram 2](image2) |
| 2 | ![Diagram 3](image3) | ![Diagram 4](image4) |
| 3 | ![Diagram 5](image5) | ![Diagram 6](image6) |
| 4 | ![Diagram 7](image7) | ![Diagram 8](image8) |

- The poor environmental performance zone (1500mm) is used as corridor (1450mm) for circulation.
- Plants (750mm) can be arranged in the corridor. The left space allows one person passing. Plants in the poor environmental performance zone help block the solar radiation and reduce the temperature of the buffer zone.
- 70% of the veranda is shaded even without plants.

- The maximum number of persons allowed having activities at the veranda at the same time is 6.
- More than 3 children can play there.
- There are enough spaces for having many plants and gardening.
- The veranda allowed some social activates, housework and entertainment such as sitting, reading, chatting, exercising, painting, having dinner, laundry and playing pool.
- Two different activates can be taken at the same time, for example, some one can have exercise while others chatting with a table.
- Residents have many chances to see, say hello to or communicate with their neighbors at the veranda.

- The poor environmental performance zone (1500mm) is used as corridor (1450mm) for circulation.
- Plants (750mm) can be arranged in the buffer zone of the veranda. Plants help block the solar radiation and reduce the temperature of the veranda.
- 70.5% of the veranda is shaded even without plants.
## 7. Organization and Presentation Of Guidelines

### Depth: 4.1m depth of veranda from 1.4m corridor (Context: tropical region, urban)

<table>
<thead>
<tr>
<th>Morphology (Variation of Configuration)</th>
<th>Operation</th>
<th>Environmental Performance</th>
<th>Social Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="image1.png" alt="Diagram" /></td>
<td><img src="image2.png" alt="Diagram" /></td>
<td>• The maximum number of persons allowed having activities at the veranda at the same time is 8.</td>
</tr>
<tr>
<td></td>
<td>• The poor environmental performance zone (1500mm) is used as corridor (1450mm) for circulation.</td>
<td></td>
<td>• More than 3 children can play there.</td>
</tr>
<tr>
<td></td>
<td>• Plants (750mm) can be arranged in the buffer zone of the veranda. Plants help block the solar radiation and reduce the temperature of the veranda.</td>
<td></td>
<td>• There are enough spaces for having many plants and gardening.</td>
</tr>
<tr>
<td></td>
<td>• 72.7% of the veranda is shaded even without plants.</td>
<td></td>
<td>• The veranda allowed many social activates, housework and entertainments such as sitting, reading, chatting, exercising, painting, having dinner, laundry, playing pool and having party.</td>
</tr>
<tr>
<td>2</td>
<td><img src="image3.png" alt="Diagram" /></td>
<td></td>
<td>• Two activates can be taken at the same time, for example, some one can have exercise while others chatting with a table.</td>
</tr>
<tr>
<td>3</td>
<td><img src="image4.png" alt="Diagram" /></td>
<td></td>
<td>• Residents have a lot of chances to see, say hello to or communicate with their neighbors at the veranda.</td>
</tr>
<tr>
<td>4</td>
<td><img src="image5.png" alt="Diagram" /></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Depth: 4.6m depth of veranda from 1.4m corridor m (Context: tropical region, urban)

<table>
<thead>
<tr>
<th>Morphology (Variation of Configuration)</th>
<th>Operation</th>
<th>Environmental Performance</th>
<th>Social Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- The poor environmental performance zone (1500mm) is used as corridor (1450mm) for circulation.
- Plants (750mm) can be arranged in the buffer zone of the veranda. Plants help block the solar radiation and reduce the temperature of the veranda.
- 75% of the veranda is shaded even without plants.

- The maximum number of persons allowed having activities at the veranda at the same time is 9.
- More than 3 children can play there. There are enough spaces for having many plants and gardening.
- The veranda allowed many social activates, housework and entertainment such as sitting, reading, chatting, exercising, painting, having dinner, laundry, playing pool and having party.
- Two or three activates can be taken at the same time.
- Residents have a lot of chances to see, say hello to or communicate with their neighbors at the veranda. They may have the opportunities to attend neighbors’ activates at the semi-open spaces.

- 75% of the veranda is shaded even without plants.
### Depth: 5.1m depth of veranda from 1.4m corridor (Context: tropical region, urban)

<table>
<thead>
<tr>
<th>Morphology (Variation of Configuration)</th>
<th>Operation</th>
<th>Environmental Performance</th>
<th>Social Performance</th>
</tr>
</thead>
</table>
| 1                                      | • The poor environmental performance zone (1500mm) is used as corridor (1450mm) for circulation.  
• Plants (750mm) can be arranged in the buffer zone of the veranda. Plants help block the solar radiation and reduce the temperature of the veranda.  
• 76.9% of the veranda is shaded even without plants. | ![Environmental Performance Diagram](image) | • The maximum number of persons allowed having activities at the veranda at the same time is 10.  
• More than 3 children can play there. There are enough spaces for having many plants and gardening.  
• The veranda allowed a lot of social activates, housework and entertainments such as sitting, reading, chatting, exercising, painting, having dinner, laundry, playing pool and having party.  
• Many activates can be taken at the same time.  
• Residents have a lot of chances to see, say hello to or communicate with their neighbors at the veranda. They may have many opportunities to attend neighbors' activates at the semi-open spaces. |
| 2                                      | ![Operation Diagram](image) | ![Environmental Performance Diagram](image) | ![Social Performance Diagram](image) |
| 3                                      | ![Operation Diagram](image) | ![Environmental Performance Diagram](image) | ![Social Performance Diagram](image) |
| 4                                      | ![Operation Diagram](image) | ![Environmental Performance Diagram](image) | ![Social Performance Diagram](image) |
CHAPTER 8

EVALUATION AND CONCLUSION

*Summary of the findings, contributions, limitations and generalisation of thesis*

In this conclusion, we will summarize the major ideas, contributions and limitations of the developed guideline. We will also discuss the potential extension, generalisation, limitation and application of present work in the last section.
Summary of major ideas in this study

We pointed out in the introduction that we seek to,

i. **Investigate why some available sustainable design guidelines cannot be used effectively and efficiently by architects in design practice,**

ii. **Explore an approach to frame the information from precedents to develop into guidelines using pre-parametric simulation, and**

iii. **Develop a socio-climatic design guideline for semi-open entrance space of high-rise apartment based on the cases of tropical dwellings in Singapore.**

This thesis reports on a framework for developing a particular set of guidelines from the angle of architects. This set of guidelines embodies correlations of interdisciplinary knowledge, namely, architecture design, social behaviour and climatic condition. This study is aimed to fill in the gap between architect and engineer, as well as research and practice. It employs pre-parametric design thinking and parametric tool.

Pre-parametric design thinking is a common heuristic used by designers in practice. Schon (1983, 49-50) argues that architects often employ heuristics as shortcuts without quantitative calculation when faced with complicated design problems, which are ‘uncertainty, instability, uniqueness and value conflict’. Although precedents are necessary for solving design problems, analogical means cannot be totally relied on to accomplish a sustainable design. An effective tool is
needed to help satisfy the requirement of accuracy of sustainable design. The parametric tool based on building simulation can assist pre-parametric design thinking depending on its quantitative property. Simulation techniques are crucial for environmental design decision-making process because they represent environmental reality and predict real-life situation. It foretells the performance and ensures the accuracy of design morphology. The combination of pre-parametric design thinking and parametric tool make the design guideline compatible with architects’ design thinking process, and ensure its accuracy, effectiveness and efficiency.

We use an interdisciplinary research method, drawing knowledge from environmental psychology, environmental engineering and architectural theory. We also use the case study approach. The case of tropical high rise in Singapore was used for investigation. We examine the role of design guidelines in provision of information for architectural design decision making and also the potential contributions of morphology-operation-performance design thinking to the development of guidelines (Chapter 2). Two cases of semi-open spaces were used to develop the socio-climatic design guidelines (Chapter 4). The methodology includes three steps: case study (Chapter 4), simulation of both thermal comfort and human activities (Chapter 5 & 6) and design of guidelines (Chapter 7). The guidelines finally are organized in using visual charts. The main findings are as follows:

1. Sustainable architecture design guidelines should not exclude human behaviour. Bio-climatic design guidelines can be developed into socio-climatic design guidelines by taking social aspects into consideration. (Chapter 1)
2. Design guidelines are quite important for sustainable design as the architect has to deal with multiple criteria in designing. Good guidelines should be developed in the way of architects. *Context-Morphology-Operation-Performance* framework is particularly suited to the provision of design information because it expresses design options in a clear, logic and accurate way. (Chapter 2)

3. Case study is a useful way of collecting design information because learning from precedents is a main manner of architectural education. In practice, designers usually use heuristics for design thinking which are pre-parametric for complex design problems and hardly used any parametric methods. However, it is not accurate enough for sustainable design. Parametric building simulation is needed to prepare guidelines to be more suitable for pre-parametric design thinking. (Chapter 3,4)

4. Building simulation, including simulation of thermal comfort and human activities, can be used before generation of design approach. Simulation based on comparison between the existing good performance and poor performance helps to address the problems and investigate the thresholds of good performance in design. The semi-open entrance space of 3.4m in depth is the threshold of good socio-climatic performance in tropical high-rise apartment. (Chapter 5,6)

5. Design guidelines should be presented in architects’ way. *Context-Morphology-Operation-Performance* framework can be used to organize the guidelines. Visual charts with sketches and colourful graph make the guidelines more user friendly. (Chapter 7)
We know that the guidelines developed here will work within the case of semi-open entrance space in tropical architecture. What is its general applicability to the wider context of design in this domain, and other architecture domain? We will discuss these and their limitations in the following section.

Extensions and generalisations

General applicability and application

Can this understanding and therapy be generalised to other architectural design problems? We know that all architectural design has the elements and structure of Morphology-Operation-Performance, even though the context changes. As long as we are designing for human beings, the requirements of climatic comfort and convenience do not change. The relationship of design elements like morphology, operation, environmental performance and social performance, remains similar. These aspects and their relationship are clearly universal for all climates. Therefore, this framework of organizing architectural knowledge is applicable to other architectural designs problems under similar contexts.

This framework measures the shading against activities and combines the social and environmental factors into design guidelines. It provides a way of dealing with the relationship of human activities and environmental performance. Socio-climatic design approach can be employed towards fabricating a desirable expression that
meets both the required environmental performance and sustainable community. There is a possibility for using this model to guide design or study which involves social activities and outdoor environment, such as Asian streets or shop house.

The study of pre-parametric design thinking and parametric simulation tools are not only applicable to practice, but also can contribute to pedagogy. We know that learning from precedents is a common way employed during architectural education. From the beginning of the teaching and learning process, designers have treated precedent knowledge as a short cut for design. But sometimes this method is not effective and efficient enough to teach student about sustainable design, which requires not only design concept but also scientific study. Therefore, an emphasis on both pre-parametric design thinking and parametric design tools will help students sharpen the design judgement, as well as the output of design thinking process.

**Limitations**

The case study is conducted among two high-rise dwellings in Singapore. One is a private condominium; the other is a public housing. During the comparison and analysis of social activities, we assume that the social behaviours, such as gardening, laundry, and chatting with neighbours, are not affected by the education, income and the spare time of the residents. Demography is not included in this study.

There is no further study to discuss if other factors will have impact on social activities besides the thermal comfort condition. In this study, it is assumed that the
lighting and acoustic conditions are comfort for activities. And the evaluation of thermal comfort condition is limited to solar radiation and temperature. It is assumed that the wind speed and humidity is within comfortable range.

This study focuses on the impact of solar radiation on thermal comfort. The north orientation is chosen because it is the worst case in hot season. It is assumed that the solar radiation only comes from the north openings. But in fact, the solar radiation can also reach the veranda from the east and west orientation through the light well in the early mornings and late afternoons as in the case of Bedok Court Condominium. This part of solar radiation is ignored in this study because it is not strong and most of the solar radiation from east and west is self-shaded by the terraced structure.

**Improvement and future extensions of this research**

This study mainly discusses the depth of semi-open entrance space and the impact of solar radiation on thermal comfort. Other parameters are assumed to be within comfortable range. The socio-climatic guidelines can be improved by including more variables such as the orientation and wind speed. Although the effects of these factors can be generally deduced, they are not reasoned out and illustrated in the guideline. Besides thermal comfort condition, there are other factors having impact on the social activities. Further study on other factors will help to extend the research of socio-climatic design and improve the applicability of the design guidelines. The following are suggestions for extension to this research, if it can be extended:
i. Study the semi-open space facing south, east and west.

ii. Study how the lighting condition will affect human activities? If day lighting changes from bright to dim, what kind of activities will be discouraged or encouraged?

iii. Change the shapes and layouts of the semi-open spaces, and see if and how they have impact on the environmental performance and social activities? In this research, the semi-open space is simplified to a rectangle. However, architectural design involves more variation of shapes and layouts, such as round shape or curved boundary. Research on this subject will provide more design schemes for architects’ reference.

Future study can also be conducted to test the effectiveness of the guidelines among the architects. Getting feedback from the users is helpful for future improvement.

Conclusion

We have applied an interdisciplinary research method that employs knowledge from architectural design, social behaviour and climatic condition. The case study approach was also used.

In addition, we have also examined why most of the available environmental design guidelines are not compatible with architecture design thinking process. We
understood that good guidelines for architectural design should be developed in the way of architects. Tzonis’s design thinking of Context-Morphology-Operation-Performance is suitable for developing and organizing the guidelines.

Socio-climatic design guidelines enable the environment and human activities to integrate and interact with each other. It helps to sustain both the environment and the community. We established a method of generating guidelines by using parametric building simulation tools based on pre-parametric design thinking.

The guideline of socio-climatic design was developed in the case of semi-open entrance space of tropical high-rise apartment. A threshold of good socio-climatic performance is found: 3.4m depth. The guidelines are in the form of visual charts, showing the correlations of expected social patterns, predicted bio-climatic behaviours and sizes.

The method of developing socio-climatic design guidelines in the study are not only suitable to the case discussed above, but also applicable to other designs related to sustainable environmental and community. They are promising areas for extending the research work that we have begun.
BIBLIOGRAPHY


Bay, Joo Hwa. 2004. Research Report: Towards more robust and holistic precedent knowledge for tropical design: Semi-open spaces in high-rise residential development. Research in collaboration with Khee-Poh Lam, Reference Number: R 295-000-034-112, Department of Architecture, National University of Singapore,


Hsin, Robert. 1996. *Guidelines and principles for sustainable community design: A study of sustainable design and planning strategies in North America from an urban design perspective.* USA: Florida Agricultural and Mechanical University.


APPENDIX A

Illustration of the design guidelines discussed in Chapter 2

Figure A-1
Cross-section through the teaching wing of a ‘selective mode’ building
Source: Hawkes 1996
Figure A-2
Glazed area and building built form in the ‘exclusive’ mode
Source: Hawkes 1996

Figure A-3
Comparison of energy demand
Source: Hawkes 1997
Figure A-4
Examples of various types of shading devices
Source: Olgyay 1963
Figure A-5
Bishan ITE landscaped street between 3 and 4-storey blocks with open sided corridors and staircases
Source: Bay 2001

Figure A-6
Kampong Bugis Design Guide Plan (DGP) proposal, with landscaped streets between building blocks
Source: After Powell 1997
Figure A-7
Stereotype of the office building in the first past of the twentieth century
Source: Hawkes 1996
Table 3.1 Design features of the Habitat prototype environmental home

- Spatial organization that provide thermal delight, environmental connectivity whilst meeting user needs and lifestyle choices
- Small building footprint to minimize the area of the site used by the building, thus maximizing the retention of existing vegetation
- Northeast orientation provides shading and maximizes breeze in summer, also provides solar access in winter and solar exclusion in summer
- Lightweight northeast oriented building skin to provide rapid heat gain in winter
- Ground connected mass construction to lower story to provide 'cool pools' for daytime living in summer and 'warm pools' for evenings in winter
- Thin plan form with open section to provide cross ventilation for summer cooling
- The use of an atrium to promote connective cooling in summer calm conditions and to provide light to deep plan spaces
- Utilization of a skeletal frame system that has low embodied energy, is factory made and is prefabricated to a high quality, uses moment joints to resist racking loads and gives internal planning flexibility and maximizes openings for ventilation
- Utilization of composite timber, steel and plywood roof diaphragm that uses monocoque construction to resist wind and thermal loads
- Utilization of materials that have minimum of off-gassing and effects on human health
- Provide storage from hydraulic systems such as rainwater and waste water for recycling and site irrigation thus minimizing mains water usage.
- Installation of grid connected PV (photovoltaic) system to export power to the grid during the day and import power at night
- Selection of energy efficient appliances that minimize power utilization
- Automated building monitoring system to audit performance and security
- Use of gas fuel for heating to reduce carbon production
Appendix A

Figure A-9
Service core configurations
Source: Yeang 1999

Figure A-10
Orientation, core position and cooling load
Source: Yeang (1999) after Nihon Sekkei
### Figure A-11
**Suggested sun orientation for rooms**
Source: Olgyay 1963

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### Figure A-12
**Roof Types**
Source: Hyde 2000
Appendix A

Figure A-13
Traditional Malay House
Source: Edward 1990

Figure A-14
Contact Theatre, Manchester University
Source: Smith 2001
Figure A-15
Typical system for a naturally ventilated office
Source: Smith 2001

Figure A-16
Combined function rotary terminal
Source: Smith 2001

Figure A-17
Bioclimatic chart
Source: Olgyay 1963

Figure A-18
Schematic Bioclimatic Index
Source: Olgyay 1963
APPENDIX B

Illustration of two specific building projects discussed in Chapter 4

Figure B-1
Photos of Jurong West public Housing Block 510 (Left: from outside; Right: from corridor)
Source: Bay 2004
Figure B-2
Site Plan of Jurong West Public Housing Block 510
Source: After drawing of Housing & Development Board

Figure B-3
Typical floor plan of Jurong West Public Housing Block 510
Source: After drawing of Housing & Development Board
Figure B-4
Photos of Bedock Court Condominium (Left: north façade; Right: south façade)
Source: Bay 2004

Figure B-5
Master plan of Bedock Court Condominium
Source: Cheng Jian Fenn Architect
Figure B-6
Typical unit plan of Bedock Court Condominium with forecourt
Source: Cheng Jian Fenn Architect

Figure B-7
Section of Bedock Court Condominium with forecourt
Source: Cheng Jian Fenn Architect
Figure B-8
Typical entrance verandas in Bedok Court Condominium
Source: Bay 2004
APPENDIX C

Arrangement of the semi-open entrance spaces of Bedok and Jurong discussed in Chapter 4

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### Appendix C

#### Units with exercise equipment

| 16:00  | 16:15  | 16:30  | 16:45  | 17:00  | 17:15  | 17:30  | 17:45  | 18:00  | 18:15  | 18:30  | 18:45  | 19:00  | 19:15  | 19:30  | 19:45  | 20:00  | 20:15  | 20:30  | 20:45  | 21:00  | 21:15  | 21:30  | 21:45  | 22:00  | 22:15  | 22:30  |
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#### Units with additional construction

| 16:00  | 16:15  | 16:30  | 16:45  | 17:00  | 17:15  | 17:30  | 17:45  | 18:00  | 18:15  | 18:30  | 18:45  | 19:00  | 19:15  | 19:30  | 19:45  | 20:00  | 20:15  | 20:30  | 20:45  | 21:00  | 21:15  | 21:30  | 21:45  | 22:00  | 22:15  | 22:30  |
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#### Units with others (Grass patch, cloth lines, Fridges, swing, Grass patch, laundry rack, storage shelf, adder, pail, box, baby trolley etc.)

| 16:00  | 16:15  | 16:30  | 16:45  | 17:00  | 17:15  | 17:30  | 17:45  | 18:00  | 18:15  | 18:30  | 18:45  | 19:00  | 19:15  | 19:30  | 19:45  | 20:00  | 20:15  | 20:30  | 20:45  | 21:00  | 21:15  | 21:30  | 21:45  | 22:00  | 22:15  | 22:30  |
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APPENDIX D

Illustration of limited space for various activities discussed in Chapter 6

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<tr>
<th>Depth (mm)</th>
<th>No. of Persons</th>
<th>Furniture</th>
<th>Possible Activities</th>
<th>Illustration</th>
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<td>Passing by</td>
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<td>1400</td>
<td>1</td>
<td>1 Sofa</td>
<td>Sitting, Watching, Reading</td>
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<tr>
<td>1850</td>
<td>1</td>
<td>1 Sofa and 1 coffee table</td>
<td>Reading, Eating, Doing some simple work</td>
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Scale: 0 500 1000 1500 2000
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<th>Area</th>
<th>People</th>
<th>Room Description</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
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<td>2</td>
<td>2 sofas and 1 coffee table</td>
<td>Chatting, Reading, Doing some simple work</td>
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<tr>
<td>3100</td>
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<td>3 sofas and 2 coffee tables</td>
<td>Chatting,</td>
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**House work**

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</tr>
<tr>
<td>2750</td>
<td>1</td>
<td>1 chair, 1 table and 1 easel, painting</td>
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<tr>
<td>2150</td>
<td>1</td>
<td>1 toy cabinet, Children's playing</td>
<td>2150</td>
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<td>3050</td>
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<td>1 toy cabinet, 1 table and 2 chairs, Children's playing</td>
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<tr>
<td>Area</td>
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<td>Seating</td>
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<td>Eating, Chatting, Playing cards</td>
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APPENDIX E

Representation of environmental performance of semi-open space by using graphic tool discussed in Chapter 7

![Diagram showing environmental performance at different depths](image-url)