ENVIRONMENTAL ASSESSMENT CRITERIA AND PROTOCOLS FOR RESIDENTIAL DEVELOPMENTS

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2007

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A THESIS SUBMITTED

FOR THE DEGREE OF MASTER OF SCIENCE (BUILDING)

DEPARTMENT OF BUILDING

NATIONAL UNIVERSITY OF SINGAPORE

2007

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude and appreciation to the following persons who have made this study possible by offering their knowledge on the subject, guidance, and encouragement in various ways.

Dr. Lim Guan Tiong and Prof. Lee Siew Eang, my supervisors, for their invaluable guidance and insights throughout the research. Their critical comments and suggestions have been a tremendous source of strength for me to persevere in revising and refining the thesis.

Ms Jessie Tan Sok Kuan and Archt. Choo Chin Hua from HDB, for their valuable contribution in the indoor survey and measurement, and the environmental assessment of the two HDB residential buildings.

Mr Tan Cheow Beng, Mr Komari Bin Tubi, Mr Seow Hock Meng, Mr Zuraimi Bin Mohd Sultan, and Mr Francis Christopher, for their kindly assistance in the indoor measurements.

Du Peng, my husband, and other family members, for their love and unwavering supports and encouragements.

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SUMMARY

Definition and building environmental assessment methods for sustainable development have been well developed over the world especially in developed countries. However, none has specifically dealt on definition and assessment methods for building sustainable development in hot-humid tropics, hence is not relevant and applicable to Singapore's tropical and high density living city context. The aims of this thesis are to identify a set of design, construction and management criteria and to develop a building environmental assessment protocol relevant to Singapore and the tropical context with respect to residential developments.

In order to determine the indoor environmental conditions of local residential buildings, objective measurements as well as a short survey with the residents were carried out in the residential units of two HDB buildings, Building One built in 1971 and Building Two built in 2001. The indoor survey and measurement results indicate that Building Two has more sustainable indoor environment in the aspects of energy efficient appliances, water efficient water cisterns and showerheads, cooker hood usage, sky visibility in living room, cloth drying facilities, and indoor thermal environment.

To examine the sustainability of local residential buildings, the same two buildings have been assessed using LEED-NC. The assessment results show that Building One and Building Two have achieved 20% and 24% of the total number of credits possible in LEED-NC assessment respectively. The assessment results also indicate that there are 22% of LEED-NC criteria not applicable to local residential buildings, and the

remained criteria do need major revision before they can be used to assess local residential buildings.

A survey of local building experts has been conducted to investigate their opinions towards environmental issues of local residential developments. Relevant issues of sustainable development in local residential buildings are identified through literature review of other assessment methods, survey of local residents and building experts' opinions, and case studies of several existing HDB blocks. Weighting scales are established for the identified environmental issues based on local building experts' opinions towards sustainable development. Environmental assessment criteria and protocol for local residential buildings are then developed based on the identified environmental issues and their weights. The new protocol could be used to assess building performance at three levels: unit level, block level and precinct level, and under six categories: sustainable sites, water efficiency, energy use, materials & resources, indoor environmental quality, and innovation & design process.

To evaluate the new developed environmental assessment criteria and protocol, the same two buildings have been assessed using the new protocol as two case studies. The assessment results reflect that Building One and Building Two have achieved Silver Grade and Gold Grade, and fulfilled 56% and 67% of the new protocol's requirements respectively. The evaluation results reveal that the new environmental assessment criteria and protocol could be considered as a satisfactory building environmental assessment method for local residential developments.

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CHAPTER 1 INTRODUCTION

1.1 Research Background

1.1.1 Sustainable development

Rapid economic development worldwide has brought massive impacts on the environment. In the 1960s, people began to face the shortage of natural resources and the destruction of the environment (Chiang *et al.*, 2001). During the 1970s and 1980s, the sustainability idea emerged in a series of meetings and reports (Sustainable Reporting Program, 2004): in 1972, the UN Stockholm Conference on the Human Environment marked the first great international meeting on how human activities were harming the environment and putting humans at risk; the 1980 World Conservation Strategy promoted the idea of environmental protection in the self-interest of the human species; in 1987, the UN-sponsored Brundtland Commission released a report that captured widespread concerns about the environment and poverty in many parts of the world; world attention on sustainability peaked at the 1992 UN Conference on Environment and Development in Rio de Janeiro, and produced two international agreements, two statements of principles and a major action agenda on worldwide sustainable development.

Sustainable development is defined as meeting "the [human] needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on the Environment and Development, 1987). Today sustainable development is widely recognized. It has become the guiding principle of many development agencies and is a primary focus not only within both economic and natural resource debates, but also increasingly in fields such as social development, health and education (Auty and Brown, 1997).

Aside from the ecological emphasis or political priorities of sustainability, a professional contention of sustainable development should include:

- Use of renewable resources in preference to non-renewable
- Use of technologies that are environmentally harmonious, ecologically stable and skill enhancing
- Design of complete systems in order to minimize waste
- Reduction of the consumption of scarce resources by designing long life products that are easily repairable and can be recycled
- Maximizing the use of all the services that are not energy or material intensive but which contribute to the quality of life (Briffett *et al.*, 1998)

1.1.2 Sustainable building and building environmental assessment methods

Growing environment awareness by the professional and the general public has fueled the demand for better understanding of the living environment within buildings, the use of the scarce natural resources to build and to maintain buildings as well as their impact on the earth fragile eco-system.

According to an OECD Project, sustainable buildings can be defined as those buildings that have minimum adverse impacts on the built and natural environment, in terms of the buildings themselves, their immediate surroundings and the broader regional and global setting (Building Energy Efficiency Research, 2000). The OECD project has identified five objectives for sustainable buildings:

- Resource Efficiency
- Energy Efficiency (including Greenhouse Gas Emissions Reduction)
- Pollution Prevention (including Indoor Air Quality and Noise Abatement)
- Harmonisation with Environment (including Environmental Assessment)
- Integrated and Systemic Approaches (including Environmental Management System) (Building Energy Efficiency Research, 2000)

Over the years many tools and methods to measure and evaluate the impact of buildings on environment have been developed around the world. Building environment assessment methods are techniques developed to specially evaluate the performance of a building design or completed building across a broad range of environmental issues. The Building Research Establishment's (BRE) Environmental Assessment Method (BREEAM), one of the pioneer environmental assessment methods developed by BRE of United Kingdom, is one of the international industry standards for the evaluation of building environmental performance of residential, office and commercial buildings. It assesses issues ranging form global atmospheric pollution to local and indoor environment of building and allocates scores to individual issues and arrives at a scoring scheme for buildings. BREEAM thus, provides a tool for evaluating a building's contribution towards the global atmospheric pollution, local built environment and indoor occupant's health and comfort. BREEAM has been updated for several times.

Encouraged by the successful application of BREEAM, many countries such as Canada, USA, and Hong Kong have developed their own building environment assessment methods for office, commercial, residential, school and supermarket buildings, taking into consideration the local climate and regulations. Hong Kong Building Environment Assessment Method (HK-BEAM), developed based on BREEAM by Hong Kong government, provides voluntary, independent and credible recognition for enhanced environmental quality and performance of buildings (HK BEAM Society, 2003). In 1996, Energy and Environment Canada (ECD) introduced BREEAM to Canada. By 1998, Public Works and Government Services requested an adaptation of BREEAM to assess all federally owned buildings. Leadership in Energy and Environmental Design (LEED) Green Building Rating System is a program of the US Green Building Council. It is a voluntary, consensus based market-driven building rating system based on the existing proven technology (Green Building Council, 2005), and evaluates building environmental performance from a whole building perspective over a building's life cycle.

1.1.3 Definition for sustainable development in Singapore is needed

Singapore is a relatively small country where the land space is limited. Today in Singapore, over 50% of the main island is urbanized and it is anticipated that by 2010 this will be 75% (Briffett *et al.*, 1998). Being an island city, Singapore is short of natural resources and has huge demands for raw resources and energy. Despite of many major constraints, Singapore has pride itself as a "garden city". With the increase in population and development density and as buildings being built nearer and nearer to the virgin green land, the sustainability of the garden city and environment has become a major concern of professionals and the general population.

Much of Singapore's protected natural land space is under threat of prospective development in the near future. Another result of further demand for housing is the burdens on raw materials, energy and water resource. Research reveals that in US, buildings consumed 30% of the total raw materials, 42% of total energy use, and 25% of total water use (Levin, *et al.*, 1995). Therefore, to fulfill the demands of increasing population, sustainable development has to be considered in Singapore to better utilize the scarce natural resources without compromising the development in the future.

Issues of sustainable development are currently of primary concern in developed countries especially western countries like the United States, Canada, Germany, United Kingdom, France, and others. Definition and assessment methods for sustainable development in these countries have been well developed. However, none has specifically dealt with definition and assessment methods for sustainable development for buildings capable of widespread application that are suitable for every country in the world. Primarily due to its identical location, climate conditions, building types, and so on, every country has its own scope of sustainable building development and meets its identical problems in sustainable building development, which might be different from other countries. The existing definition and assessment methods for sustainable development are mainly for temperate climate. Therefore they might be not suitable for tropical situation like Singapore, an island city located in hot-humid tropics.

1.1.4 Needs for assessment method of sustainable residential development in Singapore

Research reveals that more than 30% of the criteria included in the BREEAM and other systems are not relevant to Singapore's tropical and high density living city context (Toh, 1997). There are different local and regional environmental issues which should be considered. In addition, there are important features not included in the original version of BREEAM which should be considered for the Singapore's development. This includes the development of a weighting network which will give different parameters different weighting in relation to local priority. In addition, Singapore will need to examine its critical issues, and address a balance between global, local and indoor issues.

There are two environmental assessment methods developed for buildings in Singapore, one is Green Mark developed by the Building and Construction Authority (BCA) of Singapore, and the other is Building Environmental Assessment Methods developed by National University of Singapore (NUS-BEAM). Green Mark was mainly for evaluating an air-conditioned building for its environmental impact and performance when it was launched in 2005, while most residential buildings in Singapore are natural ventilated. Therefore, Green Mark is not suitable for evaluating residential buildings in Singapore. NUS-BEAM was developed based on the criteria of BREEAM/New Houses, version 3/91 which was developed in 1991. However, the definition of sustainable building and its assessment criteria have been changed a lot during the past fifteen years. As a result, the criteria developed in 1991 may no longer meet the requirement of sustainable building development today.

At present, definition and assessment method for sustainable residential development suitable for tropical countries have yet to be fully developed. To better suit for local conditions, definition and assessment method for sustainable residential development in Singapore are needed. Therefore, this study well meets this urgent needs, and is very significant at this moment.

1.2 Research Objectives

This study aims to:

a. Identify and define a set of design, construction and management criteria which are relevant to Singapore and the tropical context with respect to residential developments.
b. From the established criteria sets, and using modeling studies establish weighting scales for residential developments.
c. Develop an environmental assessment protocol for residential developments

1.3 Research Scope

Definition and assessment methods for sustainable development for buildings are not capable of widespread application primarily because of different location, climate conditions, building types, and so on. Every country has its own scope of sustainable development and meets its identical problems in sustainable development.

The focus of the study is therefore on:

- The development of environmental assessment criteria and protocol for hot and humid Singapore
- The development of environmental assessment criteria and protocol for residential buildings with particular reference to Housing and Development Board (HDB) apartments (public housing) because 82% population live in HDB apartments in Singapore (Housing and Development Board, 2006)

1.4 Research Methodology

This research identifies relevant issues of sustainable development in local residential buildings through literature review of other assessment methods, survey of local residents and building experts' opinions, and case studies of several existing HDB blocks. Weighting scales are established for the identified environmental issues based on local building experts' opinions towards sustainable development. Environmental assessment criteria and protocol for local residential buildings are then developed based on the identified environmental issues and their weights.

The assessment method LEED-NC is examined in relation to Singapore's needs of sustainable residential development. Problems and actual situations of sustainable development in existing public housing are investigated through environmental assessment of two existing HDB blocks.

Research methodologies including survey and measurement are adopted in this study. The detailed description of every methodology is given in the following chapters.

1.5 Organization of Study

The reminder of this thesis is organized as follows:

Chapter Two provides a literature review of some environmental assessment methods for residential buildings used in the world. In this part, relevant surveys and studies on HDB housing are also investigated.

Chapter Three explores indoor environment quality in public housing through the surveys and measurements conducted in two existing HDB blocks.

Chapter Four examines the actual environmental sustainability of local public housing through environmental assessment of two existing HDB blocks. The applicability of LEED-NC in assessing local residential buildings is also studied in this part.

Chapter Five presents local building experts' opinions towards sustainable development in residential buildings in Singapore.

Chapter Six describes the development of the new environmental assessment criteria and protocol for residential buildings in local context.

Chapter Seven assesses the environmental sustainability of the two HDB blocks using the new developed environmental assessment criteria and protocol. The new assessment protocol is also evaluated in this part.

Chapter Eight concludes the main research findings, and offers some comments.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter outlines building environmental assessment methods for sustainable development, with the focus on assessment methods for residential buildings. Relevant surveys and studies on HDB housing are also summarized.

2.2 Building Environmental Assessment Methods

2.2.1 Definition and characteristics of building environmental assessment methods

According to Cole (1998), environmental assessment methods are defined as those techniques developed to specifically evaluate the performance of a building design or completed building across a broad range of environmental considerations. An environmental assessment of a building can provide identification of success at meeting a level of performance, as well as serve as guidance for remedial work and feedback to design (Cole, 1998).

The characteristics that an ideal building environmental assessment method should possess are as follows (Cole, 2001):

- Simple and practical
- Transparent and credible
- Inexpensive
- Challenging
- Covers essential environmental and resource issues
- Versatile

- Offers multiple methods to report results
- Globally applicable yet regionally specific
- Capable of evolving
- Encourages innovation
- Useful as design tool
- Educational

2.2.2 Existing building environmental assessment methods

Since early 1990s, building environmental assessment methods have been well developed in developed countries like the United States, Canada, United Kingdom, and others. Because of the wide range of "green" attributes considered, no single scientific denominator exists. The main range of definitions of what constitutes a green or sustainable building includes:

- **BREEAM**

The Building Research Establishment Environmental Assessment Method (BREEAM) was launched in 1990 by the Building Research Establishment (BRE). It is one of the pioneer environmental assessment methods. Early version of BREEAM included version 2/91 (for new superstores and supermarkets), version 3/91 (for new homes), version 1/93 (for new office buildings), version 4/93 (for existing office buildings), and BREEAM new industrial units (for new industrial warehousing and non food retail units). BREEAM has been updated for several times. The latest BREEAM considers a range of building types: offices (BREEAM Offices 2004), homes (known as EcoHomes), industrial units, and retail units.

- **BEPAC**

The Building Environment Performance Assessment Criteria (BEPAC) was developed in British Columbia, Canada in 1993 (Cole, *et al.*, 1993). It provides a more detail and comprehensive assessment than BREEAM. However, this system was never fully implemented due to its complexity.

- **HK-BEAM**

The Hong Kong Building Environmental Assessment Method (HK-BEAM) is introduced in 1996. The early version of HK-BEAM included version 1/96 (for new office buildings) and 2/96 (for existing office buildings). In 1999, HK-BEAM (Residential) version 3/99 was added. Recently, HK-BEAM has been updated. The latest pilot version includes pilot version 4/03 (for new building developments) and pilot version 5/03 (for existing building developments).

- **LEED**

The US Green Building Council began development of the Leadership in Energy and Environmental Design (LEED) Green Building Rating System in 1994. Version 2.0 of the LEED standard was formally released in May 2000; Version 2.1 was released in November 2002. The latest LEED considers a range of building types: New construction and major renovation projects (LEED-NC), Existing building operations (LEED-EB, Pilot version), Commercial interiors projects (LEED-CI, Pilot version), Core and shell projects (LEED-CS, Pilot version), and Homes (LEED-H).

- **GBC**

Green Building Challenge (GBC) is an international collaborative effort to develop a building environmental assessment tool that exposes and addresses controversial aspects of building performance and from which the participating countries can selectively draw ideas to either incorporate into or modify their own tools (Green Building Challenge, 2002). GBC is a two-year process of international building performance assessment project. The first major conference GBC'98 was held in Vancouver, Canada in 1998. The following GBC 2000 and GBC 2002 were held in Maastricht, Netherlands in 2000, and Oslo, Norway in 2002 respectively.

- **Green Star**

The Green Building Council of Australia launched Green Star in 2003. The existing Green Star Rating Tools only provide environmental assessment for office building (Green Star - Office Design v2 and v3, Green Star - Office As Built v2 and v3, and Green Star - Office Interiors v1.1). However, the latest Green Star PILOT Rating Tools consider education buildings, Healthcare buildings, shopping centers and multi unit residential buildings (Green Building Council of Australia, 2008).

- **CASBEE**

The Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) was introduced by Japan Sustainable Building Consortium (JSBC) in 2002, and is continuously developed and updated. The CASBEE system includes CASBEE-NC (for new construction), EB (for existing building), RN (for building Renovation), HI (for Heat Island) and UD (for Urban Development) (Japan Sustainable Building Consortium, 2008).

2.2.3 Limitation of existing building environmental assessment methods

Cole (1998) argues that although the BREEAN, BEPAC, LEED and other existing assessment methods have made significant contributions to the understanding of building-related environmental issues and with varying degrees of success, several limitations are already evident in these first generation methods. These include (Cole, 1998):

- Ability to offer different levels of assessment/output
- Ability to acknowledge regionally specific environmental criteria
- Use of different measurement scales for different criteria sets
- Weighting of criteria
- Ability to be used as design tools
- Ability to link with other performance issues
- Ability to evolve as field matures
- Remaining voluntary in their application

2.3 Environmental Assessment Methods for Residential Buildings

2.3.1 Existing environmental assessment methods for residential buildings

Definition and assessment methods for sustainable buildings have different considerations for different building types. Environmental assessment methods for residential buildings have been well developed since 1993. Main environmental assessment methods for residential buildings include:

- **EcoHomes**

EcoHomes – the Environmental Rating for Homes is one assessment method of UK's BREEAM. It covers all standard housing developments including private and social housing schemes, flat/apartments and houses, new build and major refurbishment (Building Research Establishment, 2005).

- **HK-BEAM**

Unlike other environmental assessment methods, latest HK-BEAM versions are not classified by building types. It embraces a wide range of building developments including commercial, hotel, residential, and educational buildings. The overall assessment grade is based on the percentage of applicable credits gained (HK BEAM Society, 2003).

- **LEED-NC**

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System provides assessments for new commercial construction, major renovations and high-rise residential buildings (Green Building Council, 2005).

- **China Ecological Housing Technology Assessment Handbook**

The China Ecological Housing Technology Assessment Handbook was introduced in 2001. It has been revised twice, and the latest version was launched in 2003 (Cao and Fei, 2001).

- **NUS-BEAM**

The NUS-BEAM was established in 2001 and provides assessment for HDB buildings. It was developed based on BREEAM/new homes version 3/91 and survey of HDB apartment residents and local building experts in Singapore (Lee, 2001).

2.3.2 Scope of environmental issues

There are three different methods to classify sustainable issues considered in these environmental assessment methods for residential buildings. **Classification I** categorizes issues into three groups: global issues and use of resources, local issues, and indoor issues. NUS-BEAM adopts this classification. **Classification II** classifies issues into five groups: sustainable sites, water efficiency, energy & atmosphere, material & resources, and indoor environmental quality. The assessment methods that adopt Classification II include LEED, HK-BEAM and the Chinese Assessment Handbook. **Classification III** categorized issues into seven groups: Energy, health and well being, transport, water, materials, land use and ecology, and pollution. This classification is adopted by EcoHomes.

Despite the different classification methods adopted, sustainable issues assessed in the five environmental assessment methods for residential buildings can be categorized into six groups: sustainable sites, water efficiency, energy & atmosphere, material & resources, indoor environmental quality /health and well being, and innovation & design process. The comparison of the scope of assessed environmental issues among the five environmental assessment methods for residential buildings is shown in Table 2.1.

2.3.3 Score system

Assessment implies measuring how well or poorly a building is performing, or is likely to performing, against a set of criteria. Environmental assessment methods accommodate both quantifiable performance criteria (such as annual energy use, water use or green-house gas emissions) and more qualitative criteria (such as the ecological significance of the site).

There are three important characteristics of the assessment scale (Cole, 1998): The first is a base or reference condition. A common baseline for assessment is a typical or average performance and such recognition is given for better than industry norm performance; the second is a best condition. All performance criteria on an assessment procedure embody the notion of an ideal or best possible performance; the third is scaling increments. Most assessment methods assume a simple linear points allocation between the base and best performance benchmarks. For example, LEED-NC, 1 credit is given for 15% reduction design energy cost, 2 points for 20% reduction, 3 points for 25% reduction, etc. By contrast, some performance criteria in BEPAC have points awards increasing as the effort to achieve them increases (Cole, 1998), for example, 5 points for achieving 100-120% of the ventilation standard, 7 points for 120-150% and 10 point for exceeding by 150%.

Table 2. 1 A comparison of the scope of assessed environmental issues among the five environmental assessment methods for residential buildings

Assessed environmental issues	UK	HK	US	NUS	CHN
Sustainable site					
Erosion & sedimentation control			√		
Site selection			√		√
Development density			√		√
Ecological enhancement	√	√	√	√	√
Urban redevelopment		√			√
Public transportation access	√	√	√	√	√
Bicycle storage & changing rooms	√		√	√	
Alternative fuel vehicles			√		
Parking capacity		√	√	√	
Local amenities	√				
Provision of home office	√				
Reduced site disturbance	√		√		√
Stormwater management			√		
Heat island effect		√	√		√
Light pollution reduction		√	√		
Overshadowing		√			√
Vehicular access		√			
Construction management		√			
Pollution during construction		√			
Emissions from wet cooling towers		√			
Noise reduction		√			√
Building users handbook		√			
Air quality					√
Water efficiency					
Water efficient landscaping	√	√	√		√
Innovative wastewater technologies			√	√	√
Water use reduction	√		√		√
Water quality		√			√
Water efficient devices		√		√	√
Metering and controls		√			
Water recycling	√	√		√	√
Reduction in sewage volumes	√	√			√
Energy & atmosphere					
Building systems commissioning		√	√		
Energy performance	√	√	√	√	√
Building envelope performance	√				
CFC reduction in HVAC&R equipment			√		
Renewable energy	√	√	√		√
Ozone depletion	√	√	√	√	√
NO_x emissions	√				
Green power			√		
Maximum electricity demand		√			
Energy efficient ventilation system		√			√
Energy efficient lighting system	√	√			√

Assessed environmental issues	UK	HK	US	NUS	CHN
Natural ventilation analysis		√			
Energy efficient lift and escalator, electrical installation and appliances		√			
Energy efficient hot water supply		√			√
Energy efficient clothes drying facilities/space	√	√			
Embody energy		√			
Metering and monitoring		√	√		
Operation and maintenance		√			
Eco labeled white goods	√				
Materials & resources					
Storage & collection of recyclables	√	√	√	√	√
Building reuse		√	√		√
Construction waste management		√	√		√
Resource reuse			√	√	√
Recycled content	√	√	√	√	√
Local/regional materials			√		√
Rapidly renewable materials		√	√		
Certified wood	√		√		
Adaptability and deconstruction		√			
Envelope durability		√			
Modular and standardized design		√		√	
Off-site fabrication		√		√	
Green building materials	√	√			√
Indoor environmental quality/ Health & wellbeing					
Minimum IAQ performance		√	√		
Environmental tobacco smoke (ETS) control			√		
Carbon dioxide (CO_2) monitoring			√		
Ventilation effectiveness		√	√	√	√
Construction IAQ management plan		√	√		√
Low-emitting materials		√	√		√
Indoor chemical & pollutant source control		√	√		√
Controllability of systems			√		
Thermal comfort		√	√		√
Permanent monitoring system (thermal comfort)			√		
Daylight & views	√	√	√	√	√
Outdoor sources of air pollution		√			
Interior lighting design		√			√
Room acoustics and noise control	√	√		√	√
Provision of private space	√				
Installation of cooker hood				√	
Innovation & design process					
Innovation in design/techniques		√	√		
Accredited professional			√		
Performance enhancement		√			

Notes: "UK" means Eco-Homes; "HK" means HK-BEAM 4/03; "US" means LEED-NC; "NUS" means NUS-BEAM; and "CHN" means the China Ecological Housing Technology Assessment Handbook.

The total points of the five assessment methods vary from 69 to 500 (see Table 2.2). All the five assessment methods have assessed criteria for the fist five sustainable groups, but the points' allocations are quite different. Only HK-BEAM and LEED-NC award points for innovation and design process.

Table 2. 2 Score systems of environmental assessment methods for residential buildings

Assessed issues	UK	HK	US	NUS	CHN
Sustainable site	17	23	14	12	100
Water efficiency	6	10	5	17	100
Energy & atmosphere	27	49	17	10	100
Materials & resources	31	22	13	25	100
Indoor environmental quality/ Health & wellbeing	8	34	15	36	100
Innovation & design process	---	5	5	---	---
Total points	89	143	69	100	500

Notes: "UK" means Eco-Homes; "HK" means HK-BEAM 4/03; "US" means LEED-NC; "NUS" means NUS-BEAM; and "CHN" means the China Ecological Housing Technology Assessment Handbook.

2.3.4 Rating system

The approach to the rating system of these existing assessment methods is to award credits for incorporating features, which are better than normal practice. The methods identify and credit designs where specific targets are met. At the end of the assessment, all the credits achieved are added up to get a total score.

The environmental labeling currently used typically classifies the performance into four descriptive categories: pass, good, very good, and excellent, although the name may be different such as certified, silver, gold and platinum. The analyses reflect that although the total points and points' allocations are quite different, the percentages of total points for achieving the four environmental labeling are quite similar. Table 2.3 reveals that to be labeled as "pass" buildings need to achieve 40% of total points, to be labeled as "good" buildings need to achieve 48-55% of total points, to be labeled as "very good" buildings need to achieve 57-67% of total points, and to be labeled as "excellent" buildings need to achieve 75-79% of total points.

Table 2. 3 Labeling systems of environmental assessment methods for residential buildings

Environmental Labeling	EcoHomes		LEED-NC		HKBEAM 4/03
	Score	%	Score	%	%
Certified / Pass / Bronze	36	40%	26	38%	40%
Silver / Good	48	54%	33	48%	55%
Gold / Very Good	60	67%	39	57%	65%
Platinum / Excellent	70	79%	52	75%	75%

2.3.5 Weighting

Weighting is the difference in importance between variables, reflects consensus best judgment rather than scientific determination. Current systems use very different methods of weighting. BREEAM uses explicitly derived weightings based on average values held by various segments of British society as determined by survey (Cole, 1998). LEED has weightings implicit in the distribution of credits awarded for performance in any given area. These weights were arrived at through consensus of the members of the US Green Building Council who developed the system (Cole, 1998). NUS-BEAM's weighting were generated for each environmental attribute based on the local building experts' opinion survey results.

Comparison of the weighting of assessment methods is shown in Table 2.4. It is observed that the weighting of the five assessment methods are totally different. The analysis shows that the Chinese assessment handbook has equal weighting for the five sustainable issue groups. EcoHomes' consideration of health and wellbeing issue is quite weak compared to other assessment methods, only 9%. NUS-BEAM's consideration of water efficiency is 17%, much more than EcoHomes, HK-BEAM and LEED-NC, this is reasonable because water is very important issue in Singapore.

However NUS-BEAM's consideration of energy & atmosphere is the weakest among the five, only 10%.

Table 2. 4 Weighting of environmental assessment methods for residential buildings

Assessed issues	UK	HK	US	NUS	CHN
Sustainable site	19%	16%	20%	12%	20%
Water efficiency	7%	7%	7%	17%	20%
Energy & atmosphere	30%	34%	25%	10%	20%
Materials & resources	35%	15%	19%	25%	20%
Indoor environmental quality/ Health & wellbeing	9%	24%	22%	36%	20%
Innovation & design process	---	3%	7%	---	---

Notes: "UK" means Eco-Homes; "HK" means HK-BEAM 4/03; "US" means LEED-NC; "NUS" means NUS-BEAM; and "CHN" means the China Ecological Housing Technology Assessment Handbook.

2.4 Surveys and Studies on HDB Housing

There are some researches relevant to sustainable development of HDB housing. Associate professor Wong Nyuk Hien and his research teams in Department of Building (DOB), National University of Singapore (NUS) have explored the passive cooling of HDB housing mainly involved in thermal comfort and natural ventilation. Associate professor Lee Siew Eang and his research teams in DOB, NUS have investigated a variety of environmental issues with respect to HDB housing, including thermal comfort, natural ventilation, day lighting, energy and water consumptions, and so on. Their researches provide the theoretical base to set up the benchmark of the credit requirements of the new protocol. Main findings of these researches are summarized in Table 2.5.

2.5 Conclusion

Building environmental assessment methods for sustainable development including assessment methods for residential buildings have been well developed since early

1990s. Review of these assessment methods mainly touched on their range of environmental issues, score systems, rating systems, and weighting scales.

Several researches have been carried out regarding a variety of environmental issues of HDB housing. The findings of these researches are used to identify relevant parameters and to adjust the identified criteria of the new environmental assessment method for local residential buildings.

Table 2. 5 A summary of researches on environmental issues of HDB housing

	Researcher	Sample size	Research findings
Thermal comfort	Wong *et al.* (2002a)	257 subjects & 4 estates	• Thermal acceptability: (ASHRAE scale/TS, Bedford scale/TC) • Morning > evening > afternoon; 3R > Exec > 4R • Top(above 10) > low(1-5) > middle(6-9) floor levels • Preference on adaptive actions: fan > open window >AC > drink • Non-thermal factors may affect decision of adaptive actions
	Feriadi (2004)	255(sub) 128 units & 283(sub) 147 units	• Neutral temperature: 28.6°C(OT) 29.3°C(ET*) • Preferred temperature: 25.68°C(OT) • Acceptable temperature: 26.4─31.3°C(OT) 26.8─32.7°C(ET*) • (ASHRAE & Bedford scale are used in questionnaire)
	Wong (2004)	12 units (1 3R block, L4,7,14; 1 5R block, L4, 10, 14)	• HDB buildings' façade materials have a good thermal protection except the aluminum panel. Light color contributes to lower surface temperature of façade and maintains a better indoor thermal environment. • Measured mean hourly indoor temperature: 27.1-29.6°C(3R) & 26.6-28.5°C(5R), mean RH: 60-70%(3R) & 65-75% (5R). • A guidance on the acceptable U-value of external walls and shading devices for the naturally ventilation building façade in Singapore. Acceptable roof U-value: 1.5W/m^{2}K (NV HDB buildings)
	De Dear *et al*. (1991)	583 (sub) 214 units	• Measured result (daytime & early evening): • Mean operative temperature: 29.6°C, mean RH: 74%. • Mean thermal comfort half way between 'just right' & 'slightly warm'(questionnaire by marking standard 7 point scale) • Thermal neutrality (comfort) at 28.5°C (OT)
	Lee (2001)	1000 units (living room)	• Measured mean dry bulb temperature: 30.13 ─ 30.75°C • Measured mean Relative Humidity: 72.10% ─ 77.14% • Residents ranked 3R thermal comfort level: 'fair', 4R, 5R & Exec thermal comfort level: 'comfortable' (on 1-5 scale)

	Researcher	Sample size	Research findings
Air velocity	De Dear *et al.* (1991)	214 units	• Measured result (daytime & early evening): • Mean air velocity: 0.22 m/s
	Lee (2001)	1000 units (living room)	• Measured mean air velocity: 0.26 ─ 0.46 m/s & 5R > 3R > 4R > Exec • Sliding full wall height >sliding half wall height >louvered>casement • The most popular mechanical ventilation equipment are fans
	Wong *et al.* (2002b)	3 units (every room inside)	• Ventilation: 3R>4R>Exec in both situations when the internal doors are opened (Cv: 1.05>0.77>0.73) and closed (Cv: 0.95>0.59>0.38). (Cv: ratio of the mean airspeed)
	Wong (2002)	3 HDB car parks	• ICP (Integrated Car Parks) has an overall better natural ventilation performance compared to MSCP (Multi-storey Car Parks) and SCP (Surface Car Parks)
	Priya-darsini *et al.* (2004)	1 units	• A 0.4m x 0.4m active stack can increase in the velocity up to 550% and the maximum velocity achieved was 0.67 m/s. A velocity of 0.26 m/s was achieved even with the smallest stack (0.15m x 0.15m).
IAQ	Wong and Huang (2004)	3 units	• CO_2 level: AC (700-1600 ppm) > NV (550-750 ppm) (R*: 1000ppm) • Particulate level: AC < NV (both under the threshold level) • Bacteria and fungi level: AC > NV (both under the threshold level)
		163 subjects	• Sick building syndrome symptoms: AV > NV
	Lee (2001)	1000 units	• Freshness, cleanness and odor of indoor air are ranked by residents as ‘acceptable’, ‘moderate’ and ‘most acceptable’ respectively. (on 1-7 scale)
Noise	Lee and Ho (1996)	1080 units (near roads (R)), 541 units (near MRT lines (MRT))	• Vote for ‘Noisy’ & ‘very noisy’: R:47.6% & MRT: 34.6% • Indoor Measured Noise Levels (dBA): Mean: 62.9(R) & 67.5(MRT); Median: 63.8(R) & 67.1(MRT) • Acceptable Indoor Noise Levels: 54dBA (80%) for traffic noise & MRT: 65dBA(70%) for train noise

	Researcher	Sample size	Research findings
Noise	Lee (2001)	997 units (living room)	• 3R & 5R indoor noise level: 'moderate', 4R & Exec: 'noisy'. • Traffic, MRT, children playing: 'less' or 'least' disturbing (opinion) • Measured mean noise level: 57.15 ─ 61.91 dB • No relationship between noise ranking & field measured data.
Indoor day lighting	Lee (2001)	1000 units (living room)	• Measured mean daylight level for 10:00am-12:00pm, 12:00pm-14:00pm, 14:00pm-16:00pm & 16:00pm-18:00pm are 72, 157, 139& 119 lux respectively (CIBSE R* 100-200 Lux for living room) • Residents rank all apartment types as 'most acceptable' (on 1-7scale)
	Ullah and Liaw (2003)	HDB blocks in 4 areas: Bishan, Clementi, Pasir Ris, and Jurong West	• Simulated room mid-point illuminance values: • Bishan (have side window) > Clementi > Pasir Ris > Jurong West • Older buildings are spaced more apart, daylight penetrates deeper into rooms and is able to reach the lower floors. The Jurong West estate (the newest and tallest) tends to have generally the lowest illuminances of the four. The highest diffuse sky illuminance is in Clementi (19407 lux), the absolute lowest is in Pasir Ris (139 lux). (simulated by Lightscape under cloudy, CIE clear, and partly cloudy sky conditions)
	Ullah (2001)	360 units (20 blocks)	• Window transmittance: 0<65%<0.3, 0.4<24.5%<0.6, 0.7<10.3%<0.9 • People feel the indoor environment: bright 71%, dull 20%, glare 9% • 50% use clear glasses, 50% use dark glasses
	Wittkopf (2003)	Atrium block, slab block & point block. 36 units	• Point block has better Daylight Factor (DF) (around 1%) than other two block types. External corridors can be attributed to cause DF of below 0.5% in adjacent interior spaces. DF<1% may result in a high demand of electrical lighting. Kitchens seldom have DF>0.2%. A less tinted glass improves the DF significantly with only a moderate increase of daylight glare. DF may reach a satisfactory value (1%) even though the Vertical Sky Component (VSC) is far below a satisfactory value (27%)

	Researcher	Sample size	Research findings
Electricity consumption	Lee (2001)	944 units	• Mean electricity consumption of 3R, 4R, 5R & Exec are 102, 77, 73, & 63 kwh/m^2/year respectively. • Range of electricity consumption is 10(Exec) ─ 304(4R) kwh/m^2/year
Water consumption		958 units	• Mean water consumption of 3R, 4R, 5R & Exec are 156, 138, 150, & 164 liter/capita/day respectively. • Range of water consumption is 27(5R) ─ 896(5R) liter/capita/day • 10% of the residents consume water over 200 liter/capita/day
Cooker hood	Lee (2001)	1000 units	• 59% of HDB apartments utilize cooker hoods in their kitchens • Usage of cooker hoods in 3R, 4R, 5R & Exec are 43%, 53%, 67% & 71% respectively.
Waste			• Residents almost don't have any waste disposal problem. • Residents are not provided any waste recycling facilities.

Notes: "AC" means air-conditioned room; "NV" means naturally ventilation room; "R*" means recommended value.

CHAPTER 3 INDOOR SURVEY AND MEASUREMENT

3.1 Introduction

Indoor environment quality, energy efficiency and water efficiency of residential units are three of the main categories of building environmental assessment methods such as LEED, as well as three of the primary requirements of environmental sustainable residential developments. In order to determine the indoor environmental conditions of HDB housing, objective measurements as well as a short survey with the residents were carried out in the residential units of two HDB buildings, Building One and Building Two (the addresses of the two buildings are excluded for privacy reason).

3.2 Description of the Two Buildings

Building One was built in 1971. It is a 16-storey slab building including residential apartments and some commercial space. The residential part comprises of 224 3-Room Units located from 3 to 16 storey. The commercial space consists of 2 food courts and a few small shops located at the ground floor and level 2. Building One has an estimated gross floor area of 20,100 m^2. This building is located within 100m of Mass Rapid Transportation (MRT) station, and faces a major city roadway (see Figure 3.1 and Figure 3.2).

Building Two, was built in 2001. It is a 16-storey residential building comprises of 90 4-Room Units located from 2 to 16 storey. Building Two has an estimated gross floor area of 13,100 m^2. This building is located at the edge of a HDB housing precinct and adjacent to the expressway (see Figure 3.3 and Figure 3.4).

Figure 3. 1 Front elevation of Building One

Figure 3. 2 MRT station and city roadway near Building One

Figure 3. 3 Elevation of Building Two

Figure 3. 4 Expressway near Building Two

3.3 Objectives of Indoor Survey and Measurement

The objectives of the indoor survey and measurement are to:

- Investigate and compare the sustainability of the indoor environment within the two public housing buildings
- Explore the residents' perception towards current indoor environmental quality of their units
- Examine the improvement of indoor environment of public housing design in Singapore by comparing the measured results of the two buildings

3.4 Parameters Measured in the Site Measurement

According to the credit requirements of relevant indoor environmental quality criteria gathered from environmental assessment methods for residential buildings including LEED, EcoHomes, and HK-BEAM, following parameters were measured in the site measurement. Indoor air temperature, relative humidity, air velocity, radiant temperature, and noise level were measured to investigate the indoor thermal and acoustic environment. The water flow rate of faucets and showerheads as well as the capacity of water cisterns were also measured to ascertain how water efficient the fixtures are. Besides, readings from the electricity and water meters of all the units in the two blocks were recorded so as to determine the amount of electricity and water each household consumed approximately (see Figure 3.5). Other indoor environmental conditions such as cooker hood, sky visibility in living room, cloth drying facility, and energy efficient appliances were also explored during the indoor survey and measurement.

Figure 3. 5 Electricity meter and water meters outside residential units

3.5 Methodology

3.5.1 Selection of measured units

3.5.1.1 Sampling method

As the process of carrying out the relevant measurements requires entry into the residents' apartments, the survey team had to request for permission from the residents to take the readings at their convenience. The survey team went on a door to door basis to visit all the households to try to gain permission to conduct the on-site measurements in the apartments.

In this case, random sampling was deployed because the household that gets selected depends on the owner. It was proposed initially that the sampling method adopted should be stratified sampling according to the floor level and the orientation the household is located. However, this was not possible because of practical difficulties encountered in the actual process due to the residents' reluctance which was understandable because of security and privacy reasons.

3.5.1.2 Sample size

- **Building One**

Survey and measurements were conducted in 15 occupied units of Building One. The sample size is about 6.7% of the total household population in the block. The distribution of the measured units in Building One is illustrated in Figure 3.6.

- **Building Two**

Survey and measurements were conducted in 9 occupied units of Building Two. The sample size is about 10% of the total residential units in the block. The distribution of the measured units in Building Two is illustrated in Figure 3.7.

3.5.2 Objective measurement

- **Equipment used in the measurement**

Storey 16			16-294										16-276					
Storey 15												15-278						
Storey 14	14-298								14-284									
Storey 13																	13-270	
Storey 12																		
Storey 11		11-296													11-274			
Storey 10		10-296							10-284									
Storey 9					Lift Lobby									Lift Lobby				
Storey 8																		
Storey 7																		
Storey 6	06-298																	
Storey 5									05-284						05-274			
Storey 4											04-280							
Storey 3								03-286										
Storey 2																		
Storey 1	298	296	294	292		290	288	286	284	282	280	278	276		274	272	270	268

(Shaded green) Units where indoor survey and measurement were conducted

Figure 3. 6 Units where indoor survey and measurement were conducted in Building One

Storey 16					16-81	
Storey 15						
Storey 14						
Storey 13						
Storey 12				12-79	12-81	
Storey 11					11-81	
Storey 10		10-75				
Storey 9						
Storey 8						
Storey 7						
Storey 6						
Storey 5		05-75				
Storey 4				04-79		04-83
Storey 3					03-81	
Storey 2						
Storey 1	73	75	77	79	81	83

Units where indoor survey and measurement were conducted

Figure 3. 7 Units where indoor survey and measurement were conducted in Building Two

Table 3.1 shows the equipments used in the measurement of occupied units. The indoor measurement plan is explained in Table 3.2. Indoor air temperature, relative humidity, air velocity, radiant temperature, and noise level were measured in living room, all bedrooms, and kitchen.

- **Measurement time periods**

The objective measurements were conducted in all occupied units over a period of 2 weeks. The owners could decide the dates and times that were convenient for them in this period. Indoor air temperature, relative humidity, air velocity, radiant temperature, and noise level were measured three times a day from 10am to 7pm for one to three days according to the owners' willingness.

3.5.3 Data processing

Survey data were gathered through personal interviews with the owners, creating an opportunity for the survey team to ensure that the owners fully understand the questions. Microsoft Excel software program was used for the analysis of data. The descriptive statistics, such as cross tables and charts were employed to analyze the survey and measurement data.

Table 3. 1 Equipments used in spot measurement in occupied units

Name	Picture	Parameter measured
Vaisala humidity & temperature meter		Air temperature, relative humidity
Globe thermometer		Radiant temperature
Anemomaster		Air velocity
Sound level meter		Noise level

Table 3. 2 Indoor measurement plan of two HDB blocks

Measured parameter	Measuring method	Measuring time	Requirement & notes
• Energy consumption • Water consumption	Electricity and water meters' reading of all units were taken in two weeks' period	Twice	The first and second readings were taken two weeks apart from one another and then pro-rated accordingly.
• Water flow rate of faucet • Water flow rate of shower head	Use measuring cup and stopwatch to measure the amount of water flow from the faucet and shower head in 10 seconds	Once	
Capacity of WC	Use ruler to measure the size of WC's water tank, thus to calculate its capacity	Once	
Number of residents lived in the unit	Residents will be asked how many people lived in their units		This will be used to calculate the water consumption per capita of the units.
• Air temperature • Relative humidity • Air velocity • Radiant temperature	Spot measurement will be carried out at 0.6m above the floor level in the center of every room except storage and toilet	One to three times a day for occupied units	The measured rooms need to be natural ventilated, no air-con and fan is used during measurement
Noise level (caused by noise sources outside the unit)	Spot measurement will be carried out in the center of every room except storage and toilet	One to three times a day for occupied units	The residents need to be quiet, and those things that will affect the measured result (e.g. TV, radio) need to be turned off during the 1 minute measurement
Cooker hood with extract fan ducted to the outdoor air	Check the cooker hood in the kitchen (or a passive stack ventilation / mechanical ventilation system extract point and hood above the cooker)		
Sky visibility	Check if the sky can be seen from the center point of the living room		

Measured parameter	Measuring method	Measuring time	Requirement & notes
Cloth drying facilities	Check the type of cloth drying facilities		use natural environment to dry cloth
Energy efficiency hot water supply equipment and devices	Check if any energy efficiency hot water supply equipment and devices is installed in the units		e.g. hot water is supplied by gas
Energy efficient appliances	• Check if any energy efficient appliances is provided or purchased in the units. • Take the model number, brand, and purchasing year of refrigerators and air-conditioners in the units		e.g. refrigerators and air-conditioners have been labeled under the Singapore's Energy Efficiency Labeling scheme)

3.6 Indoor Survey and Measurement Results

3.6.1 Building One

- **Electricity consumption**

Among the 224 residential units in the block excluding the first two levels, 104 units used air-conditioners in the house, which means the air-conditioner usage rate is 46.4%. The measured results reflect that the average electricity consumption of the whole block (residential part) is about 51.3 kWh/m^2/year (see Table 3.3).

Table 3. 3 Electricity consumption of Building One

	Electricity Consumption of the sampled households (kWh/m^2/year)	Electricity Consumption of the whole block (kWh/m^2/year)
Mean	55.1	51.3
Minimum	21.1	9.9
Maximum	115.9	164.7

- **Water consumption**

Table 3.4 shows that the average water consumption of the sampled households is 151.74 l/capita/day. On the other hand, the average water consumption of the whole block (residential part) is about 400 l/household/day.

Table 3. 4 Water consumption of Building One

	Water Consumption of the sampled households (l/capita/day)	Water Consumption of the whole block (l/household/day)
Mean	151.74	400.25
Minimum	41.29	1.77
Maximum	285.70	1405.47

- **Water flow rate of faucets and shower heads**

The water flow rates of faucets and showerheads were measured to find out whether the residents are adopting water efficient fixtures. The measured average flow rate of bathroom showerhead, wash basin and kitchen sink was 0.11 l/s, 0.32 l/s and 0.31 l/s (see able 3.5) whereas the government recommended flow rate for best water conservation practice was 0.12 l/s, 0.10 l/s and 0.10 l/s respectively (Public Utilities Board, 2005). It is observed that the average water flow rate of showerheads has met the recommended flow rate but the average water flow rates of wash basin and kitchen sink have exceeded the recommended flow rates. However, the maximum water flow rate measured for all the fixtures have greatly exceeded the recommended flow rate which indicates that there are some households still using water inefficient fixtures. On the other hand, there are also households using very efficient water fixtures as the minimum flow rate measured for the fixtures are much lower than the recommended flow rate.

Table 3. 5 Water flow rate of faucets and showerheads in Building One

Water Flow rate	Kitchen Sink (l/s)	Wash Basin(l/s)	Bathroom showerhead(l/s)
Min	0.09	0.06	0.05
Average	0.31	0.32	0.11
Max	0.78	0.90	0.31

- **Capacity and type of water cisterns**

The measured result shows that the average capacity of the water cisterns in the sampled households is 12 liter, which exceeds that of the capacity of low flushing cisterns (4.5 liter per flush). This is because Building One was built before 1992 when the new legislation of installing low capacity water cisterns in new public housing apartments had not been implemented yet. There are 3 units using dual flush water cisterns, which is 20% of the 15 sampled units.

- **Cooker hood**

It is desirable to install cooker hood with the extract fan ducted to the outdoor air (or a passive stack ventilation/mechanical ventilation system extract point and hood above the cooker) rather than elsewhere in the kitchen. This is so because the smoke from the cooking will be directed out of the apartment and in the process be diluted instead of polluting the kitchen.

However, it is observed that only 20% of sampled units have cooker hoods and all of them do not extract cooking smoke to the outdoor air. The remaining 80% has not installed cooker hood.

- **Sky visibility of living room**

Apartments that are located in such a way that the sky can be seen from the center point of the living room tend to let in more daylight. In this sense, the use of artificial lighting during the daytime might be reduced if the lighting requirements in the apartment can be fulfilled by daylight.

The survey results show that 7 units (46.7% of the sampled units) have access to sky visibility, which are located from 10^{th} storey to 14^{th} storey. The units on the lower levels tend to have their view blocked by the MRT station. On the other hand, those units on the higher floors and around the corner of the block tend to have their views obstructed by the flats in the opposite direction.

- **Cloth drying facilities**

To save energy, cloth drying facilities which utilize the natural environment are encouraged to be provided for majority of residential units. It is observed that all units have a row of bamboo slots on the external wall of the kitchen for residents to place bamboo poles and dry cloth (see Figure 3.8).

Figure 3. 8 Cloth drying facilities on the external wall of kitchen of Building One

- **Energy efficient appliances**

The use of energy efficient appliances at home constitutes part of the energy conservation measures that should be encouraged to be adopted. Among the sampled 15 units, 7 units have installed air-conditioners, and 10 units have refrigerators. However, only 1 air-conditioner (14.3%) was labeled under Singapore Energy Labeling scheme.

- **Indoor thermal environment**

Air temperature

Figure 3.9 shows the average temperature recorded across different times of the day for the 15 households at different locations in the apartments. The outdoor temperature is the average temperature recorded across the period of time when the measurements were conducted. The highest average temperature was recorded in the afternoon at 30.5ºC in the living room. As observed, the living room has the highest air temperature in comparison to the other locations at all times of the day. Bedroom 2 (common bedroom) was observed to have the lowest air temperature as compared to other locations throughout the day. However, the differences in air temperature at different locations are really quite marginal, with a difference of about 1ºC.

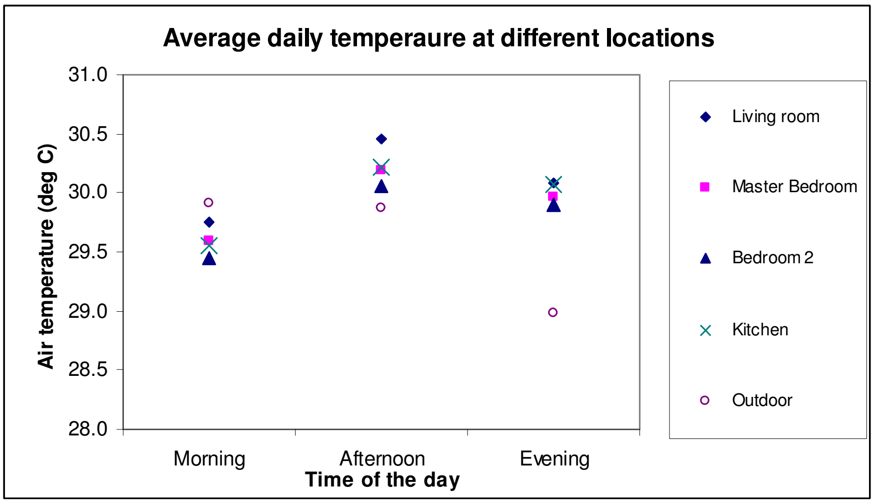


Figure 3. 9 Average daily temperatures at different locations in Building One

Relative humidity

The measured results reflect that the average relative humidity at different locations is generally higher in the evening (see Figure 3.10). The average relative humidity at various locations ranges from 64% to 67% throughout the measuring period. The living room recorded a lower average relative humidity as compared to other locations.

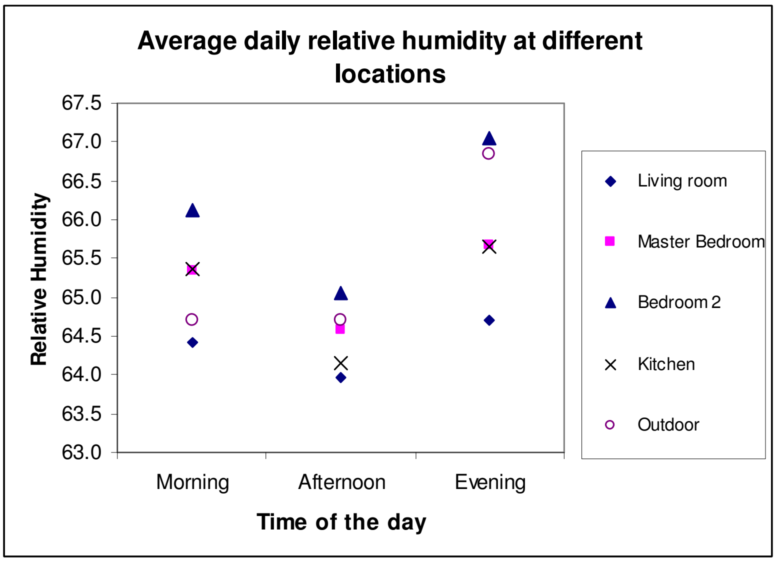


Figure 3. 10 Average daily relative humidity at different locations in Building One

Air velocity

The air velocity measures the adequacy of natural wind for ventilation in the apartment. It is observed that the measured outdoor average air velocity ranges from 0.6 to 0.7 m/s across the day (see Figure 3.11). This reflected that the outdoor condition was rather windy. However, the average air velocity in the apartment only ranges from 0 to 0.3m/s which indicated that it was rather stuffy inside the apartment. This might be attributed to the fact that not all the windows were open at the time of measurements. In addition, the MRT station and a number of trees are located right in front of the block. These might impede air movement into the apartment especially for apartments located at the lower floors. As observed from Figure 3.11, the living room and the kitchen appeared to have a higher average air velocity throughout the day as compared to other locations. This is most probably because the living room and kitchen are situated at each end of the apartment where there are the most number of window openings.

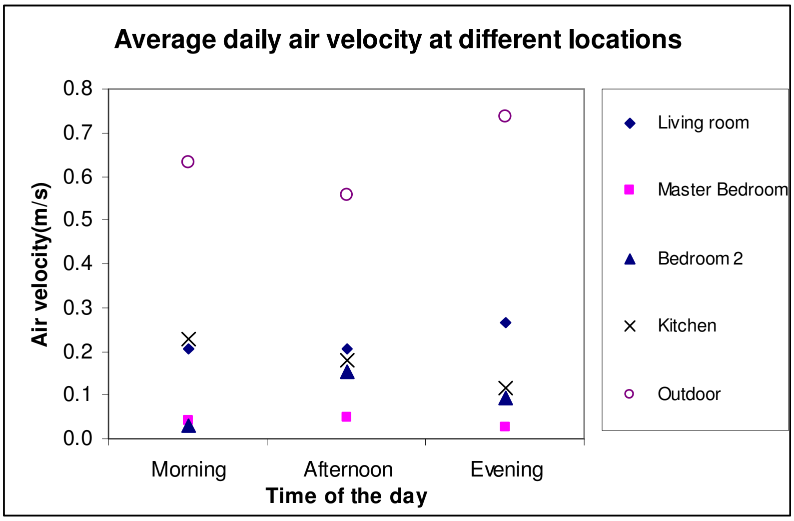


Figure 3. 11 Average daily air velocity at different locations in Building One

Radiant temperature

The mean radiant temperature (MRT) of a space is the measure of the combined effects of temperatures of surfaces within that space, i.e. all these surface areas and temperatures acting on a person's location in the room. It is observed from Figure 3.12 that the kitchen has the highest mean radiant temperature as compared to other locations across the day, especially in the evening. This might be because the kitchen is directly exposed to the sky and thus in the evening, the walls are radiating the heat absorbed during the day. Another possible reason could be that most people cook in the evening thus the heat from the cooking could affect the mean radiant temperature as well. On the other hand, the master bedroom recorded the lowest mean radiant temperature in the afternoon probably because the room is not exposed directly to the open sky.

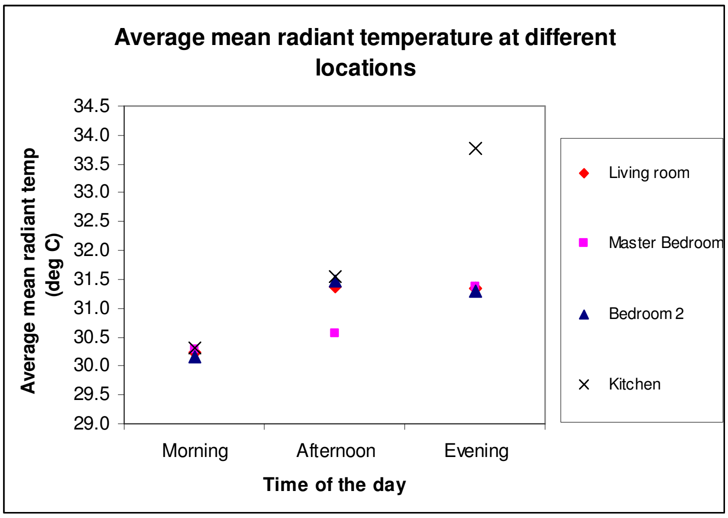


Figure 3. 12 Average daily mean radiant temperature at different locations in Building One

- **Indoor noise level**

Figure 3.13 shows the average noise level at different locations across different times of the day. As observed, the noise level in the living room tends to be higher than other locations as the living room is facing the MRT station and the major roadway. The noise level in the living room ranges from about 59 to 61dBA and it is slightly higher in the morning and the evening probably because the traffic is heavier during these times when people are going to and from work. The kitchen also experienced higher noise level because it is facing the open car-park. On the other hand, bedroom 2 experienced a slightly higher noise level in the morning and evening as compared to the master bedroom. This is probably attributed to the fact that bedroom 2 is located along the corridor so when people go to work in the morning and return from work in the evening, the noise level tends to be higher.

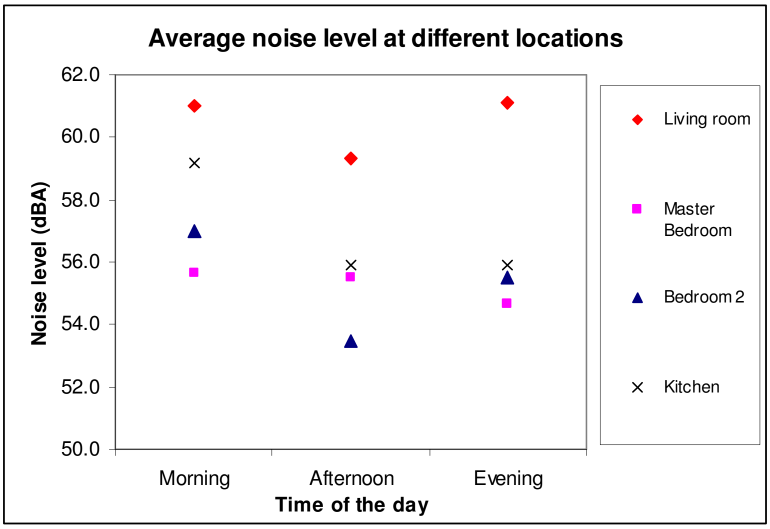


Figure 3. 13 Average daily noise level at different locations in Building One

- **Results of the residents' survey**

Table 3.6 shows that most of the residents in Building One are dissatisfied with the living condition in the unit and the neighborhood environment. The reasons of complaints range from the unit being too hot, humid and dim as well the presence of rats because of the coffee shop below the flat. Being in close proximity with the MRT station also brought some noise disturbances to the residents.

Table 3. 6 Results of the survey on residents of Building One

Criteria	Satisfied		Reasons if not satisfied
	Yes	No	
Living condition of the unit	46.7%	53.3%	a. The units are too hot, humid and dim b. Presence of pests such as rats c. MRT is quite noisy
Living environment of the neighborhood	40%	60%	a. Inconvenient because of transport problems b. Shopping malls/grocery shops etc nearby preferred

3.6.2 Building Two

- **Electricity consumption**

Building Two is a five-year new building. Most units are occupied by young families with children. Although 89 units are already purchased by residents, only 82 units are frequently occupied. Among them, 57 units installed air-conditioners. The air-conditioner usage rate is 69.5%. Measured results reflect that the average electricity consumption of the whole block is about 55.83 kWh/m^2/year (see Table 3.7).

Table 3. 7 Electricity consumption of Building Two

	Electricity Consumption of the sampled households (kWh/m^2/yr)	Electricity Consumption of the whole block (kWh/m^2/yr)
Mean	59.28	55.83
Minimum	16.69	13.1
Maximum	115.70	507.87

- **Water consumption**

The measured results show that each person of the sampled units used about 296.6 liter of water per day (see Table 3.8). This is on the rather high side. However, the water consumed by each individual varies considerably. This is reflected from the minimum and maximum values where one individual has used only 42.5 liter of water per day and another has used up to a shocking amount of 888.9 liter per day. On the other hand, it is estimated that each household in the block uses on the average about 536.6 liter of water per day. Same as the sampled units, the water usage by different households differs considerably. This is also reflected from the minimum and maximum values where the difference is very big.

Table 3. 8 Water consumption of Building Two

	Water Consumption of the sampled households (l/capita/day)	Water Consumption of the whole block (l/household/day)
Mean	296.6	536.1
Minimum	42.5	23.6
Maximum	888.9	1777.9

- **Water flow rate of faucets and shower heads**

It is seen from Table 3.9 that on the average, the water flow rate of the fixtures has failed to meet the recommended flow rate specified for water efficient fixtures.

However, the average flow rate of shower head still fulfils the requirement of CP48 which is 0.2 liter. From the minimum flow rate depicted in the table, there are households that have met the recommended flow rate of 0.10 l/s for sinks and wash basins and 0.12 l/s for showerheads.

Table 3. 9 Water flow rate of faucets and showerheads in Building Two

Water Flow rate	Kitchen Sink (l/s)	Wash Basin (l/s)	Wash Basin (Master Bedroom) (l/s)	Bathroom showerhead (l/s)	Bathroom showerhead (Master Bedroom) (l/s)
Min	0.06	0.09	0.10	0.04	0.08
Max	0.30	0.33	0.33	0.50	0.50
Average	0.16	0.20	0.20	0.18	0.19

- **Capacity and type of water cisterns**

All the surveyed units have standard dual flush water cisterns with the same capacity of 4.5 liter/flush. This is because all water cisterns were installed by HDB before the units were sold to residents. The survey results reflect that HDB realizes the importance of water conservation and provide water efficient water cisterns for their new residential buildings.

- **Cooker hood**

It is observed that 100% of the sampled units had cooker hoods although all of them do not extract cooking smoke to the outdoor air. This fact reveals that young families are more willing to purchase cooker hood for improving their indoor air quality.

- **Sky visibility of living room**

The survey results show that 70% of the sampled units had access to sky visibility. The remain 30% of the sampled units had their views obstructed by the nearby blocks in the precinct.

- **Cloth drying facilities**

It is observed that all units have a set of standard cloth hanging rack for residents to place bamboo poles and dry cloth. This drying facility consists of two cloth hanging rack facing each other; one is fixed on the external wall of the kitchen and the other on the external wall of bedroom, so residents can place bamboo poles with wet clothes on them. This drying facility can prevent poles from being blown away (see Figure 3.14).

Figure 3. 14 Cloth drying facilities on the external walls of bedroom and kitchen in Building Two

- **Energy efficient appliances**

Among the sampled nine units, eight units have installed air-conditioners, and 100% units have refrigerators. Among them, two air-conditioners (25%) and three refrigerators (33.3%) were labeled under Singapore Energy Labeling scheme. The result shows that young families are more concern about energy consumption within their homes and more willing to purchase energy efficient appliances even they are more expensive than conventional ones.

- **Indoor thermal environment**

Air temperature

Figure 3.15 shows the average daily temperature at different locations. It can be seen that the living room has the highest temperature measured at different times of the day in comparison to the other locations. This is perhaps attributed to the greater glazed area in the living room with the full height windows which let in more heat.

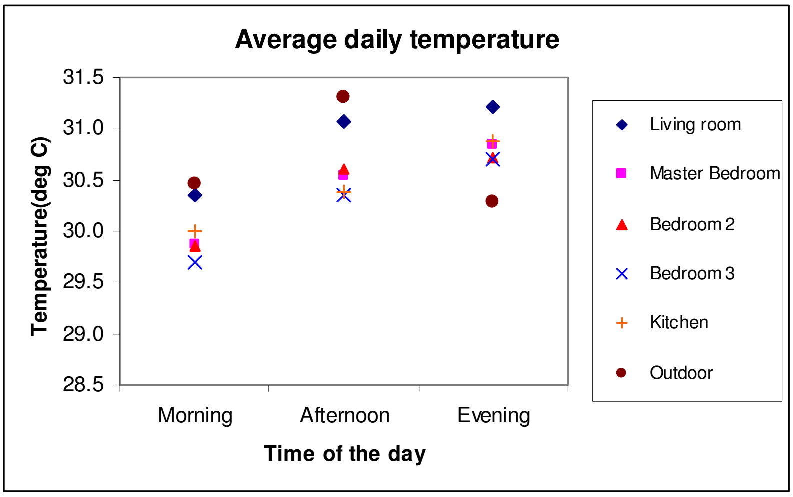


Figure 3. 15 Average daily temperature at different locations in Building Two

Relative humidity

The relative humidity at different locations appears to be slightly higher in the morning as compared to other times of the day (see Figure 3.16). On the whole, the relative humidity measured at different locations was lower than 60%. This may indicate that probably, the measurements were taken on days that were less humid.

Air velocity

Figure 3.17 shows that the average outdoor air velocity is quite high ranging from 1.3m/s to 1.8 m/s which reflects that the surrounding environment is quite windy. However it is observed that the average air velocity at different locations of the apartment is not very high. This might be because not all the windows were opened during the time of measurements. If the windows be all opened, the potential of cross ventilation in the apartment can be further enhanced as reflected by the maximum air velocity measured 3.1m/s. The results also indicate that the kitchen is the windiest place with the highest air velocity measured at different times of the day in comparison to other locations.

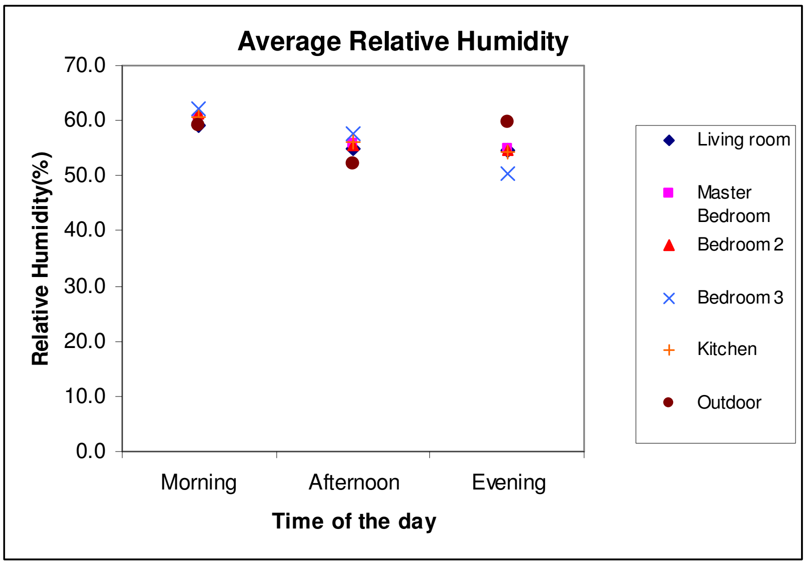


Figure 3. 16 Average relative humidity at different locations in Building Two

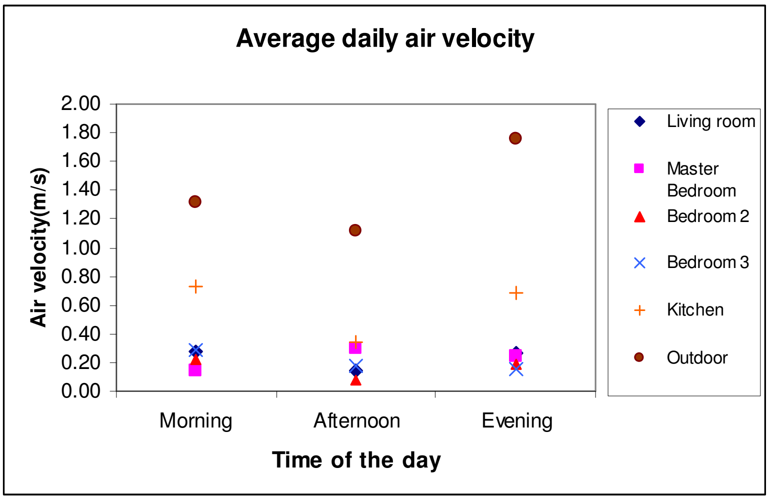


Figure 3. 17 Average daily air velocity at different locations in Building Two

Radiant temperature

The measured results reveal that the average mean radiant temperature is higher at all locations in the afternoon and evening (see Figure 3.18). This is most probably because the surfaces of the rooms get heated up from the radiation of the sun in the daytime and the heat is then dissipated into the interior space in the evening.

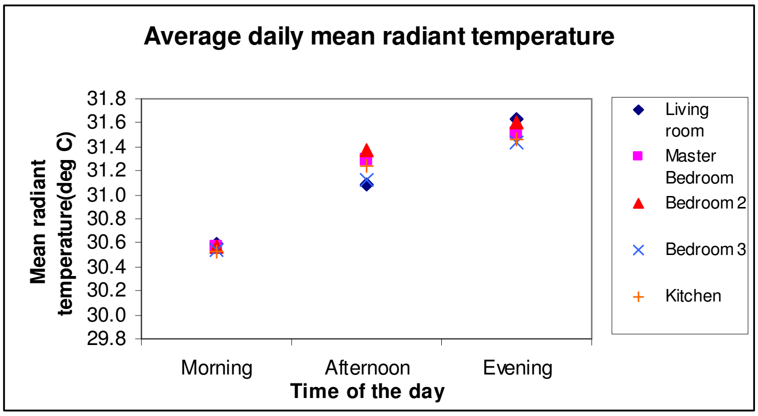


Figure 3. 18 Average daily mean radiant temperature at different locations in Building Two

- **Indoor noise level**

Figure 3.19 reveals that on the whole, the noise level measured at different locations of the apartment during different times of the day is on the high side, averaging more than 55dBA, and the maximum is 66.2dBA. This might be attributed to the location of the block. There is a major expressway located beside the block and there is also disturbance from aircraft noise as the block is located in the area which is in the direction of Changi Airport.

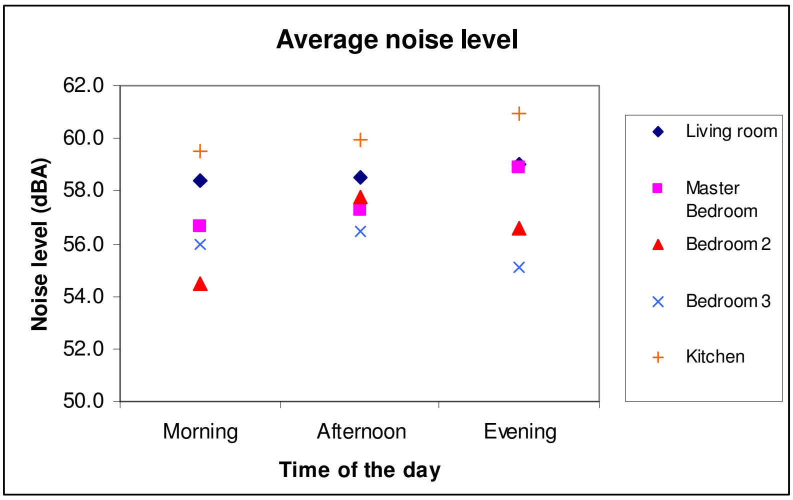


Figure 3. 19 Average noise level at different locations in Building Two

- **Results of the residents' survey**

On the whole, it can be seen that a larger percentage of residents interviewed are dissatisfied with the current living condition in the unit and also the neighborhood environment (see Table 3.10). The most common complaints from the residents are that the apartment is too hot and humid and also the presence of pests. The residents are also unhappy about the inconveniences because of transport reasons. They would also prefer shopping malls and grocery shops to be nearby.

Table 3. 10 Results of the survey on residents of Building Two

Criteria	Satisfied		Reasons if not satisfied
	Yes	No	
Living condition of the unit	22%	78%	a. Hot, humid and dusty b. Rain when accompanied with strong wind will seep into the main door c. Presence of pests such as mosquitoes and ants
Living environment of the neighborhood	27%	73%	a. Inconvenient because of transport problems b. Shopping malls/grocery shops etc nearby preferred

3.7 Comparison of Building One and Building Two

- **Energy consumption**

Measured results reveal that Building Two has higher electricity consumption than Building One. This may be explained by the higher air-conditioner usage rate in Building Two. However, the survey results also reflect that residents of Building Two are more willing to purchase energy efficient air-conditioners and refrigerators. The residents living in Building Two are general younger than the residents living in Building One. It seems that local young generation tends to have better awareness of energy conservation.

- **Water efficiency**

Residents of Building Two consumed slightly more water per unit than residents of Building One. This may be due to the fact that Building One is 3-Room block while Building Two is 4-Room block which is likely to have more family members per household than Building One.

It is obvious that showerheads and water cisterns installed in Building Two are more water efficient than those in Building One. The provision of 100% duel-flush water cisterns in Building Two demonstrates that HDB has advanced concern of water conservation other than just following the recommendation of 4.5 liter/flush.

- **Cooker hood**

It is observed that the usage rate of cooker hood in kitchen in Building Two is much higher than that in Building One. This may reveal that local young generation tend to pay more attention to their indoor air quality and willing to improve the air quality in kitchen by purchasing cooker hood.

- **Cloth drying facilities**

Although the cloth drying facilities of the two buildings were both provided by HDB before the residents moved in, it is obviously that the cloth hanging racks provided on Building Two is safer than bamboo slots provided on Building One regarding the possibility of bamboo poles falling. It also increases the safety for residents who hang the bamboo poles with wet clothes.

- **Indoor thermal environment**

The average indoor air temperature is 0.5^{o}C higher in Building Two than that in Building One. However, the indoor environment of Building Two is apparently more windy and dryer than that of Building One, and Building Two has a slightly lower (0.08^{o}C) average mean radiant temperature than Building One as well.

- **Indoor noise environment**

The indoor environment is a little noisier in Building Two than Building One. This can be attributed to the heavy traffic on the expressway beside the building and the frequent aircraft passing over the sky of the building.

- **Indoor daylight environment**

Although indoor daylight level is not measured in sampled units, it is no doubt that Building Two has much brighter indoor environment than Building One. Other than the different surrounding environment of the two buildings, two main reasons are that in Building One, the assessing corridors obstruct part of daylight from entering the living rooms and common bedrooms, and the external walls of bathroom also block part of daylight from entering master bedrooms.

- **Residents' perception**

Survey results indicate that surveyed residents living in Building One tend to be more satisfied with their living condition of the unit and the living environment of the neighborhood. One reason that can partly explain the difference of satisfactory may be that Building One is located in a well developed area and not far away from the city center; on the other hand, Building Two is located in a new developing town and relatively far away from the city center.

3.8 Conclusion

The indoor survey and measurement results reveal that Building Two has more sustainable indoor environment in the areas of energy efficient appliances, water flow rate of showerheads, water efficient water cisterns, cooker hood usage, sky visibility in living room, cloth drying facilities, and indoor thermal environment. On the other hand, Building One is slightly quiet and cooler, and consumes less electricity and water which may be due to different life style of residents.

Residents' main concerns on their living conditions are the hot and humid indoor thermal environment, and the presence of pests. Regarding their living environment of the neighborhood, the survey results reflect that the inconvenient transportation and shortage of shopping malls/grocery shops are the residents' main concerns.

The survey and measurement results also demonstrate the improvement of design in the indoor environment of public housing in Singapore especially in the layout design to improve indoor environment of daylight and view, natural ventilation and dehumidification, as well as the provision of water efficient facilities and safer cloth drying facilities.

CHAPTER 4 ASSESSMENT OF TWO HDB BLOCKS USING LEED-NC

4.1 Introduction

To investigate the building environmental sustainability of local public housing, the building performance of two HDB public housing buildings, Building One and Building Two, is assessed using the "Leadership in Energy and Environmental Design (LEED) Green Building Rating System". The applicability of LEED for assessing local residential developments is also examined. The descriptions of Building One and Building Two are detailed in section 3.2.

4.2 Selection of Assessment Method

LEED-NC version 2.1 is selected for the assessment of the two HDB blocks in this chapter.

- **LEED**

The US Green Building Council began its development of the "Leadership in Energy and Environmental Design" (LEED) — a Green Building Rating System in 1994. In late 90s it was revamped taking into consideration the more recent developments put forth by the World Green Building Challenge. Presently LEED is one of the most successful environmental assessment methods which is gaining international acceptance. It is reasonably comprehensive covering a wide range of issues and yet not as complex and difficult to implement as in the case of the Green Building Challenge's protocol. Around 1800 new construction projects from 51 states in US have been registered with LEED-NC the rating system for new commercial buildings and high-rise residential buildings and 164 new construction projects have been certified (Green Building Council, 2005).

In addition, LEED has affected the development of environmental assessment methods internationally since its establishment. It classifies sustainable issues into five groups:

- Sustainable sites
- Water efficiency
- Energy & atmosphere
- Material & resources
- Indoor environmental quality

This classification covers a wider range of sustainable issues as compared with the one used by early version of BREEAM. BREEAM is another system of environmental assessment method which was widely used in the early 90s. The early version of BREEAM was adapted and used in areas such as Hong Kong (HK-BEAM), which divided sustainable issues into three groups: global, local and indoor environment. The latest version of HK-BEAM has adopted some of the criteria used by LEED. The China Ecological Housing Technology Assessment Handbook released in 2001 used the same classification as LEED too. EcoHomes, the latest version of BREEAM for homes categorized sustainable issues into seven groups: Energy, health and well being, transport, water, materials, land use and ecology, and pollution, which is similar to LEED’s classification. Therefore LEED has the representation of the environmental assessment methods currently used in the world.

Furthermore, LEED has relatively simple documentation process and lower cost of documenting LEED credits. This virtue will make this HDB building assessment more practical and easier to carry out.

One objective of this assessment is to choose an international environmental assessment method for assessing HDB buildings developed in different periods. Summarizing from above characteristics, it can be concluded that LEED as a representation of existing international environmental assessment methods with successful industrial experience and practicability, is suitable to be chosen for this HDB building assessment.

- **LEED-NC**

LEED-NC is the rating system for new commercial construction, major renovations and high-rise residential buildings. LEED-NC assesses building planning, design, construction and commission, while LEED-EB, the rating system for existing buildings, addresses operations, maintenance and systems retrofits. Although these two HDB blocks are existing buildings, one of the main objectives of this assessment is to find out whether HDB's design of public housing is getting more sustainable, and the operations and maintenance of public housing are not the main concern. Therefore the assessment using LEED-NC will be more important than LEED-EB. The criteria requirements of LEED-NC are summarized in Appendix A.

4.3 Site Survey and Measurement

In order to determine the environmental conditions of the two assessed buildings, both outdoor and indoor survey and measurements were conducted.

4.3.1 Outdoor site survey and measurement

Outdoor site survey was carried out to investigate the environmental conditions of the two assessed buildings including public transportation access, storage facilities and cycling path for bicycles, parking capacity, parking for carpools or vanpools, site ecologic condition, development footprint, urban heat island effect related characteristics of roof surfaces and non-roof surface areas, and storage facilities of recycled material.

4.3.2 Indoor site survey and measurement

In order to determine the indoor environmental conditions of the two assessed buildings, objective measurements as well as a short survey with the residents were carried out in the residential units of the two buildings. Indoor air temperature, relative humidity, air velocity, radiant temperature, and noise level were measured to investigate the indoor thermal and acoustic environment. The water flow rate of faucets and showerheads as well as the capacity of water cisterns were also measured to ascertain how water efficient the fixtures are. Besides, readings from the electricity and water meters of all the units in the two blocks were recorded so as to determine the amount of electricity and water each household consumed approximately. Other indoor environmental conditions such as cooker hood, sky visibility in living room, cloth drying facility, and energy efficient appliances were also explored during the indoor survey and measurement. The detail of indoor site survey and measurement are presented in Chapter Three.

4.4 LEED Assessment

The first step of LEED certification is to register the project with the U.S. Green Building Council (USGBC). Once registered, the project team will receive information, tools, and communication that will help guide them through the certification process which includes:

- **Application** — All applications must be documented in English with U.S. customary units of measurement (not metric).
- **Review** — Documentation submittals for every prerequisite and credit are reviewed for compliance. After the USGBC issues a Preliminary LEED Review document, the project team needs to provide a supplementary submittal to the application. Then the USGBC will conduct a Final LEED Review of the application. These may take up to 65 working days.
- **Certification Award** — Upon delivery of the Final LEED Review, the project team can choose to accept or appeal the rating. After receiving notice of the team's acceptance, USGBC will then contact the team regarding fulfillment details, including their certificate and LEED plaque (Green Building Council, 2005).

The LEED assessment of the two buildings presented here is only a self check using LEED-NC rating system check list download from the official website of LEED (the criteria requirements is summarized in Appendix A). As mentioned above, in order to be certified by LEED, all project application materials and the corresponding fee (check payable to USGBC) need to be submitted to the LEED Certification Manager. Therefore, the LEED certification is beyond the scope of this study.

4.4.1 LEED-NC assessment of Building One

Table 4.3 sets out the assessment of the existing design of Building One under sustainable sites, water efficiency, energy & atmosphere, material & resources, indoor environmental quality, and innovation & design process, respectively.

4.4.1.1 Sustainable Sites

- **Erosion & Sedimentation Control —** There is no particular sedimentation control measures during construction stage.

- **Site Selection —** The site meets the credit requirement of avoid development of inappropriate sites and reduce the environmental impact.

- **Development Density —** The site is located within the area of Gross Plot Ratio (GPR) 3.0 which meets the credit requirement of minimum development density of 60,000 square feet per acre (two story downtown development).

- **Brownfield Redevelopment —** The site is not on a contaminated nor brownfield site.

- **Alternative Transportation:**

  Public Transportation Access — The project site is located within 100m of Mass Rapid Transportation (MRT) station, and there are nine public bus lines usable by building occupants. One credit is achieved.

Bicycle Storage & Changing Rooms — There is no covered storage facilities for securing bicycles.

Alternative Fuel Vehicles — There is no indication of providing alternative fuel vehicles for building occupants, or installing alternative-fuel refueling stations.

Parking Capacity — HDB's development is required to comply with the minimum carparking provision as stipulated by LTA. There is no provision for carpools or vanpools, but it can be achieved easily.

- **Reduced Site Disturbance:**

Protect or Restore Open Space — The project site is neither Greenfield nor previously developed site.

Development Footprint —

Development footprint in accordance to the LEED Reference Guide is defined as the area on the project site that has been impacted by any development activity. Hardscape, access roads, parking lots, non-building facilities and building structure are all included in the development footprint. On the other hand, open space must be vegetated and pervious, thus providing habitat and other ecological services.

In the context of Singapore, there are no local zoning requirements for open space for an individual HDB block. Hence for the building to comply with the LEED criteria, the open space area adjacent to it has to be equal to that of the development footprint. For Building One, there is no adjacent open space beside the building. Therefore, it is not entitled to the credit under this criterion.

- **Stormwater Management:**

  Rate and Quantity — HDB does not track the volume of the stormwater discharge from the project site. There is no stormwater treatment facility required on-site as the stormwater is collected across the whole-catchment area to be treated at the local reservoirs.

  Treatment — There is no stormwater treatment facility required on-site, and neither any local government best practices for stormwater treatment on-site.

- **Heat Island Effect:**

  Non-Roof — The site's non-roof impervious surfaces areas are not constructed with high-albedo materials, all parking spaces are on the ground, and the open-grid pavement system has more than 50% impervious area.

  Roof — The project's roof is made of RC and Ferrocement which are not highly reflective and high emissivity materials, and there is no green (vegetated) area on the roof.

- **Light Pollution Reduction —**

  There are four aspects of requirements. For the first aspect of requirements, as the IESNA Recommended Practice Manual RP-33-99 is not accessible in either the NUS library or the national libraries and has to be purchased, the establishment of compliance to this particular requirement is not possible. In addition, a computer generated lighting calculation using lighting software is required to show the horizontal illuminance on a 10’ by 10’ grid for a minimum of 10’ beyond the property line. This is beyond the time and resources of the study in this context.

However, exterior site survey results show that Building One fulfilled the other three aspects of requirements: all the exterior luminaries do no exceed 1000 or 3500 initial lamp lumens; the maximum candela value of all interior lighting fall within the building; the maximum candela value of all the exterior lighting falls within the property because the lamps are all faced towards the property and appropriately shielded such that there is no spill over to adjacent property; and the exterior lamps are all appropriately shielded so no light from the luminaries cross the property boundary.

4.4.1.2 Water Efficiency

- **Water Efficient Landscaping:**

  Reduce by 50% ─ The landscaping is irrigated by rain. There is no potable water used for the irrigation.

  No Potable Use or No Irrigation ─ Permanent landscape irrigation system is not installed on the site.

- **Innovative Wastewater Technologies ─** There is no treatment of wastewater on-site.

- **Water Use Reduction (20%/30% Reduction) —** The measured results reflect that the average flow rate of bathroom showerhead is 0.11 l/s, which is 30.4% less than the requirement of the Energy Policy Act of 1992. However, the measured results reveal that the average flow rate of faucet and the capacity of the water cisterns are 0.32 l/s and 12 liter respectively, which failed to meet the requirements. The measured average water consumption of Building One is 151.74 l/capita/day, which is much more than the requirement of 81 l/capita/day.

4.4.1.3 Energy & Atmosphere

- **Fundamental Building Systems Commissioning —** HDB has implemented the following fundamental best practice commissioning procedures:

  a. Engage a commissioning team that does not include individuals directly responsible for project design or construction management.

  b. Review the design intent and the basis of design documentation.

  c. Incorporate commissioning requirements into the construction documents.

  d. Develop and utilize a commissioning plan.

  e. Verify installation, functional performance, training and operation and maintenance documentation.

  There is no commissioning report, only the commissioning result e.g. "approval".

- **Minimum Energy Performance —** There is no energy code for naturally ventilated buildings in Singapore.

- **CFC Reduction in HVAC&R Equipment —** This residential building is a natural ventilated building. There is no HVAC&R equipment in this building. Therefore, this credit is not applicable.

- **Optimize Energy Performance —** Building One is designed to be naturally ventilated with no mechanical cooling system hence the Energy Cost Budget method is not applicable. Therefore, this credit is not applicable here.

- **Renewable Energy: 5% or 10% or 20% —** No on-site renewable energy is provided for this building.

- **Additional Commissioning —** According to HDB, a commissioning authority independent of the design team has conducted a review of the design after the construction documents phase, and an independent commissioning authority has conducted a review of the construction documents near completion of the construction document development and prior to issuing the contract documents for construction.

- **Ozone Protection —** This building is natural ventilated. There is no base building level HVAC&R equipment. The fire suppression systems do not contain HCFCs or Halons.

- **Measurement and Verification —** This building only has a single meter that tracks the electrical usage of all common area facilities like lighting, lifts and pumps.

- **Green Power ─** No green power is provided for this building.

4.4.1.4 Material & Resources

- **Storage & Collection of Recyclables ─** In this building, every unit has its own refuse chute in the kitchen. But there is no area dedicated to recycled material collection and storage in the building.

- **Building Reuse: Maintain 75% or 100% of Existing Walls, Floors and Roof, Maintain 100% of Shell/Structure and 50% of Non-Shell/Non-Structure ─** This project is a new building. It does not reuse any existing building.

- **Construction Waste Management: Divert 50% or 75% From Landfill ─** HDB does not impose an active waste management system on the building contractor at construction stage.

- **Resource Reuse: 5% or 10% ─** No resource was reused in the project.

- **Recycled Content: 5% or 10% (post-consumer + 1/2 post-industrial) ─** No recycled content material was used in this building.

- **Regional Materials: 20% manufactured regionally and 50% extracted regionally ─** Concrete and sand used by the contractor in this project are from Malaysia and Indonesia, which are within the 500 mile radius. And concrete constitutes more than 80% of the whole materials used in the project. Therefore, 2 credits are achieved.

- **Rapidly Renewable Materials ─** No rapidly renewable materials was used in the project.

- **Certified Wood ─** Most wood used in the project is from Malaysia and Indonesia, which is tropical wood and is not certified.

4.4.1.5 Indoor Environmental Quality

- **Minimum IAQ Performance ─** According to the architect, the minimum openable window areas is 10% of the occupiable floor area, which fully compliant with the ASHRAE requirement of minimum 4%.

- **Environmental Tobacco Smoke (ETS) Control ─** The communal spaces of the building are not designated as non-smoking areas.

- **Carbon Dioxide (CO_2) Monitoring ─** This building is designed to be natural ventilated, and no centralized HVAC system is provided. However, 104 units in this building have installed air-conditioners, and all of them provide individual controls of the ventilation air flows. All communal areas are natural ventilated. Therefore, this credit is not applicable.

- **Ventilation Effectiveness ─** The only code that controls ventilation is the Building Code, which specifies minimum 10% ventilation for every room. HDB flats all comply with this 10% natural ventilation requirement. However, according to the architect, there was no airflow simulation and sketches indicating the airflow pattern done by mechanical engineer during the design stage for this building.

- **Construction IAQ Management Plan: During Construction and Before Occupancy —** This is a natural ventilated building therefore has no HVAC system to protect during the construction and flush-out is not applicable. However, according to the architect, there was no IAQ management plan to control pollutant sources and interrupt contamination pathways during the construction, neither was any baseline indoor air quality testing before occupancy.

- **Low-Emitting Materials:**

  Adhesives & Sealants — There is no control on VOC emission level for adhesives and sealants.

  Paints — All HDB approved paints and coatings have to comply with PSB standard SS 150:1998 for interior applications and SS 345:1990 for exterior applications. In addition, primers for painting metal have to comply with SS 494:2001 to be lead and chromate free. Exact VOC emission levels cannot be obtained from product brochures, but all of them do not contain lead or mercury.

  Carpet — No carpet is used in the building. The credit is not applicable.

  Composite Wood — There is no control on composite wood and agrifiber products containing no added urea-formaldehyde resins.

- **Indoor Chemical & Pollutant Source Control ─** There is no permanent walkoff system for the entryway of the building. Although housekeeping areas are physically separated with deck to deck partitions and have plumbing systems, no outside exhaust is provided, and no negative pressure is maintained there.

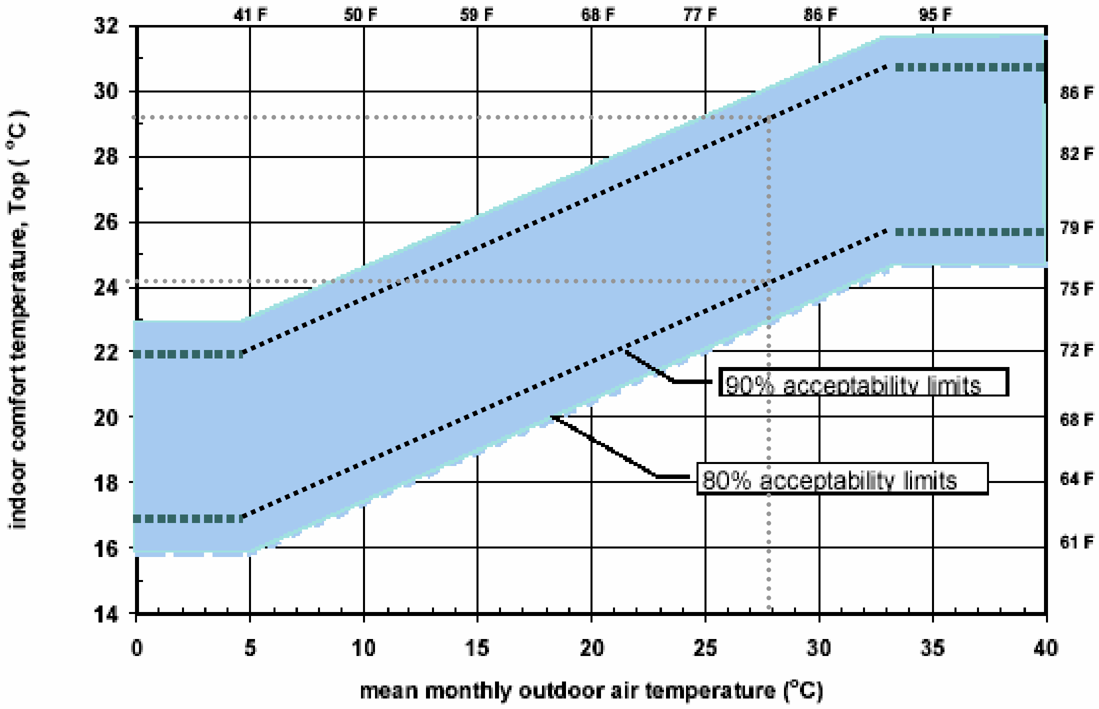
- **Controllability of Systems: Perimeter Spaces ─** This building fulfills the LEED requirement that regularly occupied perimeter areas (e.g. living room and bed rooms) have a minimum of one operable window and one lighting control zone per $18.58m^2$ (200 square feet) on average.

- **Non-Perimeter Spaces ─** There is no regularly occupied non-perimeter spaces in this building. This credit is not applicable.

- **Thermal Comfort: Compliance with ASHRAE 55-1992 ─**
  For naturally ventilated buildings, the requirement is to utilize the adaptive comfort temperature boundaries, using the 90% acceptability limits as defined in the California High Performance Schools (CHPS) Best Practice Manual, Appendix C-A Field Based Thermal Comfort Standards for Naturally Ventilated Buildings (see Figure 4.1).

  As the indoor measurements in the two blocks were conducted in the month of July, the hourly air temperature for the month of July was obtained in order to calculate the acceptable range of indoor operative temperatures. The mean monthly outdoor air temperature for the month of July was 28°C. From Figure 4.1

it can be seen that the acceptable range of indoor air temperature (Top) falls between 24°C to 29°C.



(**Source:** Collaborative for High Performance School, 2001)

Figure 4. 1 Proposed adaptive comfort standard for naturally ventilated buildings

The calculation results of indoor measurement data show that the minimum, average, and maximum indoor operative temperature are 29.3°C, 31.8°C, and 31.9°C respectively. Therefore, Building One fails to meet the 90% acceptability limit because its indoor operative temperature has exceeded the acceptable range of 24°C to 29°C.

- **Permanent Monitoring System —** This building is designed to be naturally ventilated. This credit is not applicable.

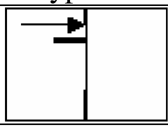
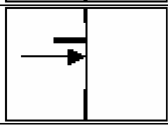
- **Daylight and Views: Daylight 75% of Spaces —**

The daylight factor for each window type is calculated using Equation 1 and Table 4.1 as follows:

$$DaylightFactor = \frac{WindowArea}{FloorArea} \times WindowGeometryFactor \times \frac{ActualT_{vis}}{MinimumT_{vis}} \times WindowHeightFactor \times 100\% \qquad \textbf{Equation 1}$$

Where, T_{vis} is the visible light transmittance.

Table 4. 1 Geometry Factor, Minimum Tvis and Height Factor for different window types

Window Type		Geometry Factor	Minimum T_{vis}	Height Factor
Side light, daylight glazing		0.1	0.7	1.4
Side light, vision glazing		0.1	0.4	0.8

Notes: Daylight glazing is the glazing positioned above 2.3 meter above the floor, and vision glazing is the glazing positioned between 0.75 and 2.3 meter above the floor.

(**Source:** Acuity Brands Lighting, 2005)

For rooms with more than one window type, the total daylight factor is summed from the calculation of all the window types in the room. If the total daylight factor for a room is 2% or greater, then the floor area of the room is applicable to the credit. The floor area of all applicable rooms is summed and divided by the total floor area of all the regularly occupied spaces. If this percentage is greater than 75%, then the building qualifies for one point of this LEED credit.

The identified regularly occupied spaces in each unit consist of the Living/Dining room, the master bedroom and bedroom 2. The kitchen is not considered to be a regularly occupied space in this case. The total daylight factor for all the window types in these rooms are computed and shown in Table 4.2. Corridor units constitute 87.5% of all residential units in Building One, while corner units constitute 12.5% of all residential units. It is observed that the daylight factor is 2% or greater only in the master bedroom and bedroom 2 of the corner apartments in the block. The computation result shows that only 30% of the regularly occupied spaces meet the minimum daylight factor of 2%. Hence Building One is not eligible for any point under this credit.

Table 4. 2 Floor area and daylight factor in Building One

Rooms		Floor area (m^2)	Daylight factor (%)
Corridor units (87.5%)	Living room	18.7	0.3
	Master bedroom	12.2	1.4
	Bedroom 2	11.7	1.3
Corner units (12.5%)	Living room	22.3	1.3
	Master bedroom	15.4	2.4
	Bedroom 2	12.2	2.1

Views for 90% of Spaces — The floor plan drawings show that building occupants in all regularly occupied spaces will have direct lines of site to perimeter glazing.

4.4.1.6 Innovation and Design Process

- **Innovation in Design —** According to the architect, this building has no exceptional performance above the requirements set by the LEED Green Building Rating System, and no innovative performance in Green Building categories not specifically addressed by the LEED Green Building Rating System.

- **LEED Accredited Professional —** This is not applicable in Singapore.

Table 4. 3 LEED-NC assessment of Building One

Possible Points	Assessed Issues	Not Applicable	Score achieved
	Sustainable Sites		
Prereq	Erosion & Sedimentation Control		—
1	Site Selection		1
1	Development Density		1
1	Brownfield Redevelopment		0
1	Alternative Transportation — Public Transportation Access		1
1	Alternative Transportation — Bicycle Storage & Changing Rooms		0
1	Alternative Transportation — Alternative Fuel Vehicles		0
1	Alternative Transportation — Parking Capacity		0
1	Reduced Site Disturbance — Protect or Restore Open Space		0
1	Reduced Site Disturbance — Development Footprint		0
1	Stormwater Management — Rate and Quantity		0
1	Stormwater Management — Treatment		0
1	Heat Island Effect — Non-Roof		0
1	Heat Island Effect — Roof		0
1	Light Pollution Reduction		1
	Water Efficiency		
1	Water Efficient Landscaping — Reduce by 50%		1
1	Water Efficient Landscaping — No Potable Use or No Irrigation		1
1	Innovative Wastewater Technologies		0
2	Water Use Reduction		0
	Energy & Atmosphere		
Prereq	Fundamental Building Systems Commissioning		—
Prereq	Minimum Energy Performance	√	—
Prereq	CFC Reduction in HVAC&R Equipment	√	—
10	Optimize Energy Performance	√	—
3	Renewable Energy		0
1	Additional Commissioning		0
1	Ozone Depletion		1
1	Measurement & Verification		0
1	Green Power		0
	Materials & Resources		
Prereq	Storage & Collection of Recyclables		—
3	Building Reuse		0
2	Construction Waste Management		0
2	Resource Reuse		0
2	Recycled Content		0
2	Local/Regional Materials		2
1	Rapidly Renewable Materials		0

Possible Points	Assessed Issues	Not Applicable	Score achieved
1	Certified Wood		0
	Indoor Environmental Quality		
Prereq	Minimum IAQ Performance		—
Prereq	Environmental Tobacco Smoke (ETS) Control		—
1	Carbon Dioxide (CO_2) Monitoring	√	—
1	Ventilation Effectiveness		0
1	Construction IAQ Management Plan, During Construction		0
1	Construction IAQ Management Plan, Before Occupancy		0
1	Low-Emitting Materials — Adhesives & Sealants		0
1	Low-Emitting Materials — Paints		0
1	Low-Emitting Materials — Carpet	√	—
1	Low-Emitting Materials — Composite Wood		0
1	Indoor Chemical & Pollutant Source Control		0
1	Controllability of Systems — Perimeter		1
1	Controllability of Systems — Non-Perimeter	√	—
1	Thermal Comfort — Comply with ASHRAE 55-1992		0
1	Thermal Comfort — Permanent Monitoring System	√	—
1	Daylight & Views — Daylight 75% of Spaces		0
1	Daylight & Views — Views for 90% of Spaces		1
	Innovation & Design Process		
4	Innovation in Design		0
1	LEED™ Accredited Professional	√	—
69	**Summary**	15	11

4.4.1.7 Summary of Building One

It is shown in Table 4.4 that Building One hasn't achieved average scores in any of the six categories. Overall, the environmental performance of Building One is below average. It only achieved 20% of the total number of credits possible. The low score can be partly explained by the different code and regulation systems between Singapore and US. For some LEED credits e.g. "stormwater management", no relevant requirement can be found in local code and regulation. For other LEED credits e.g. "development footprint", their definitions are different from the definitions in local code and regulation. Therefore, it is not easy for local building to achieve satisfied score of the LEED assessment.

Table 4. 4 Summary of LEED-NC assessment for Building One

	Maximum credits achievable	Number of credits achieved	Percentage
Sustainable Sites	14	4	29%
Water Efficiency	5	2	40%
Energy & Atmosphere	7	1	14%
Materials & Resources	13	2	15%
Indoor Environmental Quality	11	2	18%
Innovation & Design Process	4	0	0%
Total	54	11	20%

Despite the above reason, there is a lot of room for improvement, particularly under the section of "energy & atmosphere", "materials & resources", and "indoor environmental quality". Further, the low score on material related credits and renewable energy indicates that improvement in these areas should be looked into, especially the recycle and reuse of material and energy.

4.4.2 LEED-NC assessment of Building Two

Table 4.6 explains the assessment of the existing design of Building Two under sustainable sites, water efficiency, energy & atmosphere, material & resources, indoor environmental quality, and innovation & design process, respectively.

4.4.2.1 Sustainable Sites

- **Erosion & Sedimentation Control —** There is no particular sedimentation control measures during construction stage.

- **Site Selection —** The site meets the credit requirement of avoid development of inappropriate sites and reduce the environmental impact.

- **Development Density ─** The site is located within the area of Gross Plot Ratio (GPR) 3.0 which meets the credit requirement of minimum development density of 60,000 square feet per acre (two story downtown development).

- **Brownfield Redevelopment ─** The site is not on a contaminated or brownfield site.

- **Alternative Transportation:**

  Public Transportation Access ─ The project site is located within 300m of LRT station, and within 200m there are four public bus lines usable by building occupants. One credit is achieved.

  Bicycle Storage & Changing Rooms ─ There are covered storage facilities for securing six bicycles on the ground floor of this building. However, it is much less than the required 15% of building occupants.

  Alternative Fuel Vehicles ─ There is no indication of providing alternative fuel vehicles for building occupants, or installing alternative-fuel refueling stations.

  Parking Capacity ─ HDB's development is required to comply with the minimum carparking provision as stipulated by LTA. There is no provision for carpools or vanpools, but it can be achieved easily.

- **Reduced Site Disturbance:**

Protect or Restore Open Space — The project site is neither Greenfield nor previously developed site.

Development Footprint —

As mentioned in the assessment of Building One, for the building to comply with the LEED criteria, the open space area adjacent to it has to be equal to that of the development footprint. For Building Two, the development footprint is $2067.5m^2$, and open space adjacent to the building (including common green) is 4500 m^2. The area of open space adjacent to Building Two greatly exceeds that of the development footprint. Hence Building Two has succeeded in fulfilling the requirement and is thus entitled to the credit.

- **Stormwater Management:**

Rate and Quantity — HDB does not track the volume of the stormwater discharge from the project site. There is no stormwater treatment facility required on-site as the stormwater is collected across the whole-catchment area to be treated at the local reservoirs.

Treatment — There is no stormwater treatment facility required on-site, and neither any local government best practices for stormwater treatment on-site.

- **Heat Island Effect:**

Non-Roof — All the parking spaces except one for disable persons are placed in a four-storey multi-storey carpark near by. One credit is achieved.

Roof ─ The project's roof is made of RC and Ferrocement which are not highly reflective and high emissivity materials, and there is no green (vegetated) area on the roof.

- **Light Pollution Reduction ─**

  There are four aspects of requirements. As explained in assessment of Building One, The first aspect is beyond the time and resources of the study in this context. Exterior site survey results reveal that Building Two has fulfilled the other three aspects of requirements: all the exterior luminaries do no exceed 1000 or 3500 initial lamp lumens; the maximum candela value of all interior lighting fall within the building; the maximum candela value of all the exterior lighting falls within the property because the lamps are all faced towards the property and appropriately shielded such that there is no spill over to adjacent property; and the exterior lamps are all appropriately shielded so no light from the luminaries cross the property boundary.

4.4.2.2 Water Efficiency

- **Water Efficient Landscaping:**

  Reduce by 50% ─ The landscaping is irrigated by rain. There is no potable water used for the irrigation.

  No Potable Use or No Irrigation ─ Permanent landscape irrigation system is not installed on the site.

- **Innovative Wastewater Technologies ─** There is no treatment of wastewater on-site.

- **Water Use Reduction (20%/30% Reduction) ─** The measured capacity of the water cisterns is 4.5 l/flush, which is 25% less than the requirement of the Energy Policy Act of 1992. Nevertheless, the measured results reveal that the average flow rate of faucet and showerhead are 0.187 l/s and 0.185 l/s respectively, which failed to meet the requirements. The measured average water consumption of Building Two is 296.6 l/capita/day, which is much more than the required 81 l/capita/day.

4.4.2.3 Energy & Atmosphere

- **Fundamental Building Systems Commissioning ─** HDB has implemented the following fundamental best practice commissioning procedures:
    - ♦ Engage a commissioning team that does not include individuals directly responsible for project design or construction management.
    - ♦ Review the design intent and the basis of design documentation.
    - ♦ Incorporate commissioning requirements into the construction documents.
    - ♦ Develop and utilize a commissioning plan.
    - ♦ Verify installation, functional performance, training and operation and maintenance documentation.

  There is no commissioning report, only the commissioning result e.g. "approval".

- **Minimum Energy Performance ─** There is no energy code for naturally ventilated buildings in Singapore.

- **CFC Reduction in HVAC&R Equipment —** This residential building is a natural ventilated building. There is no HVAC&R equipment in this building. Therefore, this credit is not applicable.

- **Optimize Energy Performance —** Building Two is designed to be naturally ventilated with no mechanical cooling system hence the Energy Cost Budget method is not applicable. Therefore, this credit is not applicable here.

- **Renewable Energy: 5% or 10% or 20% —** No on-site renewable energy is provided for this building.

- **Additional Commissioning —** According to HDB, a commissioning authority independent of the design team has conducted a review of the design after the construction documents phase, and an independent commissioning authority has conducted a review of the construction documents near completion of the construction document development and prior to issuing the contract documents for construction.

- **Ozone Protection —** This building is natural ventilated. There is no base building level HVAC&R equipment. The fire suppression systems do not contain HCFCs or Halons.

- **Measurement and Verification —** This building only has a single meter that tracks the electrical usage of all common area facilities like lighting, lifts and pumps.

- **Green Power ─** No green power is provided for this building.

4.4.2.4 Material & Resources

- **Storage & Collection of Recyclables ─** In this building, every floor has one refuse chute in the outdoor common area. But there is no area dedicated to recycled material collection and storage in the building.

- **Building Reuse: Maintain 75% or 100% of Existing Walls, Floors and Roof, Maintain 100% of Shell/Structure and 50% of Non-Shell/Non-Structure ─** This project is a new building. It does not reuse any existing building.

- **Construction Waste Management: Divert 50% or 75% From Landfill ─** HDB does not impose an active waste management system on the building contractor at construction stage.

- **Resource Reuse: 5% or 10% ─** No resource was reused in the project.

- **Recycled Content: 5% or 10% (post-consumer + 1/2 post-industrial) ─** No recycled content material was used in this building.

- **Regional Materials: 20% manufactured regionally and 50% extracted regionally ─** Concrete and sand used by the contractor in this project are from Malaysia and Indonesia, which are within the 500 mile radius. And concrete constitutes more than 80% of the whole materials used in the project. Therefore, 2 credits are achieved.

- **Rapidly Renewable Materials ─** No rapidly renewable materials was used in the project.

- **Certified Wood ─** Most wood used in the project is from Malaysia and Indonesia, which is tropical wood and is not certified.

4.4.2.5 Indoor Environmental Quality

- **Minimum IAQ Performance ─** According to the architect, the minimum openable window areas is 10% of the occupiable floor area, which fully compliant with the ASHRAE requirement of minimum 4%.

- **Environmental Tobacco Smoke (ETS) Control ─** The communal spaces of the building are not designated as non-smoking areas.

- **Carbon Dioxide (CO_2) Monitoring ─** This building is designed to be natural ventilated, and no centralized HVAC system is provided. However, 57 units in this building have installed air-conditioners, and all of them provide individual controls of the ventilation air flows. All communal areas are natural ventilated. Therefore, this credit is not applicable.

- **Ventilation Effectiveness ─** The only code that controls ventilation is the Building Code, which specifies minimum 10% ventilation for every room. HDB flats all comply with this requirement. However, according to the architect, there was no airflow simulation and sketches indicating the airflow pattern done by mechanical engineer during the design stage for this building.

- **Construction IAQ Management Plan: During Construction and Before Occupancy ─** This is a natural ventilated building therefore has no HVAC system to protect during the construction and flush-out is not applicable. However, according to the architect, there was no IAQ management plan to control pollutant sources and interrupt contamination pathways during the construction, neither any baseline indoor air quality testing before occupancy.

- **Low-Emitting Materials:**

  Adhesives & Sealants ─ There is no control on VOC emission level for adhesives and sealants.

  Paints ─ All HDB approved paints and coatings have to comply with PSB standard SS 150:1998 for interior applications and SS 345:1990 for exterior applications. In addition, primers for painting metal have to comply with SS 494:2001 to be lead and chromate free. Exact VOC emission levels cannot be obtained from product brochures, but all of them do not contain lead or mercury.

  Carpet ─ No carpet is used in the building. The credit is not applicable.

  Composite Wood ─ There is no control on composite wood and agrifiber products containing no added urea-formaldehyde resins.

- **Indoor Chemical & Pollutant Source Control ─** There is no permanent walkoff system for the entryway of the building. Although housekeeping areas are physically separated with deck to deck partitions and have plumbing systems, no outside exhaust is provided, and no negative pressure is maintained there.

- **Controllability of Systems: Perimeter Spaces ─** This building fulfills the LEED requirement that regularly occupied perimeter areas (e.g. living room and bed rooms) have a minimum of one operable window and one lighting control zone per 18.58m^2 (200 square feet) on average.

- **Non-Perimeter Spaces ─** The floor plan drawings reflect that there is no regularly occupied non-perimeter spaces in this building. This credit is not applicable.

- **Thermal Comfort: Compliance with ASHRAE 55-1992 ─**
  The calculation results of indoor measurement data show that the minimum, average, and maximum indoor operative temperature are 30.5°C, 30.7°C, and 31.0°C respectively. Therefore, Building Two fails to meet the 90% acceptability limit because its indoor operative temperature has exceeded the acceptable range of 24°C to 29°C as explained in assessment of Building One.

  Permanent Monitoring System ─ This building is designed to be naturally ventilated. This credit is not applicable.

- **Daylight and Views: Daylight 75% of Spaces ─** No rapidly
  The identified regularly occupied spaces in each unit consist of the Living/Dining room, the master bedroom, bedroom 2 and bedroom 3. The kitchen is not

considered to be a regularly occupied space in this case. Corridor units constitute 66.7% of all residential units in Building Two, while corner units constitute 33.3% of all residential units. The daylight factor for each window type is calculated using Equation 1 and Table 4.1. Table 4.5 shows total daylight factor for all the window types in these rooms. It is observed that the daylight factor is 2% or greater in Bedroom 3 of the corridor units as well as the master bedroom and bedroom 3 of the corner units in the block. The computation result shows that only 25% of the regularly occupied spaces meet the minimum daylight factor of 2%. Hence Building Two is not eligible for any point under this credit.

Table 4. 5 Floor area and daylight factor in Building Two

Rooms		Floor area (m^2)	Daylight factor (%)
Corridor units (66.7%)	Living room	41.0	1.2
	Master bedroom	17.0	0.8
	Bedroom 2	11.2	1.3
	Bedroom 3	12.3	2.5
Corner units (33.3%)	Living room	44.7	1.4
	Master bedroom	15.0	2.0
	Bedroom 2	13.2	2.3
	Bedroom 3	11.2	1.3

Views for 90% of Spaces — The floor plan drawings show that building occupants in all regularly occupied spaces will have direct lines of site to perimeter glazing.

4.4.2.6 Innovation and Design Process

- **Innovation in Design —** According to the architect, this building has no exceptional performance above the requirements set by the LEED Green Building Rating System, and no innovative performance in Green Building categories not specifically addressed by the LEED Green Building Rating System.

- **LEED Accredited Professional ─** This is not applicable in Singapore.

4.4.2.7 Summary of Building Two

Table 4.7 shows that Building Two fails to achieve average scores in any of the six categories. Overall, its environmental performance is below average. It only achieved 24% of the total number of credits possible. The low score can be partly due to two reasons as mentioned in the assessment of Building One. The first reason is the different code and regulation systems between Singapore and US. For some LEED credits, there is no relevant local requirement for local building industry to follow during the design and construction stages. The other reason is the limited attention to environmental sustainability of material and energy emphasized in the building industry then.

However, Building Two has achieved part of the requirement of some LEED credits. This is not reflected in the score because the building's performance failed to meet the other part of the requirement e.g. for "commissioning" credits, or the percentage achieved is lower than LEED required e.g. in "bicycle storage" credit.

4.4.3 Comparison of LEED-NC assessment results of Building One and Building Two

The comparison of LEED-NC assessment results of Building One and Building Two is shown in Table 4.8. It is observed that Building Two has better environmental performance in "sustainable sites" section than Building One. The two buildings have achieved same scores in the other five sections. Both buildings' environmental performances are below average.

Table 4. 6 LEED-NC assessment of Building Two

Possible Points	Assessed Issues	Not Applicable	Score achieved
	Sustainable Sites		
Prereq	Erosion & Sedimentation Control		—
1	Site Selection		1
1	Development Density		1
1	Brownfield Redevelopment		0
1	Alternative Transportation — Public Transportation Access		1
1	Alternative Transportation — Bicycle Storage & Changing Rooms		0
1	Alternative Transportation — Alternative Fuel Vehicles		0
1	Alternative Transportation — Parking Capacity		0
1	Reduced Site Disturbance — Protect or Restore Open Space		0
1	Reduced Site Disturbance — Development Footprint		1
1	Stormwater Management — Rate and Quantity		0
1	Stormwater Management — Treatment		0
1	Heat Island Effect — Non-Roof		1
1	Heat Island Effect — Roof		0
1	Light Pollution Reduction		1
	Water Efficiency		
1	Water Efficient Landscaping — Reduce by 50%		1
1	Water Efficient Landscaping — No Potable Use or No Irrigation		1
1	Innovative Wastewater Technologies		0
2	Water Use Reduction		0
	Energy & Atmosphere		
Prereq	Fundamental Building Systems Commissioning		—
Prereq	Minimum Energy Performance	√	—
Prereq	CFC Reduction in HVAC&R Equipment	√	—
10	Optimize Energy Performance	√	—
3	Renewable Energy		0
1	Additional Commissioning		0
1	Ozone Depletion		1
1	Measurement & Verification		0
1	Green Power		0
	Materials & Resources		
Prereq	Storage & Collection of Recyclables		—
3	Building Reuse		0
2	Construction Waste Management		0
2	Resource Reuse		0
2	Recycled Content		0
2	Local/Regional Materials		2
1	Rapidly Renewable Materials		0

Possible Points	Assessed Issues	Not Applicable	Score achieved
1	Certified Wood		0
	Indoor Environmental Quality		
Prereq	Minimum IAQ Performance		—
Prereq	Environmental Tobacco Smoke (ETS) Control		—
1	Carbon Dioxide (CO_2) Monitoring	√	—
1	Ventilation Effectiveness		0
1	Construction IAQ Management Plan, During Construction		0
1	Construction IAQ Management Plan, Before Occupancy		0
1	Low-Emitting Materials — Adhesives & Sealants		0
1	Low-Emitting Materials — Paints		0
1	Low-Emitting Materials — Carpet	√	—
1	Low-Emitting Materials — Composite Wood		0
1	Indoor Chemical & Pollutant Source Control		0
1	Controllability of Systems — Perimeter		1
1	Controllability of Systems — Non-Perimeter	√	—
1	Thermal Comfort — Comply with ASHRAE 55-1992		0
1	Thermal Comfort — Permanent Monitoring System	√	—
1	Daylight & Views — Daylight 75% of Spaces		0
1	Daylight & Views — Views for 90% of Spaces		1
	Innovation & Design Process		
4	Innovation in Design		0
1	LEED™ Accredited Professional	√	—
69	**Summary**	15	13

Table 4. 7 Summary of LEED-NC assessment for Building Two

	Maximum credits achievable	No. of credits achieved	Percentage
Sustainable Sites	14	6	43%
Water Efficiency	5	2	40%
Energy & Atmosphere	7	1	14%
Materials & Resources	13	2	15%
Indoor Environmental Quality	11	2	18%
Innovation & Design Process	4	0	0%
Total	54	13	24%

According to the assessment results, the better environmental performance of Building Two are reflected in "reduced site disturbance" aspect that Building Two has plenty open space and greenery adjacent to it, and in "heat island effect" aspect by placing all the parking spaces except one for disable persons in a four-storey multi-storey carpark near by. In addition, Building Two has some improvement in providing bicycle storage, although it is not reflected in the LEED score achieved.

Table 4. 8 Comparison of LEED-NC assessment results of Building One and Building Two

	Score achieved	
	Building One	Building Two
Sustainable Sites	4	6
Water Efficiency	2	2
Energy & Atmosphere	1	1
Materials & Resources	2	2
Indoor Environmental Quality	2	2
Innovation & Design Process	0	0
Total	11	13

The comparison results also demonstrate the improvement of outdoor environment in public housing in Singapore especially in the enlargement of open space and greenery in the precinct, reduction of heat island effect by centralizing car parking into multi-storey carpark, and bicycle storage provision on the ground floor of HDB blocks.

The low LEED score of the two buildings can be primarily explained by two reasons as mentioned before: the different code and regulation systems between Singapore and US, and the amount of attention emphasized for material and energy. LEED criteria relevant to the different code and regulation systems constitute 30% of the total number of scores applicable for local HDB buildings. Since there is no relevant local requirement for the two HDB buildings to follow during the design and construction stages, it is not easy for them to achieve satisfied score in these criteria.

However, the assessment results of the two HDB blocks reveal a common problem in local public housing: the limited attention to environmental sustainability of material and energy. In LEED-NC, material related criteria constitute 35% of the total number of scores achievable for local HDB buildings, and renewable/green energy related criteria constitute another 7%. The assessed two buildings only achieve 2 credits (9%) in the material and renewable/green energy related credits.

4.5 Applicability of LEED-NC to Public Housing in Singapore

It is observed in Table 4.6 that 22% (15 credits) of LEED-NC criteria are not applicable to local public housing. This is primarily due to the tropical climate and the fact that local public housing is designed to be natural ventilated. Therefore, heating related criteria and air-conditioning related criteria are not applicable to HDB buildings.

Besides, the code and regulation systems used in US are different from those used in Singapore especially for public housing. In LEED-NC, criteria relevant to the different code and regulation systems constitute 30% of the total number of scores achievable for local HDB buildings. For these criteria, no relevant requirement can be found in local code and regulation for HDB housing to follow during the design and construction stages. Consequently, it is very difficult for local public housing to achieve satisfied score of the LEED assessment. Furthermore, the difficulty to access the US code and regulation required in LEED and the software required for LEED simulation have brought great difficulty in the assessment process of the two HDB blocks.

Therefore, although the majority (78%) of LEED-NC criteria is applicable, the environmental sustainable assessments of local public housing do need a Singapore/tropical version. In this version, relevant local code and regulation should replace the US ones and simulation software needs to be available. Hence, it is easy for local building industry to understand the requirements of environmental sustainability, to follow the requirements during the design and construction stages, and to prepare the assessment submittals. This will also improve the environmental sustainability of public housing, and simplify the assessment process conducted by the authority in charge.

4.6 Conclusion

The assessment results indicate that Building Two has better environmental performance than Building One. Building Two achieved 24% of the total number of credits possible in LEED-NC assessment, while Building One only achieved 20% of the total number of credits possible in LEED-NC assessment. However, both buildings have failed to achieve average score in the assessment.

The assessment results also demonstrate the significant improvement of outdoor environment as well as indoor environmental quality in local public housing. The improvement is mainly presented in following aspects:

- Enlarging open space and greenery in the precinct
- Reducing heat island effect by centralizing car parking into multi-storey carpark
- Providing bicycle storage on the ground floor of HDB blocks and cycling paths in the precinct
- Using durable and reusable formwork systems to replace timbers formwork during the construction
- Using standardized prefabricated building elements in the design and construction
- Improving natural ventilation

- Improving indoor daylight
- water conservation in water cisterns (not reflected in the assessment score)
- high cooker hood usage rate (not reflected in the assessment score)

However, there is still a lot of room for local public housing to improve. The assessment results reveal that local public housing has paid limited attention to environmental sustainability of material, renewable/green energy and local environment protection, especially the recycle and reuse of material and energy. Being an island country with limited natural resources, it is urgent for Singapore to upgrade the material usage in building industry now.

There are 22% of LEED-NC criteria not applicable to local public housing primarily due to the tropical climate in Singapore and the fact that local public housing is designed to be natural ventilated. However, the remained 78% of LEED-NC criteria do need major revision before they can be used to assess local public housing. Furthermore, the US code and regulation required in LEED and the software required for LEED simulation are not easy to access, thus cause trouble to the assessment process. Therefore, a Singapore/tropical version for local public housing assessment is needed.

CHAPTER 5 BUILDING EXPERT SURVEY

5.1 Introduction

A local building expert survey was conducted to investigate local building experts' opinions towards the importance of identified environmental sustainable issues which are relevant to Singapore and the tropical context with respect to residential developments.

5.2 Objectives of Building Expert Survey

The data gathered from building expert survey will be used to prioritize different environmental issues according to the ratings provided by respondents. Weights will be generated for each environmental criterion based on the experts' opinion. The new environmental sustainable assessment criteria and protocol will then be developed using these weights as a foundation in assigning score for each criterion. The objectives of the building expert survey are to:

- Adjust the identified criteria
- Construct weighting scales of the new environmental assessment protocol

5.3 Methodology

5.3.1 Sample design for building expert survey

Random sampling method was used to select the respondents for this survey because the population of the whole building experts in Singapore is unknown. Local experts who are concerned with the build environment of Singapore, and are within the building sector have been selected for this survey. These selected local building experts included 500 Singapore Institute of Architects (SIA) registered architects, 1000 Professional Engineers Board (PEB) registered professional engineers including civil, electrical, and mechanical engineers, faculties of architecture, building, and civil engineering departments in NUS, and HDB officers. In total, 171 building experts responded to this survey. Therefore the actual sample size is 171 persons.

5.3.2 Questionnaire design for building expert survey

Prior to the survey, a review of the various major building environmental assessment methods in use has been conducted. The key environmental issues which are relevant to local public housing industry have been identified. They cover three levels: unit level, block level, and precinct level. This is to facilitate the environmental assessment for different parts of residential buildings. These environmental issues are classified into five groups, namely sustainable site, water efficiency, energy use, material & resources, and indoor environmental quality. The main target areas for assessment are planning, design, construction and commissioning of the building and engineering systems.

The questionnaire is divided into two sections (see Appendix B). Section A quizzes the experts on these identified environmental issues. The respondents are asked to rate on the Likert five-point scale based on the importance of the identified environmental issues concerning local residential buildings. The results obtained will be used to generate a weighting scale for the new environmental assessment protocol. Section B is the respondents' details, such as gender, occupation, education background, and residence experience. It provides better understanding of the respondents' professional, educational, and residential backgrounds.

5.3.3 Data collection

The selected experts were invited to complete the survey form according to the instructions provided and return the form to the sender. The survey form was sent individually to every selected building expert. Since the communication through email is convenient, the survey forms were sent to the selected experts by email except the 1000 professional engineers to who the survey forms were sent by post, because their email addresses were unknown. The corresponding email address and mail address were abstracted from personal contacts and PEB website.

5.3.4 Data processing

Completed survey forms were returned through email, fax, and post. Microsoft Excel software program was used for the analysis of data. The descriptive statistics was employed to analyze the survey data.

5.4 Survey Results Analyses

5.4.1 Respondents' background

5.4.1.1 Age

As shown in Figure 5.1, the majority of the respondents are between 30 to 59 years old: 36.3% of the respondents are in their forties, 29.8% of the respondents are in their thirties, 25% of the respondents are in their fifties. Only 2.4% of the respondents are in their twenties and 6.5% of the respondents are older than sixty years old.

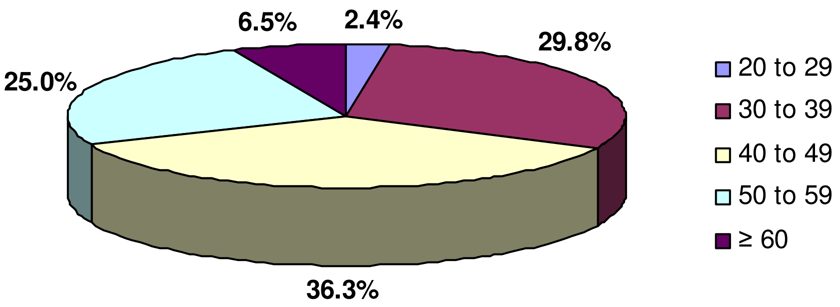


Figure 5. 1 Age group distribution of respondents

5.4.1.2 Gender

There are much more male respondents than female respondents. As shown in Figure 5.2, 86.3% of the respondents are male. However, only 13.7% of the respondents are Female.

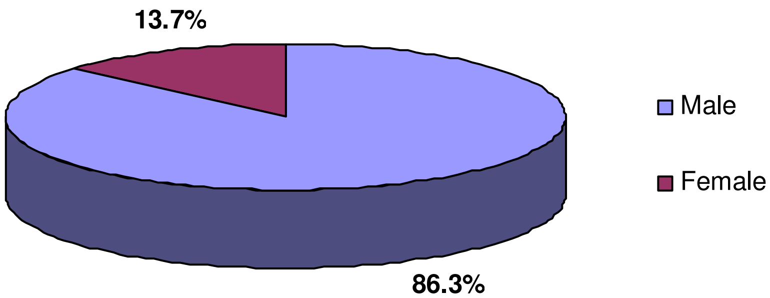


Figure 5. 2 Gender of respondents

5.4.1.3 Profession

- **Occupation**

Figure 5.3 indicates that the majority of respondents are M&E engineers (47.6%), architects (26.8%), and civil engineers (12.5%). Other respondents are faculties of educational institute (5.4%), government officers (4.8%), building managers (1.8%), and other occupation.

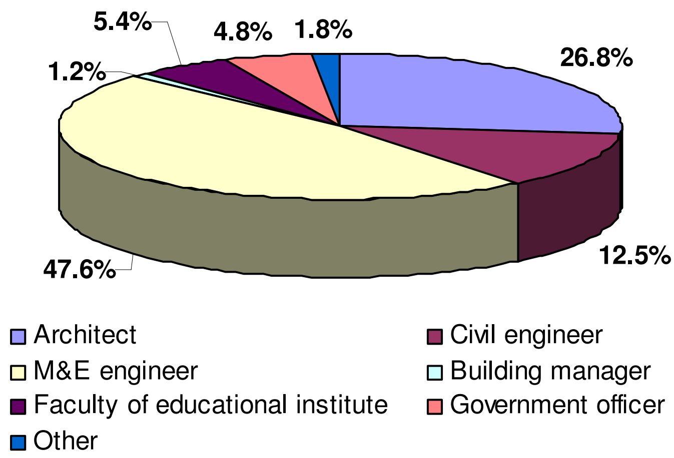


Figure 5. 3 Occupation distribution of respondents

- **Working experience**

The results reveal that most respondents (96.3%) have more than five years' working experience (Figure 5.4). This may be explained by the sample selection. Survey forms were sent to 500 SIA registered architects and 1000 PEB registered professional engineers, and normally building experts need sufficient working experience to be able to registered with SIA and PEB, therefore it is reasonable that most respondents have worked for more than five years. This is beneficial to the survey because experienced building experts tend to have more comprehensive understanding of building environment.

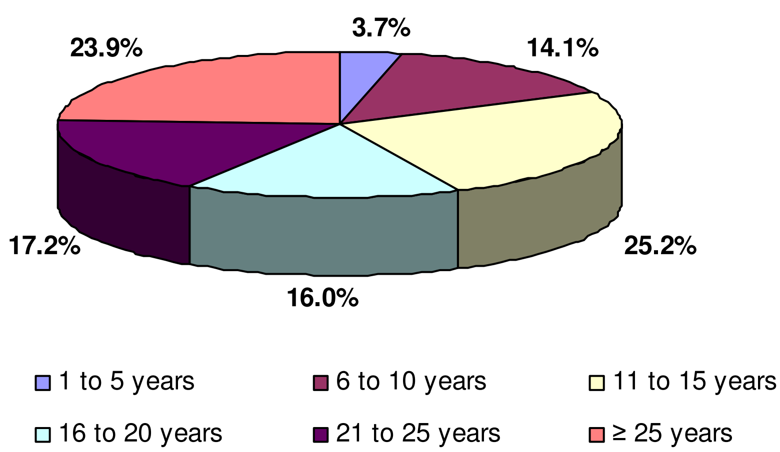


Figure 5. 4 Working experience of respondents

5.4.1.4 Education

- **Highest education degree**

The results show that more than half of the respondents (58.9%) have Bachelor degree, and 33.3% of the respondents have Master degree. Only 4.8% of the respondents have Diploma and 3% respondents have PhD degree. Figure 5.5 reveals that the majority of respondents are highly educated.

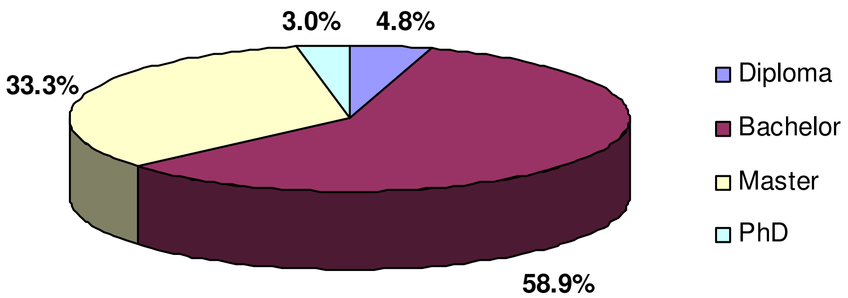


Figure 5. 5 Education level of respondents

- **Professional background**

Figure 5.6 indicates that among the respondents, 49.1% have M&E engineering background, 29.3% have architecture background, and 12.6% have civil engineering background. This distribution matches respondents' occupation distribution well: 47.6% M&E engineers, 26.8% architects, and 12.5% civil engineers.

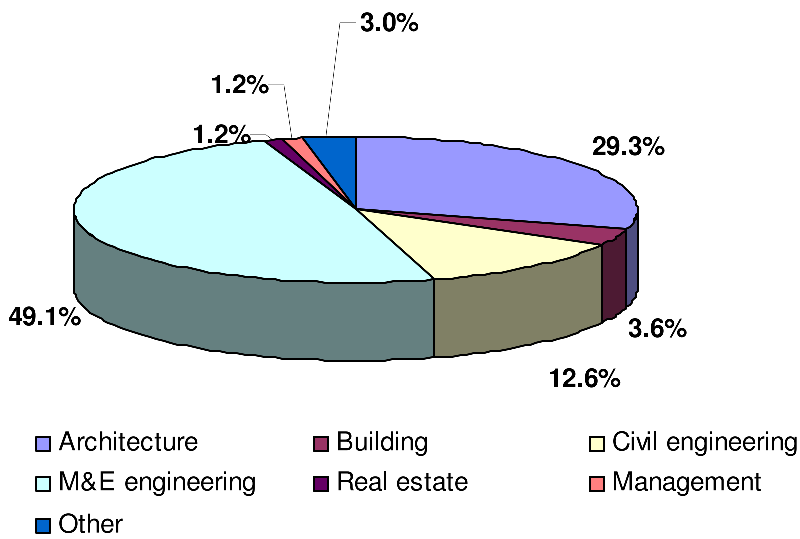


Figure 5. 6 Professional background of respondents

- **Location**

Figure 5.7 illustrated that more than half (51.5%) of respondents received local education, 31.5% of respondents received their education overseas, and 17% respondents received both local and overseas education.

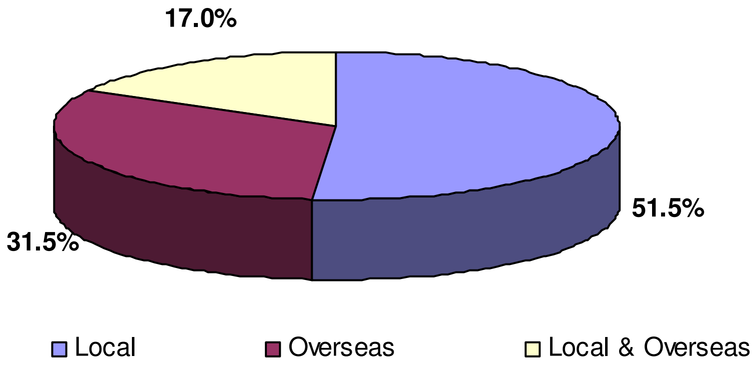


Figure 5. 7 Place of receiving education of respondents

5.4.1.5 Residence

- **Present residence**

As shown in Figure 5.8, at present, the majority of the respondents live in HDB apartments (40.4%) and condominium (38.6%). There are 15.7% of the respondents live in semidetached houses and 5.4% of the respondents live in detached houses.

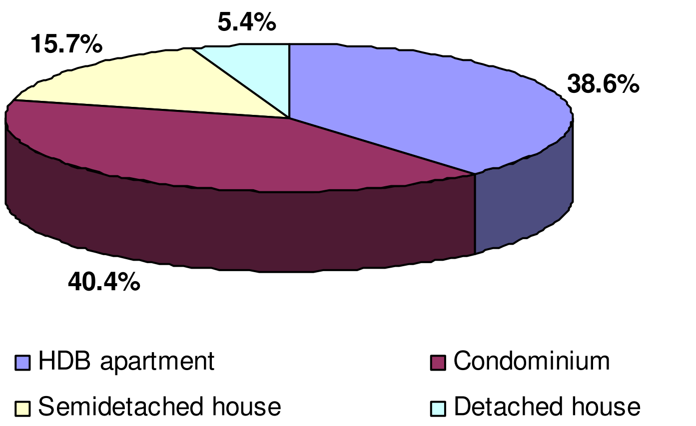


Figure 5. 8 Present residence of respondents

- **Time lived in present residence**

The results reflect that 79.8% of the respondents have lived in their present residence less than sixteen years: 29.8% of the respondents have lived in their present residence less than six years, 30.4% of the respondents have lived in their present residence between six and ten years, and 19.6% of the respondents have lived in their present residence between ten and fifteen years (see Figure 5.9). Only 11.9% of the respondents have lived in their present residence more than twenty years.

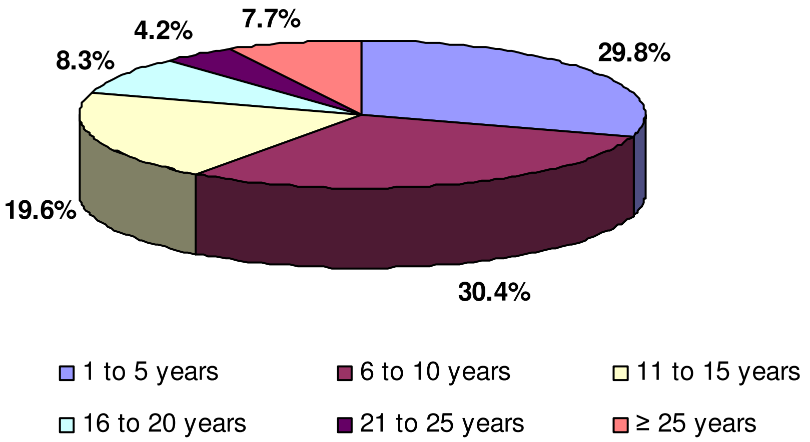


Figure 5. 9 Year lived in present residence of respondents

- **HDB apartment living experience**

Figure 5.10 indicates that 81% of respondents have lived in HDB apartments, while the other 19% have no HDB apartment living experience. This may have some effects on their opinions towards building environment of residential buildings because of their different living experience.

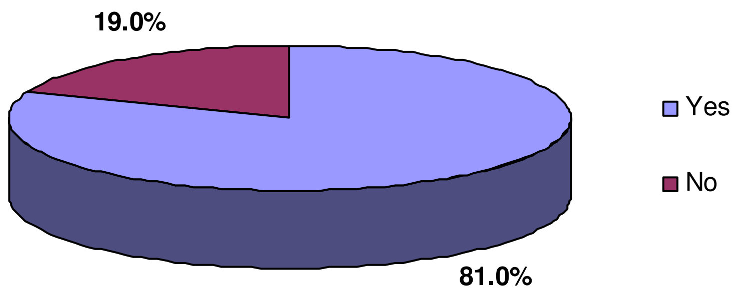


Figure 5. 10 HDB apartment living experience of respondents

- **Time lived in HDB apartment**

The results reveal that more than half (63.2%) of the respondents has one to fifteen years' living experience in HDB apartments (see Figure 5.11), and 15.4% of the respondents has more than twenty five years' living experience in HDB apartments.

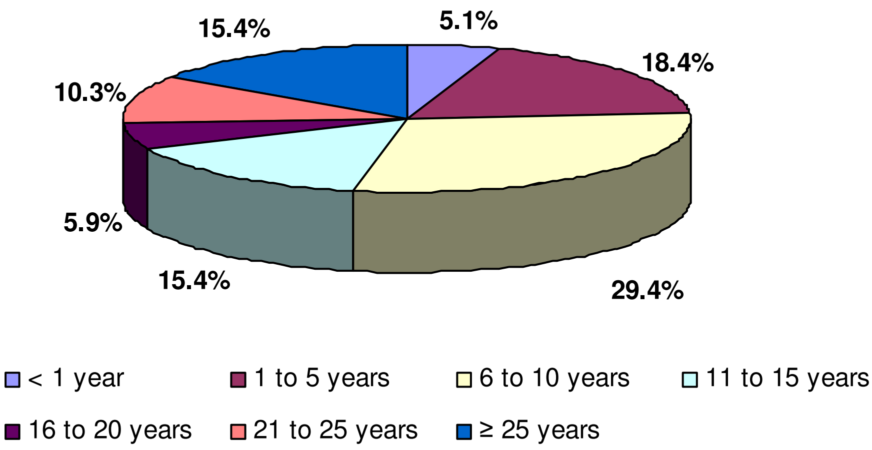


Figure 5. 11 Year lived in HDB apartment of respondents

5.4.2 Respondents' opinions towards building environment of residential buildings

Since the respondents are asked to rate on the Likert five-point scale based on the importance of the identified environmental issues concerning local residential buildings, the mean rating of the importance of the identified environmental issues may be used to reveal the respondents' opinions towards environmental sustainable issues related to residential buildings in local and tropical context. Table 5.1 shows the mean importance rating of the identified issues where 1 = least important; 2 = less important; 3 = important; 4 = more important; and 5 = most important. Therefore, the identified issues with mean important rating not less than "3" can be considered as important to the environmental sustainability of residential buildings and thus will be included in the new environmental sustainable assessment criteria and protocol.

The results reveal that all the mean important ratings of identified issues are not less than "3", therefore according to the respondents' opinions, all the identified issues are important to the environmental sustainability of residential buildings in local and tropical context.

As shown in Table 5.1, the issue "No asbestos" has the highest mean importance rating 4.46, while the issue "Local/regional materials" has the lowest mean importance rating 3.15. According to the respondents' opinions, eleven issues are considered as "more important" regarding the environmental sustainability of residential buildings in Singapore. Among them, four issues are related to ventilation, two issues are about energy efficient lighting in communal areas, and two issues are concerning public transportation access. These eleven issues are:

- **Unit level**

a. Natural ventilation

b. Ventilation effectiveness

c. Thermal comfort

d. Daylight & views

- **Block level**

a. Public transportation access

b. Natural ventilation

c. Energy efficient lighting in public areas

d. No asbestos

e. Ventilation effectiveness

- **Precinct level**

a. Local transportation and amenities

Table 5. 1 Mean important rating for different identified issues

Identified environmental issues	Number of respondents					Mean rating
	1#	2#	3#	4#	5#	
UNIT LEVEL						
Water Efficiency						
Water efficient devices	4	17	29	67	54	3.88
Energy Use						
CO_2 emission due to energy consumption	8	24	59	51	27	3.38
Natural ventilation	1	1	24	59	85	4.33
Hot water supply	2	20	44	71	33	3.66
Energy efficient appliances	0	10	30	89	42	3.95
Indoor Environmental Quality						
Ventilation effectiveness	1	6	33	72	59	4.06
Cooker hood	2	30	53	59	27	3.46
Thermal comfort	2	3	33	75	55	4.07
Daylight & views	3	5	27	76	59	4.08
Room acoustics	2	9	49	77	34	3.77
Noise isolation	0	14	52	72	32	3.72
Indoor sources of air pollution	1	7	48	60	55	3.94
BLOCK LEVEL						
Sustainable Site						
Urban redevelopment	2	24	68	58	12	3.33
Public transportation access	1	1	20	75	70	4.27
Heat island effect	0	12	41	80	34	3.81
Construction management	1	18	71	62	17	3.45
Pollution during construction	0	4	42	79	44	3.96
Noise from building equipment	0	4	46	78	41	3.92
Building user handbook	4	20	75	41	29	3.42
Water Efficiency						
Innovative wastewater technologies	2	12	54	62	38	3.72
Metering and controls	2	22	60	53	31	3.54
Water quality	1	12	43	59	54	3.92
Water recycling	3	13	44	58	50	3.83
Energy Use						
Improvement of the average U-value	1	7	43	78	41	3.89
Building orientation	5	11	39	63	51	3.85
CO_2 emission due to energy consumption in public areas	6	20	65	67	11	3.34
Renewable energy	3	21	65	58	21	3.44
Clothes drying facilities	4	10	52	64	39	3.73
Natural ventilation	1	6	33	65	63	4.09
Energy efficient lighting in public areas	1	5	30	73	60	4.10
Energy efficient appliances	1	10	41	75	42	3.87
Energy consumption on site	5	24	68	58	14	3.31

Identified environmental issues	Number of respondents					Mean rating
	1#	2#	3#	4#	5#	
Building systems commissioning	2	13	60	68	26	3.61
Metering and monitoring	1	20	65	53	30	3.54
Operation and maintenance manual	2	12	69	61	25	3.56
Materials & Resources						
Recycled materials	2	21	71	50	24	3.43
Resource reuse	2	29	69	47	21	3.33
Rapidly renewable materials	5	29	67	52	15	3.26
Local/regional materials	3	32	77	49	7	3.15
Sustainable forest products	1	24	58	58	27	3.51
Green building materials	3	10	71	61	23	3.54
Off-site fabrication	2	23	61	57	25	3.48
Ozone depletion	1	13	39	64	51	3.90
No asbestos	1	6	16	37	108	4.46
Adaptability and deconstruction	2	7	49	75	35	3.80
Modular and standardized design	2	12	45	66	42	3.80
Construction waste management	1	11	58	70	28	3.67
Storage of recyclables and waste disposal	2	10	64	61	31	3.65
Indoor Environmental Quality						
Ventilation effectiveness	1	3	36	65	62	4.10
PRECINCT LEVEL						
Sustainable Site						
Contaminated land	0	6	51	64	46	3.90
Local transportation and amenities	0	7	31	74	56	4.07
Heat island effect	1	6	53	68	38	3.82
Ecological impact	1	8	51	66	41	3.83
Landscaping and planters	1	6	41	74	46	3.93
Microclimate around buildings	4	22	74	57	11	3.29
Overshadowing and views	1	14	65	59	28	3.59
Vehicular access	2	8	56	59	42	3.78
Stormwater management	1	8	56	74	30	3.73
Light pollution reduction	3	22	67	58	19	3.40
Low environmental impact pest management policy	1	13	68	57	30	3.60
Pollution during construction	0	3	49	81	36	3.89
Water Efficiency						
Water efficient landscaping	1	7	42	68	50	3.95
Energy Use						
Energy efficient lighting in external areas	1	4	30	72	62	4.12
Materials & Resources						
Storage of recyclables and waste disposal	1	8	56	68	36	3.77
Indoor Environmental Quality						
IAQ in car parks	2	17	56	61	33	3.63

b. Energy efficient lighting in external areas

5.4.3 Respondents' background versus their opinions

Among their background in the five aspects, respondents' occupation, place to receive education and residential experience tend to be the most significant factors that may affect their opinions towards the importance of environmental issues.

5.4.3.1 Occupation

The majority of respondents are M&E engineers (47.6%), architects (26.8%), and civil engineers (12.5%). Other respondents are faculties of educational institute (5.4%), government officers (4.8%), building managers (1.8%), and other occupation. Table 5.2 shows the mean important rating of environmental issues from respondents with different occupations. It also reveals the three most important environmental issues from the viewpoint of M&E engineers, architects, civil engineers, faculties of educational institute, and government officers respectively. Only two respondents are building management, therefore their ranking are not representative and their highest three mean rating are not indicated here. The results reflect that respondents' occupation do affect their opinions towards environmental sustainability. Respondents with different occupations have their proper perspectives of the importance of different environmental sustainable issues of residential developments.

5.4.3.2 Place to receive education

More than half (51.5%) of respondents received local education, 31.5% of respondents received their education overseas, and 17% respondents received both local and overseas education. As shown in Table 5.3, the three most important environmental issues from the respondents' point of view are identical despite the places where they received education are local or overseas. However, respondents who received both local and overseas education have higher mean importance rating on unit (4.04), building (3.83) and precinct (3.90) levels than respondents who received their education overseas (3.92, 3.65, 3.66 respectively) and respondents who received local education (3.75, 3.65, 3.78 respectively). The results also reflect that respondents from the group of overseas education and the group of both local and overseas education tend to care most about environmental sustainability at unit level. On the contrary, respondents from the group of local education are likely to concern environmental sustainability at precinct levels most.

5.4.3.3 Residential experience

- **Present residence**

The majority of the respondents live in HDB apartments (40.4%) and condominium (38.6%). There are 15.7% of the respondents live in semidetached houses and 5.4% of the respondents live in detached houses. The results reveal that all the four groups of respondents regard "no asbestos" as the most important environmental issues of residential buildings (see Table 5.4) despite their different types of present residence.

Table 5. 2 Mean important rating from respondents with different occupations

Identified environmental issues	Mean rating					
	ME	Arch	CE	FE	GO	BM
UNIT LEVEL						
Water Efficiency						
Water efficient devices	3.83	3.82	4.10	4.11	3.88	3.00
Energy Use						
CO_2 emission due to energy consumption	3.45	3.20	3.62	3.00	4.00	2.50
Natural ventilation	4.36	4.39	4.05	4.22	4.50	4.50
Hot water supply	3.63	3.57	3.71	3.56	4.50	3.00
Energy efficient appliances	3.93	3.89	4.10	3.78	4.38	3.50
Indoor Environmental Quality						
Ventilation effectiveness	4.00	4.16	4.19	3.78	4.13	4.50
Cooker hood	3.48	3.42	3.48	3.67	3.38	4.50
Thermal comfort	3.99	4.11	4.05	4.22	4.43	4.50
Daylight & views	3.92	4.27	4.00	3.89	4.38	4.50
Room acoustics	3.76	3.64	3.81	4.00	4.25	4.50
Noise isolation	3.69	3.62	3.75	4.11	4.13	4.50
Indoor sources of air pollution	4.08	3.49	4.19	4.44	4.25	4.50
BLOCK LEVEL						
Sustainable Site						
Urban redevelopment	3.16	3.35	3.67	3.67	3.63	3.00
Public transportation access	4.30	4.12	4.43	4.56	4.25	4.00
Heat island effect	3.77	3.70	3.86	3.89	4.25	4.00
Construction management	3.47	3.27	3.67	3.22	3.75	4.50
Pollution during construction	4.03	3.78	4.14	3.89	4.00	4.50
Noise from building equipment	3.85	3.86	4.00	4.33	4.00	4.50
Building user handbook	3.46	3.48	3.33	2.78	3.63	2.50
Water Efficiency						
Innovative wastewater technologies	3.68	3.59	3.90	3.89	4.13	2.50
Metering and controls	3.42	3.52	3.90	3.44	3.88	2.50
Water quality	3.83	4.09	3.95	4.00	4.13	2.50
Water recycling	3.67	3.91	3.95	4.00	4.63	2.50
Energy Use						
Improvement of the average U-value	3.84	3.96	3.67	4.00	4.25	4.50
Building orientation	3.78	4.07	3.86	3.67	3.75	3.00
CO_2 emission due to energy consumption in public areas	3.35	3.27	3.48	3.22	3.50	3.50
Renewable energy	3.38	3.44	3.48	3.11	4.00	3.00
Clothes drying facilities	3.77	3.84	3.71	3.11	3.88	3.50
Natural ventilation	4.25	3.86	4.05	3.89	3.88	4.00
Energy efficient lighting in public areas	4.16	4.02	3.95	3.78	4.50	4.00
Energy efficient appliances	3.92	3.69	4.00	3.78	4.13	3.00
Energy consumption on site	3.33	3.30	3.43	3.00	3.63	2.50
Building systems commissioning	3.78	3.53	3.38	3.56	3.38	3.00
Metering and monitoring	3.65	3.44	3.43	3.78	3.13	3.00

Identified environmental issues	Mean rating					
	ME	Arch	CE	FE	GO	BM
Operation and maintenance manual	3.65	3.60	3.48	3.00	3.50	3.00
Materials & Resources						
Recycled materials	3.28	3.47	3.86	3.33	3.63	2.50
Resource reuse	3.19	3.36	3.67	3.33	3.50	2.50
Rapidly renewable materials	3.08	3.22	3.67	3.56	3.38	2.50
Local/regional materials	3.04	3.27	3.24	3.22	3.25	3.00
Sustainable forest products	3.37	3.56	3.76	3.22	4.00	3.00
Green building materials	3.49	3.49	3.86	3.22	3.75	3.00
Off-site fabrication	3.40	3.71	3.57	3.00	3.38	3.00
Ozone depletion	3.86	3.76	4.38	3.56	3.75	3.00
No asbestos	4.53	4.36	4.67	4.11	4.38	4.00
Adaptability and deconstruction	3.74	3.93	3.76	3.56	3.63	4.50
Modular and standardized design	3.77	3.89	3.86	3.67	3.75	4.00
Construction waste management	3.68	3.51	3.86	3.67	4.00	3.50
Storage of recyclables and waste disposal	3.62	3.56	3.81	3.44	4.13	3.50
Indoor Environmental Quality						
Ventilation effectiveness	4.06	4.11	4.05	4.00	4.29	4.50
PRECINCT LEVEL						
Sustainable Site						
Contaminated land	3.74	3.93	4.33	4.00	3.63	4.00
Local transportation and amenities	4.09	3.89	4.33	3.89	4.25	4.50
Heat island effect	3.79	3.73	3.86	3.67	4.00	4.50
Ecological impact	3.77	3.86	3.95	3.44	3.88	4.00
Landscaping and planters	3.81	4.13	4.00	3.56	4.13	4.00
Microclimate around buildings	3.27	3.18	3.52	3.22	3.50	3.50
Overshadowing and views	3.55	3.62	3.57	3.56	3.75	4.00
Vehicular access	3.74	3.80	4.05	3.56	3.88	4.50
Stormwater management	3.73	3.69	3.95	3.56	3.63	3.50
Light pollution reduction	3.39	3.29	3.48	3.11	3.63	4.00
Low environmental impact pest management policy	3.59	3.47	3.71	3.89	3.88	4.50
Pollution during construction	3.85	3.78	4.10	4.00	4.00	4.50
Water Efficiency						
Water efficient landscaping	3.89	3.95	4.10	3.78	4.38	3.00
Energy Use						
Energy efficient lighting in external areas	4.04	4.18	4.14	4.22	4.38	3.50
Materials & Resources						
Storage of recyclables and waste disposal	3.71	3.73	4.00	3.44	4.13	3.50
Indoor Environmental Quality						
IAQ in car parks	3.67	3.53	3.71	3.44	3.25	4.50

Notes: "ME" means M&E engineer; "Arch" means architect; "CE" means civil engineer; "FE" means faculty of educational institute; "GO" means government officer; and "BM" means building managers.

[magenta] Means the highest mean rating by respondents within the same occupation.
[yellow] Means the second highest mean rating by respondents within the same occupation.
[cyan] Means the third highest mean rating by respondents within the same occupation.

Table 5. 3 Mean important rating from respondents receive education at different places

Identified environmental issues	Mean rating		
	Local	Overseas	L&O
UNIT LEVEL			
Water Efficiency			
Water efficient devices	3.73	4.02	4.00
Energy Use			
CO_2 emission due to energy consumption	3.31	3.46	3.43
Natural ventilation	4.25	4.33	4.57
Hot water supply	3.60	3.81	3.50
Energy efficient appliances	3.86	4.08	3.93
Indoor Environmental Quality			
Ventilation effectiveness	3.93	4.12	4.32
Cooker hood	3.38	3.52	3.68
Thermal comfort	3.93	4.08	4.43
Daylight & views	3.99	4.08	4.21
Room acoustics	3.65	3.79	4.07
Noise isolation	3.64	3.69	3.93
Indoor sources of air pollution	3.78	4.00	4.36
BLOCK LEVEL			
Sustainable Site			
Urban redevelopment	3.28	3.37	3.33
Public transportation access	4.22	4.19	4.52
Heat island effect	3.82	3.80	3.64
Construction management	3.32	3.62	3.43
Pollution during construction	3.93	3.88	4.11
Noise from building equipment	3.96	3.75	4.07
Building user handbook	3.43	3.25	3.64
Water Efficiency			
Innovative wastewater technologies	3.66	3.65	3.93
Metering and controls	3.65	3.29	3.54
Water quality	3.85	3.83	4.21
Water recycling	3.80	3.71	4.11
Energy Use			
Improvement of the average U-value	3.92	3.75	4.00
Building orientation	3.95	3.75	3.79
CO_2 emission due to energy consumption in public areas	3.32	3.17	3.64
Renewable energy	3.44	3.25	3.64
Clothes drying facilities	3.69	3.67	4.00
Natural ventilation	3.99	4.06	4.43
Energy efficient lighting in public areas	4.08	4.06	4.25
Energy efficient appliances	3.81	3.83	4.11
Energy consumption on site	3.30	3.33	3.32
Building systems commissioning	3.56	3.49	3.93
Metering and monitoring	3.47	3.51	3.79

Identified environmental issues	Mean rating		
	Local	Overseas	L&O
Operation and maintenance manual	3.61	3.41	3.71
Materials & Resources			
Recycled materials	3.38	3.55	3.32
Resource reuse	3.32	3.45	3.18
Rapidly renewable materials	3.18	3.43	3.07
Local/regional materials	3.06	3.29	3.14
Sustainable forest products	3.31	3.67	3.75
Green building materials	3.42	3.57	3.75
Off-site fabrication	3.37	3.41	3.86
Ozone depletion	3.87	3.75	4.14
No asbestos	4.39	4.45	4.64
Adaptability and deconstruction	3.76	3.78	3.89
Modular and standardized design	3.74	3.80	4.04
Construction waste management	3.65	3.75	3.61
Storage of recyclables and waste disposal	3.61	3.65	3.68
Indoor Environmental Quality			
Ventilation effectiveness	4.09	3.96	4.32
PRECINCT LEVEL			
Sustainable Site			
Contaminated land	3.85	3.81	4.11
Local transportation and amenities	4.16	3.77	4.39
Heat island effect	3.89	3.67	3.82
Ecological impact	3.85	3.69	3.89
Landscaping and planters	3.99	3.83	3.96
Microclimate around buildings	3.31	3.25	3.21
Overshadowing and views	3.55	3.50	3.82
Vehicular access	3.83	3.65	3.93
Stormwater management	3.73	3.71	3.79
Light pollution reduction	3.37	3.38	3.39
Low environmental impact pest management policy	3.61	3.50	3.86
Pollution during construction	3.90	3.79	4.00
Water Efficiency			
Water efficient landscaping	3.89	3.90	4.14
Energy Use			
Energy efficient lighting in external areas	4.14	3.88	4.43
Materials & Resources			
Storage of recyclables and waste disposal	3.74	3.69	3.89
Indoor Environmental Quality			
IAQ in car parks	3.59	3.59	3.71

Notes: "L&O" means local and overseas.

(magenta) Means the highest mean rating by respondents within the same occupation.
(yellow) Means the second highest mean rating by respondents within the same occupation.
(cyan) Means the third highest mean rating by respondents within the same occupation.

Table 5. 4 Mean important rating from respondents with different residential experience

Identified environmental issues	Mean rating					
	HDB	Con	SDH	DH	Yes	No
UNIT LEVEL						
Water Efficiency						
Water efficient devices	3.83	3.94	3.81	3.78	3.86	3.91
Energy Use						
CO_2 emission due to energy consumption	3.30	3.39	3.35	3.67	3.38	3.41
Natural ventilation	4.30	4.36	4.36	4.11	4.35	4.25
Hot water supply	3.64	3.63	3.92	3.11	3.69	3.52
Energy efficient appliances	3.92	3.96	4.15	3.33	4.01	3.66
Indoor Environmental Quality						
Ventilation effectiveness	3.97	4.15	4.12	3.78	4.06	4.09
Cooker hood	3.59	3.36	3.50	3.56	3.44	3.63
Thermal comfort	4.10	4.00	4.12	4.00	4.10	3.91
Daylight & views	4.00	4.09	4.12	3.89	4.05	4.09
Room acoustics	3.72	3.84	3.73	3.56	3.82	3.56
Noise isolation	3.67	3.70	3.92	3.33	3.75	3.56
Indoor sources of air pollution	3.92	4.06	3.77	3.56	3.96	3.88
BLOCK LEVEL						
Sustainable Site						
Urban redevelopment	3.30	3.29	3.46	3.25	3.27	3.58
Public transportation access	4.33	4.14	4.48	4.33	4.28	4.25
Heat island effect	3.92	3.80	3.81	3.11	3.86	3.55
Construction management	3.46	3.49	3.46	3.00	3.46	3.41
Pollution during construction	3.98	3.88	4.12	3.78	3.99	3.84
Noise from building equipment	3.88	3.83	4.27	3.78	3.93	3.84
Building user handbook	3.42	3.30	3.68	3.56	3.38	3.56
Water Efficiency						
Innovative wastewater technologies	3.73	3.58	4.04	3.44	3.72	3.69
Metering and controls	3.48	3.46	3.88	3.22	3.57	3.34
Water quality	3.98	3.76	4.08	3.89	3.89	4.00
Water recycling	3.79	3.78	4.12	3.33	3.85	3.72
Energy Use						
Improvement of the average U-value	3.88	3.81	4.08	3.78	3.92	3.72
Building orientation	3.92	3.72	4.16	3.56	3.90	3.69
CO_2 emission due to energy consumption in public areas	3.41	3.24	3.38	3.22	3.35	3.25
Renewable energy	3.48	3.28	3.81	3.00	3.48	3.19
Clothes drying facilities	3.67	3.69	3.92	3.89	3.71	3.88
Natural ventilation	4.10	4.03	4.15	4.00	4.11	3.97
Energy efficient lighting in public areas	4.06	4.06	4.23	4.11	4.14	3.91
Energy efficient appliances	3.79	3.87	4.08	3.56	3.93	3.56
Energy consumption on site	3.28	3.28	3.48	3.33	3.33	3.25
Building systems commissioning	3.56	3.53	3.92	3.67	3.65	3.42
Metering and monitoring	3.47	3.44	3.92	3.78	3.57	3.39

Identified environmental issues	Mean rating					
	HDB	Con	SDH	DH	Yes	No
Operation and maintenance manual	3.50	3.48	4.00	3.33	3.62	3.32
Materials & Resources						
Recycled materials	3.41	3.38	3.62	3.22	3.45	3.32
Resource reuse	3.33	3.32	3.42	3.00	3.34	3.29
Rapidly renewable materials	3.22	3.21	3.42	2.78	3.27	3.13
Local/regional materials	3.17	3.09	3.23	3.22	3.13	3.26
Sustainable forest products	3.56	3.44	3.38	3.56	3.53	3.39
Green building materials	3.57	3.45	3.50	3.67	3.57	3.39
Off-site fabrication	3.44	3.38	3.77	3.56	3.47	3.45
Ozone depletion	3.94	3.74	4.19	3.56	3.96	3.55
No asbestos	4.33	4.44	4.73	4.44	4.43	4.55
Adaptability and deconstruction	3.81	3.70	4.12	3.33	3.83	3.65
Modular and standardized design	3.86	3.72	4.00	3.67	3.83	3.77
Construction waste management	3.68	3.62	3.77	3.78	3.72	3.52
Storage of recyclables and waste disposal	3.65	3.55	3.77	3.78	3.67	3.52
Indoor Environmental Quality						
Ventilation effectiveness	4.08	4.05	4.23	3.89	4.10	4.03
PRECINCT LEVEL						
Sustainable Site						
Contaminated land	3.90	3.91	3.84	3.56	3.95	3.59
Local transportation and amenities	4.19	3.92	4.19	3.89	4.15	3.75
Heat island effect	3.92	3.63	4.08	3.44	3.92	3.34
Ecological impact	3.89	3.66	3.88	3.89	3.91	3.41
Landscaping and planters	4.02	3.79	4.08	3.78	4.01	3.59
Microclimate around buildings	3.30	3.24	3.42	3.11	3.31	3.19
Overshadowing and views	3.76	3.50	3.44	3.22	3.64	3.34
Vehicular access	3.76	3.69	4.12	3.78	3.83	3.63
Stormwater management	3.73	3.63	3.96	3.78	3.77	3.59
Light pollution reduction	3.38	3.27	3.65	3.33	3.39	3.38
Low environmental impact pest management policy	3.56	3.52	4.04	3.33	3.61	3.63
Pollution during construction	3.87	3.81	4.15	3.78	3.95	3.63
Water Efficiency						
Water efficient landscaping	3.84	3.88	4.19	4.22	3.93	4.00
Energy Use						
Energy efficient lighting in external areas	4.05	4.03	4.38	4.33	4.12	4.09
Materials & Resources						
Storage of recyclables and waste disposal	3.67	3.75	4.00	3.56	3.80	3.56
Indoor Environmental Quality						
IAQ in car parks	3.64	3.58	3.77	3.13	3.67	3.39

Notes: "HDB" means HDB apartments; "Con" means condominium; "SDH" means semidetached house; "DH" means detached house; "Yes" means have HDB apartment living experience; and "No" means have no HDB apartment living experience.

(magenta) Means the highest mean rating by respondents within the same occupation.
(yellow) Means the second highest mean rating by respondents within the same occupation.
(cyan) Means the third highest mean rating by respondents within the same occupation.

However, due to different living conditions of their present residence types, respondents do have their own priority of concern on environmental issues. According to respondents living in HDB apartments, "public transportation access" is the most issue too. "Natural ventilation" and "local transportation and amenities" are their second and third most important concerns. Respondents living in condominium consider "natural ventilation" and "ventilation effectiveness" as the second and third most important environmental issues. In contrast, respondents living in semidetached houses and detached houses regard "public transportation access", "energy efficient lighting in external areas", and "water efficient landscaping" as their second and third most important environmental issues.

- **HDB apartment living experience**

81% of respondents have lived in HDB apartments, while the other 19% have no HDB apartment living experience. The results reveal that both the two groups of respondents regard "no asbestos" as the most important environmental issues of residential buildings (see Table 5.4) despite they have lived in HDB apartment or not. Respondents with HDB apartment living experience consider "natural ventilation" and "public transportation access" as their next two most important issues. Besides "natural ventilation" and "public transportation access", respondents without HDB apartment living experience also take "daylight & view" and "energy efficient lighting in external areas" into their consideration for the three most important issues.

5.4.4 Other environmental issues

Other than ranking the importance of identified environmental issues, respondents were asked to give their opinions on what else environmental issues that are important and should be considered for sustainable residential buildings in Singapore. Respondents' opinions are summarized in Table 5.5.

Table 5. 5 Other important environmental issues according to respondents' opinion

	Other environmental issues
Unit level	❑ Storage of "toxic" materials; e.g. vapor from paint, spray can etc. ❑ Lightning hazard ❑ Less uses of toxic finishes that gradually emit toxic ❑ Less usage of wireless system if this could cause damage to health via radiation ❑ Keep the odor of waste (sewerage or garbage collection) areas out of units e.g. garbage point connecting to central rubbish chute should be located exterior to unit ❑ Need sunny balconies for indoor plants and for natural clothes drying ❑ Control heat emission from neighbors' aircon units from not entering into others' units e.g. discharge of hot air form the air conditioners' condensing units shall not be directly facing windows or opening from other residential units ❑ Dust control by air filler at window and door
Block level	❑ Measure to include detection of microbiological, volatile organic compound and vector control prior to TOP or COC ❑ Do not locate buildings to close to electrical substations/ bin centers ❑ Built-in pest and rodent control system ❑ Devise means to detect harmful (invisible) radiation ❑ Water harvesting features, ❑ Recycling water, provide sun shading device ❑ Thicker external wall and heat-reduction glass
Precinct level	❑ Measures to monitor and control the smell and bacteria emitted from waste that affect the environment. ❑ Separate pedestrian cycling ❑ Fogging and pest control by the town council need to consider using much environment friendly chemicals ❑ Control the moisture, pollutants and odor from barbeque pit of condominium ❑ More greenery, but do not plant fruit trees in public fields ❑ Public toilet

5.5 Conclusion

From local building experts' point of views, "no asbestos" is the most important environmental issue in residential buildings, while "local/regional materials" is the least important environmental issue. Eleven issues are considered as "more important". Among them, four issues are related to ventilation, two issues are about energy efficient lighting in communal areas, and two issues are concerning public transportation access.

Different background of occupation, education, and residence affect respondents' consideration of the importance of environmental issues. Respondents with different occupations have their proper perspectives of the importance of environmental issues. Respondents who received education overseas and respondents who received both local and overseas education tend to care most about environmental sustainability at unit level. In contrast, respondents who received local education concern most about environmental sustainability at precinct level. According to respondents living in HDB apartments, "public transportation access" and "natural ventilation" are very important. On the contrary, respondents living in semidetached houses and detached houses regard "energy efficient lighting in external areas" and "water efficient landscaping" as significant environmental issues too.

CHAPTER 6 ENVIRONMENTAL ASSESSMENT CRITERIA AND PROTOCOL FOR RESIDENTIAL BUILDINGS

6.1 Introduction

Sustainable issues of local residential developments have been identified based on literature review and opinions of local experts and residents. Weights have been generated for each environmental criterion based on the experts' opinion. The new environmental sustainable assessment criteria and protocol are then developed using these weights as a foundation in assigning score for each criterion.

6.2 Identification of Environmental Criteria

A set of environmental criteria including design, construction and management relevant to Singapore and the tropical context with respect to residential developments are identified according to local environmental consideration, literature review of currently used environmental assessment methods including BREEAM, HK-BEAM, LEED, and NUS-BEAM, and opinions of local experts and residents. These sustainable issues are categorized into five groups:

- Sustainable site
- Water efficiency
- Energy use
- Material & resources
- Indoor environmental quality

6.3 A New Model of Environmental Assessment Criteria and Protocol for Residential Developments

Based on the identified sustainable criteria, a new model of environmental assessment criteria and protocol for local residential buildings are developed. The new environmental assessment criteria and protocol for residential buildings will cover three levels:

- Unit level
- Block level
- Precinct level

This is to facilitate the assessment of different parts of residential developments. In the environmental assessment criteria and protocol, environmental issues are categorized into five groups: sustainable site, water efficiency, energy use, material & resources, and indoor environmental quality.

6.4 Weighting Scale Generation

Since each environmental issue has different degree of importance in the basket of issues considered, the respective importance may be measured by assigning relative weight which expresses the importance of each attribute relative to the others. Weights can be assigned by either an ordinal or a cardinal scale. Although it is usually easier to assign weights by an ordinal scale, most Multiple Attribute Decision Making (MADM) methods require cardinal weights (Yoon, K.P. and Hwang C.L., 1995). Therefore cardinal weights is used in this study, where w_j is the weight assigned to the jth attribute, and $\sum w_j = 1$.

Weights can be assessed from either ranks or ratio. The techniques of ratio weighting compare two attributes at a time by asking for the importance ratio between them, e.g., "how many times is X_i attribute more important than attribute X_j?" It will need (n-1) pairwise comparisons to establish the relative importance among n attributes. However, it is quite possible that the pairwise comparisons will be inconsistent. Hence these approaches require more information to compensate for the inconsistencies of human judgment (Yoon, K.P. and Hwang C.L., 1995).

The simplest way of assessing weights is to arrange the attributes in a simple rank order (Yoon, K.P. and Hwang C.L., 1995) therefore it is adopted in this study. That is, the most important attribute is assigned 1, and the least important attribute is assigned 65 (there are sixty five attributes in this study) (see Table 6.1). Because the mean rating of every environmental attribute reflects its relative importance among the sixty five attributes according to building experts' opinions, the attribute with the highest mean rating is assigned 1, and the attribute with the lowest mean rating is assigned 65. In the case that attributes are tied in the ranking, their mean ranking will be used. For example, if two attributes are tied for the second and third place, the number 2.5 is assigned to both of them.

The rank reciprocal weights for each individual attribute can be obtained from the following equation:

$$w_j = \frac{\frac{1}{r_j}}{\sum_{k=1}^{n} \frac{1}{r_k}} \qquad \textbf{Equation 2}$$

where, r_j is the rank of the jth attribute.

Using Equation 2, weights for each attribute is calculated and given in Table 6.1.

6.5 Assignment of Score for Environmental Attributes

The score for each environmental attribute is calculated based on the weights generated from the building experts' ratings of attributes. A total of three-hundred points are distributed among the sixty five environmental attributes in the new environmental sustainable assessment criteria and protocol. Three-hundred point is adopted so as to assign score 1 to the least important attribute. Therefore, a particular residential building is awarded a score out of the three-hundred points based on the attributes' performance level.

The score for each environmental issue can be obtained from the following equation:

$$S_j = w_j \times 300 \qquad \textbf{Equation 3}$$

where,

w_j is the weight assigned to the jth attribute

S_j is the score assigned to the jth attribute.

Using Equation 3, score for each attribute is calculated and shown in Table 6.1.

6.6 Development of New Environmental Assessment Criteria and Protocol for Residential Buildings

The new environmental assessment criteria and protocol for residential buildings cover three levels: unit level, block level, and precinct level. In this protocol, sustainable issues are categorized into five groups: sustainable site, water efficiency, energy use, material & resources, and indoor environmental quality.

The issues considered concentrate on the planning, design, construction and commissioning of the building and engineering system, and should be initiated at the early stages of planning. Its assessments for new residential buildings are finalized upon completion of the works and prior to occupancy and hand over. This enables construction activities to be monitored and commissioning to demonstrate certain key aspects of performance when the building is use. The credits are summarized in Table 6.2.

Due to the time limitation, another survey to decide the rate of importance of the other important environmental issues according to building experts' opinion (see Table 5.5) was not conducted. However, these criteria could be considered for the new protocol by being included in the Innovation category which has five points to award any performance in green building categories not addressed in the new protocol.

Table 6.2 shows that the five criteria (asbestos, natural ventilation, access to public transport and energy efficient lighting) account for 153 points, which is more than 50% of all available points, while some supposedly important criteria that are valued with only one point such as renewable energies, energy consumption on site, CO_2 emission, water recycling, materials and resources, etc. This could be explained by the fact that the new protocol's weight scale is based on the local building experts' opinion towards the importance of identified environmental issues. Therefore the point distribution of the protocol reflects local building experts' priority of these criteria at the time of the survey being conducted.

Table 6. 1 Weights and maximum permissible scores for each environmental criterion

Identified environmental attributes	Rank	Weight	Max score
UNIT LEVEL			
Water Efficiency			
Water efficient devices	23	0.0091	3
Energy Use			
CO_2 emission due to energy consumption	58	0.0036	1
Natural ventilation	2	0.1051	32
Hot water supply	40	0.0053	2
Energy efficient appliances	13.5	0.0156	5
Indoor Environmental Quality			
Ventilation effectiveness	11	0.0191	6
Cooker hood	52	0.0040	1
Thermal comfort	9.5	0.0221	7
Daylight & views	8	0.0263	8
Room acoustics	33.5	0.0063	2
Noise isolation	37.5	0.0056	2
Indoor sources of air pollution	15	0.0140	4
Group Sub-total			**73**
BLOCK LEVEL			
Sustainable Site			
Urban redevelopment	60.5	0.0035	1
Public transportation access	3	0.0701	21
Heat island effect	29	0.0073	2
Construction management	53	0.0040	1
Pollution during construction	12	0.0175	5
Noise from building equipment	17.5	0.0120	4
Building user handbook	56	0.0038	1
Water Efficiency			
Innovative wastewater technologies	37.5	0.0056	2
Metering and controls	48	0.0044	1
Water quality	17.5	0.0120	4
Water recycling	26.5	0.0079	2
Energy Use			
Improvement of the average U-value	21.5	0.0098	3
Building orientation	25	0.0084	3
CO_2 emission due to energy consumption in public areas	59	0.0036	1
Renewable energy	54	0.0039	1
Clothes drying facilities	35.5	0.0059	2
Natural ventilation	7	0.0300	9
Energy efficient lighting in public areas	5.5	0.0382	11
Energy efficient appliances	24	0.0088	3
Energy consumption on site	62	0.0034	1

Identified environmental attributes	Rank	Weight	Max score
Building systems commissioning	43	0.0049	1
Metering and monitoring	48	0.0044	1
Operation and maintenance manual	46	0.0046	1
Materials & Resources			
Recycled materials	55	0.0038	1
Resource reuse	60.5	0.0035	1
Rapidly renewable materials	64	0.0033	1
Local/regional materials	65	0.0032	1
Sustainable forest products	50	0.0042	1
Green building materials	48	0.0044	1
Off-site fabrication	51	0.0041	1
Ozone depletion	19.5	0.0108	3
No asbestos	1	0.2103	63
Adaptability and deconstruction	30.5	0.0069	2
Modular and standardized design	30.5	0.0069	2
Construction waste management	39	0.0054	2
Storage of recyclables and waste disposal	41	0.0051	2
Indoor Environmental Quality			
Ventilation effectiveness	5.5	0.0382	11
Group Sub-total			**173**
PRECINCT LEVEL			
Sustainable Site			
Contaminated land	19.5	0.0108	3
Local transportation and amenities	9.5	0.0221	7
Heat island effect	28	0.0075	2
Ecological impact	26.5	0.0079	2
Landscaping and planters	16	0.0131	4
Microclimate around buildings	63	0.0033	1
Overshadowing and views	45	0.0047	1
Vehicular access	32	0.0066	2
Stormwater management	35.5	0.0059	2
Light pollution reduction	57	0.0037	1
Low environmental impact pest management policy	44	0.0048	1
Pollution during construction	21.5	0.0098	3
Water Efficiency			
Water efficient landscaping	13.5	0.0156	5
Energy Use			
Energy efficient lighting in external areas	4	0.0526	16
Materials & Resources			
Storage of recyclables and waste disposal	33.5	0.0063	2
Indoor Environmental Quality			
IAQ in car parks	42	0.0050	2
Group Sub-total			**54**
Grand Total			**300**

Table 6. 2 Summary of the new environmental assessment criteria and protocol for residential buildings

UNIT LEVEL

Section	Credit Requirement	Score
UWE	**WATER EFFICIENCY**	
UWE-1	**Water Efficient Devices**	
a	Use showerheads whose flow rate is equal to or less than 7 l/min	1
b	Use faucet aerator whose flow rate is equal to or less than 6 l/min	1
c	Use low-capacity dual flush water cisterns whose water usage per flush is equal to or less than 4.5 l	1
UEU	**ENERGY USE**	
UEU-1	**CO_2 Emission Due To Energy Consumption**	
	Energy consumption of 3room is less than 102 kWh/m^2/year Energy consumption of 4room is less than 77 kWh/m^2/year Energy consumption of 5room is less than 73 kWh/m^2/year Energy consumption of Executive is less than 63 kWh/m^2/year	1
UEU-2	**Natural Ventilation**	
a	Undertake an analysis of building design, assess wind pressures on building facades to inform detailed building design on optimum locations to locate windows/openings to achieve cross ventilation	16
b	Demonstrate that indoor spaces with ventilation openings/operable windows is capable of, under average wind conditions, providing sufficient ventilation according to local regulation	16
UEU-3	**Hot Water Supply**	
	Install energy efficiency hot water supply equipment and devices	2
UEU-4	**Energy Efficient Appliances**	
a	25% of refrigerators have been labeled under the Singapore's Energy Efficiency Labeling scheme	2
b	30% of air-conditioners have been labeled under the Singapore's Energy Efficiency Labeling scheme	2
c	Use of other energy efficient appliances	1
UIEQ	**INDOOR ENVIRONMENTAL QUALITY**	
UIEQ-1	**Ventilation Effectiveness**	
a	For background ventilation in naturally ventilation buildings, demonstrate through appropriate modeling or commissioning tests that a minimum air change rate required by local regulation (or an air change rate of 1 per hour) is provided in occupied or habitable rooms under conditions of natural ventilation	3
b	For naturally ventilated spaces demonstrate a distribution and laminar flow pattern that involves not less than 90% of the room or zone area in the direction of air flow for at least 95% of hours of occupancy	3

Section	Credit Requirement	Score
UIEQ-2	**Cooker Hood**	
	Install a cooker hood with extract fan ducted to the outdoor air (or a passive stack ventilation/ mechanical ventilation system extract point and hood above the cooker) rather than elsewhere in the kitchen	1
UIEQ-3	**Thermal Comfort**	
a	Demonstrate worse case peak operative temperatures without mechanical cooling do not exceed 31.3^{o}C in any regularly occupied rooms in naturally ventilated buildings	3
b	Demonstrate mean operative temperatures without mechanical cooling do not exceed 29.6^{o}C, and mean relative humidity do not exceed 74% in any regularly occupied rooms in naturally ventilated buildings	2
c	Demonstrate mean operative temperatures without mechanical cooling do not exceed 28.5^{o}C in any regularly occupied rooms in naturally ventilated buildings	2
UIEQ-4	**Daylight & Views**	
a	For apartment where at least 80% of living rooms meets the room depth criteria	2
b	For apartment where at least 80% of living rooms achieve an average daylight factor (use BRE formula) of 1.5%	2
c	For apartment where at least 80% of bedrooms achieve an average daylight factor of 1%	2
d	For apartment where at least 80% of kitchens achieve an average daylight factor of 2%	2
UIEQ-5	**Room Acoustics**	
	The building design can be shown to achieve ambient internal noise levels as specified below: Locality — 6am—10pm (LeqA) — 10pm—6am (LeqA) Urban — 55 dB — 45 dB Suburban — 50 dB — 40 dB	2
UIEQ-6	**Noise Isolation**	
	Noise isolation between rooms, premises and/or floors meets the requirements in local regulation	2
UIEQ-7	**Indoor Sources of Air Pollution**	
a	The VOC content of adhesives and sealants used must be less than the current VOC content limits of local regulation (Good Indoor Air Quality in Office Premises, ENV, Singapore, 1996)	1
b	Provide central rubbish chutes in public area with sufficient ventilation to avoid using rubbish chutes inside residential units	1
c	VOC emissions from paints and coatings must not exceed the VOC and chemical component limits of local regulation requirements	1
d	Composite wood products is low emission formaldehyde OR no composite wood used	1

BLOCK LEVEL

Section	Credit Requirement	Score
BSS	**SUSTAINABLE SITE**	
BSS-1	**Urban Redevelopment**	
	Where the building development uses land and that has been redeveloped or reclaimed	1
BSS-2	**Public Transportation Access**	
a	Building is within 500m radius from a MRT/LRT station	6
b	Building is within 250m radius from a MRT/LRT station	3
c	Building is within 500m radius from bus stops	3
d	Building is within 250m radius from bus stops	3
e	For proximity to a food shop and a post box within 500m	3
f	For proximity to 5 of the following within 1000m: post office, bank, chemist, school, medical centre, leisure centre, community centre, public house, children’s play area	3
BSS-3	**Heat Island Effect**	
a	Use highly reflective AND high emissivity roofing (emissivity of at least 0.9) for a minimum of 75% of the roof surface	1
b	Install a “green” (vegetated) roof for at least 50% of the roof area. Combinations of high albedo and vegetated roof can be used providing they collectively cover 75% of the roof area	1
BSS-4	**Construction Management**	
	The developer, main contractor and consultant are ISO 14000 certified, OR implementation of an environmental management plan for the project (e.g. C&D waste management plan, monitoring of resources consumption)	1
BSS-5	**Pollution During Construction**	
a	Apply adequate mitigation measures for dust and air emissions during the construction as recommended by NEA	1
b	Demonstrate compliance with the Environmental pollution Control (Air Impurities) Regulations 2000	1
c	Demonstrate and confirm that the criteria and requirements laid down in Environmental Pollution Control (Control of Noise at Construction Sites) Regulations	1
d	Demonstrate compliance with the noise management guidelines as detailed by NEA	1
e	Undertake measures to reduce water pollution during construction as outlined in Environmental Pollution Control Act (Water Pollution Control)	1
BSS-6	**Noise from Building Equipment**	
	The level of the intruding noise at the façade of the nearest sensitive receiver is in compliance with the criteria recommended in local regulation	4

Section	Credit Requirement	Score
BSS-7	**Building User Handbook**	
	Provide building users a handbook giving details about the facilities within the building and a guide on environmental friendly use and operation of building	1
BWE	**WATER EFFICIENCY**	
BWE-1	**Innovative Wastewater Technologies**	
a	Reduce the use of municipally provided potable water for building sewage conveyance by a minimum of 50%, OR treat 100% of wastewater on site to tertiary standards	1
b	Reduction in sewage volumes by 25% through the use of water efficient fixtures and /or recycling technologies	1
BWE-2	**Metering and Controls**	
	Install water meters at key supply branches which permit the monitoring and audit of fresh water consumption	1
BWE-3	**Water Quality**	
a	Demonstrate that potable water at point of use meets WSD (WHO) drinking water quality standards	2
b	Install measures for treatment of potable water supplies to ensure quality to WSD (WHO) drinking water quality standards at point of use	2
BWE-4	**Water Recycling**	
a	Provide for the collection of rainwater or condensate for use in cleaning, toilet flushing or otherwise, which will reduce consumption of potable water; OR provide plumbing systems that separates black water discharges from grey water discharges to allow for separate collection for grey water	1
b	Install of an on-site grey water treatment system to treat grey water for reuse in place of potable water (e.g. in toilet flushing where rainwater is not available)	1
BEU	**ENERGY USE**	
BEU-1	**Improvement of the Average U-value**	
a	The average U-value of external building surfaces meets the local requirements of acceptable U-value of external building surfaces	2
b	The average roof U-value of the building is equal to or less than $1.5W/m^2K$.	1
BEU-2	**Building Orientation**	
a	Total area of external building surfaces facing N-S is more than total area of external building surfaces facing W-E	1
b	Total area of external building surfaces facing N-S is 50% more than total area of external building surfaces facing W-E	1
c	Total area of external building surfaces facing N-S is 75% more than total area of external building surfaces facing W-E	1

Section	Credit Requirement	Score
BEU-3	**CO_2 Emission Due To Energy Consumption in Public Areas**	
	energy consumption of the operation of lifts, lighting and other services in public areas is less than the average amount of local residential buildings	1
BEU-3	**Renewable Energy**	
	More than 10% of building energy use is generated from renewable energy sources	1
BEU-4	**Clothes Drying Facilities**	
	Provide suitable clothes drying facilities (external or internal) which utilize the natural environment for the majority of residential unit, OR provide space and posts/footings/fixings for drying clothes in a secure environment for each unit on the site.	2
BEU-5	**Natural Ventilation**	
a	Undertake an analysis of building design, assess wind pressures on building facades to inform optimum building location to achieve cross ventilation	5
b	For natural ventilation in public areas, undertake an analysis of building and adjacent building forms to assess wind pressures on ventilation openings in public/circulation areas and demonstrate that each common area has ventilation opening capable, under prevailing wind conditions, of providing adequate ventilation according to local regulation	4
BEU-6	**Energy Efficient Lighting in Public Areas**	
a	Install energy efficient lighting equipment (compact fluorescent lamps (CFL) luminaires or strip lights)	4
b	Lighting equipment are under the control of the building/estate management	4
c	Install time switching or photoelectric switching lighting control for the lamps in areas where daylight is available	3
BEU-7	**Energy Efficient Appliances**	
	For specifying the use of certified energy efficient appliances, for example, energy efficient lifts	3
BEU-8	**Building Systems Commissioning**	
	Implement or have a contract in place to implement the following fundamental best practice commissioning procedures • Engage a commissioning team that does not include individuals directly responsible for project design or construction management • Review the design intent and the basis of design documentation • Incorporate commissioning requirements into the construction documents • Develop and utilize a commissioning plan • Verify installation, functional performance, training and operation and maintenance documentation • Complete a commissioning report	1

Section	Credit Requirement	Score
BEU-9	**Energy Consumption on Site**	
	A firm commitment is made to require the constructor to set up systems to monitor and report energy consumption resulting from energy use on site and fuel consumption resulting from transport to and from site on a monthly basis	1
BEU-10	**Metering and Monitoring**	
	Install water, gas and electrical sub metering for every unit, AND install metering for landlord's electricity consumption in common space/public areas	1
BEU-11	**Operation and Maintenance Manual**	
	Provide a fully documented operations and maintenance manual to the minimum specified, AND provide a fully documented instructions that enables systems to operate at a high level of energy efficiency	1
BMR	**MATERIALS & RESOURCES**	
BMR-1	**Recycled Materials**	
	Use at least 5% (volume) of recycled materials in structures and features	1
BMR-2	**Resource Reuse**	
	Use salvaged, refurbished or reused materials, products and furnishings for at least 5% of building materials	1
BMR-3	**Rapidly Renewable Materials**	
	Use rapidly renewable building materials and products (made from plants that are typically harvested within a ten-year cycle or shorter) for 5% of the total volume of all building materials and products used in the project.	1
BMR-4	**Local/Regional Materials**	
	Use a minimum of 20% of building materials and products that are manufactured regionally within a radius of 800km (Manufacturing refers to the final assembly of components into the building product that is furnished and installed by the tradesmen.)	1
BMR-5	**Sustainable Forest Products**	
	Use of durable and reusable formwork and hoarding systems to replace timbers formwork and hoardings, and for ensuring that timber formwork, where used, is properly maintained	1
BMR-6	**Green Building Materials**	
	Choose building materials for 50% of key building elements which have been labeled under the Singapore Green Labelling scheme	1
BMR-7	**Ozone Depletion**	
a	Thermal insulation materials and products in the building fabric and services are made only from materials with zero ozone depletion potentials	2
b	CFC and HCFC have been banned by the government	1

Section	Credit Requirement	Score
BMR-8	**Off-site Fabrication**	
	The manufacture of 50% of building elements has been off-site	1
BMR-9	**No Asbestos**	
a	There is no asbestos in the structure	9
b	There is no asbestos in the services	9
c	There is no asbestos in the lifts	9
d	There is no asbestos in the other parts of building (except the above three parts)	9
e	An asbestos survey has been carried out in the building OR no asbestos in the building	9
f	All asbestos in the building have been identified, OR no asbestos in the building	9
g	All asbestos in the building have been removed, OR no asbestos in the building	9
BMR-10	**Adaptability and Deconstruction**	
a	Designs provide spatial flexibility that can adapt spaces for different uses, and allows for expansion to permit additional spatial requirements to be accommodated	1
b	Designs provide flexibility through the choice of building structural system that allows for change in future use, and which is coordinated with interior planning modules	1
BMR-11	**Modular and Standardized Design**	
a	Apply modular design in buildings	1
b	Use standardized prefabricated building elements to reduce the use of formwork	1
BMR-12	**Construction Waste Management**	
a	Develop and implement a waste management plan, quantifying material diversion goals	1
b	Construction waste is monitored, sorted and recycled on site	1
BMR-13	**Storage of Recyclables and Waste Disposal**	
a	Provide central waste recycling spaces at ground level of building. The space is dedicated to the separation, collection and storage of materials for recycling including (at a minimum) paper, corrugated cardboard, glass, plastics and metals	1
b	Provide recycling bins in each floor level in addition to central storage space	1
BIEQ	**INDOOR ENVIRONMENTAL QUALITY**	
BIEQ-1	**Ventilation Effectiveness**	
a	Building is located in isolation	6
b	Two longer sides of building face to open space	5

PRECINCT LEVEL

Section	Credit Requirement	Score
PSS	**SUSTAINABLE SITE**	
PSS-1	**Contaminated Land**	
	Land previously used for industrial purposes, or adjacent to landfills: for implementing measures for the rehabilitation of previously contaminated land, or proper preparation of sites and structures adjacent to landfill sites	3
PSS-2	**Local Transportation and Amenities**	
a	Where there exist or provide easy and substantially sheltered pedestrian access to a mainstream mass transport system or shuttle services to public transport networks and local urban centre	2
b	Provide sufficient local amenities for basic needs of building occupants	2
c	Provide secure bicycle storage (parking) for regular building occupants, and provide cycling paths which link to local cycling pathways	2
d	No car parking is provided close to buildings, except for disable persons only, and provide centralized car parking in multi-storey carpark	1
PSS-3	**Heat Island Effect**	
a	Provide shade and/or use light-colored/high-albedo materials (reflectance of at least 0.3) and/or open grid pavement for at least 30% of the site's non-roof impervious surfaces; OR use an open-grid pavement system (less than 50% impervious) for a minimum of 50% of the parking lot area	1
b	Install a "green" (vegetated) roof for at least 50% of the roof area of multi-storey car parks; OR combinations of high albedo and vegetated roof to cover 75% of the roof area of multi-storey car parks	1
PSS-4	**Ecological Impact**	
a	Where land is defined as a low ecological value	1
b	For the landscaping and other site design minimize ecological impact on Greenfield sites, or contributes positively to the ecological value of (Brownfield) sites	1
PSS-5	**Landscaping and Planters**	
a	For exterior plantings, use plants tolerant of climate, soils, and natural water availability	2
b	Provide appropriate planting on site equivalent to at least 30% of the site area	2
PSS-6	**Microclimate Around Buildings**	
	No pedestrian areas will be subject to excessive wind velocities caused by amplification due to the site layout and/or building design	1

Section	Credit Requirement	Score
PSS-7	**Overshadowing and Views**	
	For a master planning consider the solar access for individual buildings to minimize overshadowing, and optimization of view potential for the site whilst preserving the views of surrounding developments	1
PSS-8	**Vehicular Access**	
	Providing access for deliver vehicles and waste collection vehicles to the service areas of the building which lies within the site boundary and are enclosed and/or segregated from pedestrian access routes	2
PSS-9	**Stormwater Management**	
	Rainwater holding facilities and/or sustainable drainage techniques are used to provide attenuation of water run-off by 50% at peak times to either natural watercourses and/or municipal drainage systems	2
PSS-10	**Light Pollution Reduction**	
	The average illuminance for site lighting does not exceed 1.5 times the recommended maintained illuminance; AND interior and exterior lighting installations are such that no direct beam of light from luminaries leaves the area that is intended to be lit	1
PSS-11	**Low Environmental Impact Pest Management Policy**	
	Provide management plan for establishing/maintaining a low impact site and building exterior pest management (e.g. use physical controls such as blocking entry paths, removing nesting sites and food sources, or reduce usage of potentially hazardous chemical, biological and particle contaminants)	1
PSS-12	**Pollution During Construction**	
a	Demonstrate compliance with the Environmental pollution Control (Air Impurities) Regulations 2000	1
b	Demonstrate and confirm that the criteria and requirements laid down in Environmental Pollution Control (Control of Noise at Construction Sites) Regulations	1
c	Undertake measures to reduce water pollution during construction as outlined in Environmental Pollution Control Act (Water Pollution Control)	1
PWE	**WATER EFFICIENCY**	
PWE-1	**Water Efficient Landscaping**	
a	Use high-efficiency irrigation technology OR use captured rain or recycled site water to reduce potable water consumption for irrigation by 50% over conventional means	3
b	Use only captured rain or recycled site water to eliminate all potable water use for site irrigation (except for initial watering to establish plants), OR do not install permanent landscape irrigation systems	2

Section	Credit Requirement	Score
PEU	**ENERGY USE**	
PEU-1	**Energy Efficient Lighting in External Areas**	
a	Install energy efficient lighting equipment (compact fluorescent lamps (CFL) luminaires or strip lights)	6
b	Lighting equipment are under the control of the building/estate management	5
c	Install time switching or photoelectric switching lighting control for the lamps in areas where daylight is available	5
PMR	**MATERIALS & RESOURCES**	
PMR-1	**Storage of Recyclables and Waste Disposal**	
a	Provide adequate facilities in the precinct for the collection, sorting, storage or disposal of waste	1
b	Partition recycle bins to collect different waste materials such as paper, glass, plastics, metals separately	1
PIEQ	**INDOOR ENVIRONMENTAL QUALITY**	
PIEQ-1	**IAQ in Multi-storey Car Parks**	
	Comply with the design requirements specified in SS CP 13: 1999	2

INNOVATION

Section	Credit Requirement	Score
IPE	**INNOVATION & PERFORMANCE ENHANCEMENTS**	
IPE-1	**Innovation & Performance Enhancements**	
	Exceptional performance above the requirements set in this protocol, OR innovative performance in green building categories not specifically addressed in this protocol	Max 5

AWARD CLASSIFICATION

The overall assessment grade is based on the percentage of applicable credits achieved. The award classifications are:

Rating	Score (as a percentage of applicable credits)
Certified	40%
Silver	50%
Gold	60%
Platinum	75%

Acceptable U-values for external building surfaces

	East orientation	West orientation	North orientation	South orientation
WWR	U=3W/m^{2}K	U=3W/m^{2}K	U=3.5W/m^{2}K	U=3.5W/m^{2}K
WWR=0.1	U=2W/m^{2}K 300mm HS is needed	U=2W/m^{2}K 300mm HS is needed	U=2.5W/m^{2}K No shading is needed	U=2.5W/m^{2}K No shading is needed
WWR=0.2	U=2W/m^{2}K 300mm HS is needed	U=2W/m^{2}K 300mm HS is needed	U=2.5W/m^{2}K 300mm HS is needed	U=2.5W/m^{2}K 300mm HS is needed
WWR=0.3	U=2W/m^{2}K 900mm HS is needed	U=2W/m^{2}K 900mm HS is needed	U=2.5W/m^{2}K 300mm HS is needed	U=2.5W/m^{2}K 300mm HS is needed
WWR=0.4	U=2W/m^{2}K 900mm HS is needed	U=2W/m^{2}K 900mm HS is needed	U=2.5W/m^{2}K 300mm HS is needed	U=2.5W/m^{2}K 300mm HS is needed
WWR=0.5	U=2W/m^{2}K 900mm HS is needed	U=2W/m^{2}K 900mm HS is needed	U=2.5W/m^{2}K 900mm HS is needed	U=2.5W/m^{2}K 900mm HS is needed

Source: Wong, 2004.
Note: WWR is window to wall ratio, "HS" means horizontal shading.

6.7 Conclusion

Relevant environmental issues of residential developments have been identified according to local conditions and the literature review of currently used environmental assessment methods for sustainable development including EcoHomes, HK-BEAM, LEED, and NUS-BEAM. The issues considered in assessing residential buildings are mainly for public housing, because about 82% of the total populations live in HDB apartments. Building expert survey results indicate that all the identified issues are considered important according to local building experts' opinions. Therefore, all the identified issues are included in this new protocol. Weights for those issues are generated using the results of building expert survey, and scores are assigned to them accordingly.

CHAPTER 7 ASSESSMENT OF TWO HDB BLOCKS USING NEW DEVELOPED PROTOCOL

7.1 Introduction

To evaluate the new developed environmental assessment criteria and protocol, the building performance of two HDB public housing buildings, Building One and Building Two, is assessed using the new developed protocol as two case studies. The descriptions of Building One and Building Two are detailed in section 3.2.

7.2 Site Survey and Measurement

As mentioned in section 4.3, both outdoor and indoor survey and measurements were conducted in order to determine the environmental conditions of the two assessed buildings.

- **Outdoor site survey and measurement**

Outdoor environmental conditions of the two assessed buildings were investigated including public transportation access, storage facilities and cycling path for bicycles, parking capacity, parking for carpools or vanpools, site ecologic condition, development footprint, urban heat island effect related characteristics of roof surfaces and non-roof surface areas, and storage facilities of recycled material.

- **Indoor site survey and measurement**

Objective measurements of indoor environmental conditions as well as a short survey with the residents were carried out in the residential units of the two buildings. Indoor thermal and acoustic environment, electricity consumption, water consumption, water efficient devices, cooker hood, sky visibility in living room, cloth drying facility, and energy efficient appliances were all explored during the indoor survey and measurement. The detail of indoor site survey and measurement are presented in Chapter Three.

7.3 Assessment of Building One Using the New Protocol

Table 7.2 sets out the environmental assessment of the existing design of Building One under unit level, block level, precinct level, and innovation, respectively.

7.3.1 Unit Level

7.3.1.1 Water Efficiency

- **Water Efficient Devices ─** The indoor measurement results show that the average flow rate of showerheads and faucet aerators in surveyed units of Building One are 6.6 l/min and 18.9 l/min respectively. The average capacity of water cisterns is 12 l and only 20% of surveyed units install duel flush water cisterns. Therefore, one credit is achieved.

7.3.1.2 Energy Use

- **CO_2 Emission Due To Energy Consumption ─** Building One is a 3Room block, the measured average electricity consumption is 51.3 kWh/m^2/year, which meets the credit requirement.

- **Natural Ventilation ─** The only code that controls ventilation is the Building Code, which specifies minimum 10% ventilation for every room. HDB flats all comply with this 10% natural ventilation requirement. However, according to the architect, there was no airflow simulation and sketches indicating the airflow pattern done by mechanical engineer during the design stage for this building. Hence, sixteen credits are awarded.

- **Hot Water Supply ─** According to the architect, there is no installation of energy efficiency hot water supply equipment and devices in this building.

- **Energy Efficient Appliances ─** In the surveyed units of Building One, there is no refrigerator labeled under the Singapore's Energy Efficiency Labeling scheme, while there are 14.3% of air-conditioners labeled under the Singapore's Energy Efficiency Labeling scheme. There is no use of other energy efficient appliances in these units.

7.3.1.3 Indoor Environmental Quality

- **Ventilation Effectiveness ─** According to the architect, there was no modeling or commissioning test provided in occupied or habitable rooms, neither was any airflow simulation and sketches indicating the airflow pattern done by mechanical engineer during the design stage for this building.

- **Cooker Hood ─** It is observed that only 20% of surveyed units have cooker hoods and all of them do not extract cooking smoke to the outdoor air.

- **Thermal Comfort ─** The worse case peak operative temperature and mean operative temperature without mechanical cooling in Building One are 31.9^{o}C and

31.8^{o}C respectively. Therefore, it fails to meet the credit requirements and no score is achieved.

- **Daylight & Views –**

  Room depth criteria

  The room depth criteria is given by $d/w + d/h < 2/(1-R_B)$, where d = room depth, w = width, h = window head height, R_B = average reflectance of surface in the back half of the room. If the reflectance of surfaces are unknown, then $R_B = 0.5$ can be assumed for walls of light color and $R_B = 0.3$ should be used for walls with dark color.

  There are two types of living rooms in Building One. The dimensions of living rooms in corner units are 7.3m(d) x 3.05m(w), and window head height is 2.2m. The dimensions of living rooms in corridor units are 6.12m(d) x 3.05m(w), and window head height is 2.2m. The living rooms all have light color walls therefore $R_B = 0.5$ is used. The calculation results indicate that no living room in Building One meets the room depth criteria.

  Average daylight factor

  The average daylight factor (DF) is given by $DF = \theta TW/A(1-R^2)$, where θ is the angle of obstruction measured from the mid-point of the window, T is the light transmission of glazing, W is the window area, A is the area of all the surfaces of the room, and R is the average reflection factor of the room. Again, if the reflectance of surfaces are unknown, then R = 0.5 can be assumed for walls of light color and R = 0.3 should be used for walls with dark color. Table 7.1 shows the dimension and DF of rooms in Building One. Corridor units constitute 87.5% (every unit has one master bedroom and one bedroom 2) of all residential units in Building One, while corner units constitute 12.5%. All the rooms have light color walls therefore $R_B = 0.5$ is used. The results reveal that in Building One, none of living rooms achieves DF of 1.5%, 56.25% of bedrooms achieve DF of 1%, and 100% of kitchens achieve DF of 2%. Therefore, only kitchens meet the DF requirement.

Table 7. 1 Dimension and average daylight factor of rooms in Building One

Rooms		θ	T	W (m^2)	A (m^2)	DF (%)
Corridor units (87.5%)	Living room	0	0.88	0.6	82.6	0
	Master bedroom	1.57	0.88	1.7	61.0	2.9
	Bedroom 2	0	0.88	1.5	59.2	0
	Kitchen	1.57	0.88	2.9	67.5	4.5
Corner units (12.5%)	Living room	0.61	0.88	2.9	95.9	1.2
	Master bedroom	1.57	0.88	2.9	73.1	4.1
	Bedroom 2	1.57	0.88	1.7	61.0	2.9
	Kitchen	1.57	0.88	2.9	67.5	4.5

- **Room Acoustics —** The measured results show that the average indoor noise level is 57dBA, which is noisier than the credit requirement.

- **Noise Isolation —** HDB has no control on noise isolation between rooms, premises or floors.

- **Indoor Sources of Air Pollution —**

  Adhesives & sealants

  There is no control on VOC emission level for adhesives and sealants.

  Central rubbish chutes

  No central rubbish chute is provided in Building One.

Paints and coating

All HDB approved paints and coatings have to comply with PSB standard SS 150:1998 for interior applications and SS 345:1990 for exterior applications. In addition, primers for painting metal have to comply with SS 494:2001 to be lead and chromate free. Exact VOC emission levels cannot be obtained from product brochures, but all of them do not contain lead or mercury.

Composite wood

There is no control on composite wood.

7.3.2 Block Level

7.3.2.1 Sustainable Site

- **Urban Redevelopment —** The building development does not use redeveloped or reclaimed land.

- **Public Transportation Access —** The project site is located within 100m radius from a Mass Rapid Transportation (MRT) station and bus stops. Building One has a proximity to food shops and a post box within 500m, and has a proximity to bank, school, community centre, public house, and children's play area within 1000m.

- **Heat Island Effect —** The building's roof is made of RC and Ferrocement which are not highly reflective and high emissivity materials, and there is no green (vegetated) area on the roof.

- **Construction Management ─** Building One was built in 1971. However, the International Organization for Standardization (ISO) published the first edition of the ISO 14001 standard on Environmental Management System (EMS) in 1996. According to the architect, there was no implementation of an environmental management plan for the project.

- **Pollution During Construction ─** Information is not available to demonstrate that the project met the credit requirement during construction.

- **Noise from Building Equipment ─** Building One meets the credit requirement.

- **Building User Handbook ─** Building user handbook is not provided to building users.

7.3.2.2 Water Efficiency

- **Innovative Wastewater Technologies ─** No innovative wastewater technology is applied in Building One.

- **Metering and Controls ─** It is observed that water meters are installed for every unit. One credit is achieved.

- **Water Quality ─** According to Public Utilities Board, potable water meets WHO drinking water quality standards. However, no measure is installed for treatment of potable water supplies to ensure quality to WSD (WHO) drinking water quality standards at point of use.

- **Water Recycling —** Water recycling facilities are not provided in Building One.

7.3.2.3 Energy Use

- **Improvement of the Average U-value —** The average U-value of external building surfaces is $0.84W/m^2K$, and the average roof U-value of Building One is $0.5384W/m^2K$. Both of them meet the credit requirements.

- **Building Orientation —** According to the drawings of Building One, total area of external building surfaces facing N-S is less than total area of external building surfaces facing W-E. No credit is achieved.

- **CO_2 Emission due to Energy Consumption in Public Areas —** The energy consumption of the operation of lifts, lighting and other services in public areas of Building One is not available.

- **Renewable Energy —** All building energy use is not generated from renewable energy sources.

- **Clothes Drying Facilities —** It is observed that all units have a row of bamboo slots on the external wall of the kitchen for residents to place bamboo poles and dry cloth.

- **Natural Ventilation —** None of the required two analyses was undertaken. However, all public/circulation areas (corridors and staircases) are open areas and capable of providing adequate ventilation. Therefore, 4 credits are awarded.

- **Energy Efficient Lighting in Public Areas —** Site survey results show that energy efficient lighting equipments are installed in public areas, and under the control of town council with time switching and photoelectric switching lighting control for the lamps in areas where daylight is available.

- **Energy Efficient Appliances —** No certified energy efficient appliance is used in Building One.

- **Building Systems Commissioning —** HDB has implemented the following fundamental best practice commissioning procedures:
  - Engage a commissioning team that does not include individuals directly responsible for project design or construction management.
  - Review the design intent and the basis of design documentation.
  - Incorporate commissioning requirements into the construction documents.
  - Develop and utilize a commissioning plan.
  - Verify installation, functional performance, training and operation and maintenance documentation.

  There is no commissioning report, only the commissioning result e.g. “approval”.

- **Energy Consumption on Site —** No information indicates that a firm commitment is made to require the constructor to set up systems to monitor and report energy consumption resulting from energy use on site and fuel consumption resulting from transport to and from site on a monthly basis.

- **Metering and Monitoring ─** Water, gas and electrical sub metering are installed for every unit, and metering for landlord's electricity consumption in common space/public areas is installed as well.

- **Operation and Maintenance Manual ─** Operations and maintenance manual are not provided.

7.3.2.4 Materials & Resources

- **Recycled materials ─** No recycled material was used in this building.

- **Resource Reuse ─** No resource was reused in the project.

- **Rapidly Renewable Materials ─** No rapidly renewable material was used in the project.

- **Local/Regional Materials ─** Concrete and sand used by the contractor in this project are from Malaysia and Indonesia, which are within the 800km radius. And concrete constitutes more than 80% of the whole materials used in the project.

- **Sustainable Forest Products ─** HDB information shows that durable and reusable formwork systems were not used in this project.

- **Green Building Materials ─** Building One did not meet the credit requirement that choosing building materials for 50% of key building elements which have been labeled under the Singapore Green Labeling scheme.

- **Ozone Depletion ─** According to HDB architect, not all thermal insulation in building fabric and services are made only from materials with zero ozone depletion potentials. In Singapore, environmental pollution control (ozone depleting substances) regulations were issued by government in 2001 to prohibit importation and exportation of CFC and HCFC (National Environment Agency, 2001). Singapore has already successfully phased out the consumption of CFCs and Halons, and the government will work closely with local industries to move away from HCFC technologies as soon as practically possible (Ministry of the Environment, 1999). Hence one credit is achieved in "Banned by Government".

- **Off-site Fabrication ─** Off-site fabrication was not used in this project.

- **No Asbestos ─** According to the architect, no asbestos was used in Building One. Therefore, this project meets all the credits' requirements.

- **Adaptability and Deconstruction ─** The Design of Building One did not provide spatial flexibility that can adapt spaces for different uses, nor provide flexibility through the choice of building structural system that allows for change in future use.

- **Modular and Standardized Design ─** Modular and standardized design was not used in this project.

- **Construction Waste Management ─** HDB does not impose an active waste management system on the building contractor at construction stage.

- **Storage of Recyclables and Waste Disposal ─** It is observed that neither central waste recycling space at ground level of building nor recycling bin in each floor level is provided in Building One.

7.3.2.5 Indoor Environmental Quality

- **Ventilation Effectiveness ─** The building is obstructed by a MRT station and the MRT track on one longer side, and is obstructed by a seven-storey building on the other longer side. No credit is achieved.

7.3.3 Precinct Level

7.3.3.1 Sustainable Site

- **Contaminated Land─** The site is not on a contaminated land.

- **Local Transportation and Amenities ─** It is observed that there exist sheltered pedestrian access to a mainstream mass transport system. Sufficient local amenities are provided for basic needs of building occupants. However, neither bicycle storage nor cycling path is provided, and there is a carpark behind the building.

- **Heat Island Effect ─** The site's non-roof impervious surfaces areas are not constructed with high-albedo materials, all parking spaces are on the ground, and the open-grid pavement system has more than 50% impervious area.

- **Ecological Impact ─** The site is not a low ecological value site, nor Greenfield or brownfield site.

- **Landscaping and Planters** ─ The plants provided in the site are tolerant of climate, soils, and natural water availability. However, planting area is less than 30% of the site area.

- **Microclimate around Buildings** ─ It is observed that no pedestrian area is subject to excessive wind velocities caused by amplification due to the site layout and/or building design.

- **Overshadowing and Views** ─ The MRT station and the building opposite block the solar access as well as the view of Building One.

- **Vehicular Access** ─ It is observed that access is provided for deliver vehicles and waste collection vehicles to the service areas of the building which lies within the site boundary and are segregated from pedestrian access routes.

- **Stormwater Management** ─ According to the architect, HDB does not track the volume of the stormwater discharged from the project site. There is no stormwater treatment facility required on-site as the stormwater is collected across the whole-catchment area and is treated at the local reservoirs.

- **Light Pollution Reduction** ─ Survey results show that Building One fulfilled the credit requirements: all the exterior luminaries do no exceed 1.5 times the recommended maintained illuminance; the maximum candela value of all interior lighting fall within the building; the maximum candela value of all the exterior lighting falls within the property because the lamps are all faced towards the property and appropriately shielded such that there is no spill over to adjacent property.

- **Low Environmental Impact Management Policy —** The National Environment Agency and town councils are all involved in establishing/maintaining a low impact site and building exterior pest management.

- **Pollution During Construction —** Building One was built in 1971. According to the architect, there was no implementation of an environmental management plan for the project.

7.3.3.2 Water Efficiency

- **Water Efficient Landscaping —** The landscaping is irrigated by rain. There is no potable water used for the irrigation. Permanent landscape irrigation system is not installed on the site.

7.3.3.3 Energy Use

- **Energy Efficient Lighting in External Areas —** Site survey results show that energy efficient lighting equipments are installed, and under the control of town council with time switching and photoelectric switching lighting control for the lamps in areas where daylight is available.

7.3.3.4 Materials & Resources

- **Storage of Recyclables and Waste Disposal —** It is observed that no storage of recyclables and waste disposal is provided in the precinct.

7.3.3.5 Indoor Environmental Quality

- **IAQ in Multi-storey Car Parks —** Building One does not have multi-storey car park.

7.3.4 Innovation

- **Innovation & Performance Enhancements —** No information indicates that Building One has exceptional performance above the requirements set in this protocol, or innovative performance in green building categories not specifically addressed in the protocol.

7.3.5 Summary of Building One

The assessment results reveal that Building One has achieved 56% of the total number of the new protocol's credits, hence is awarded Silver Grade (see Table 7.3). The performance of Building One is above average at Block Level (66%) and Precinct Level (59%), but below average at Unit Level (29%). Overall, the environmental performance of Building One is above average.

Table 7. 2 Environmental assessment for Building One using new developed protocol

Possible Points	Assessed Issues	Score achieved
	UNIT LEVEL	
	Water Efficiency	
3	Water efficient devices	1
	Energy Use	
1	CO_2 emission due to energy consumption	1
32	Natural ventilation	16
2	Hot water supply	0
5	Energy efficient appliances	0
	Indoor Environmental Quality	
6	Ventilation effectiveness	0
1	Cooker hood	0
7	Thermal comfort	0
8	Daylight & views	2
2	Room acoustics	0
2	Noise isolation	0
4	Indoor sources of air pollution	1
73	**Group Sub-total**	**21**
	BLOCK LEVEL	
	Sustainable Site	
1	Urban redevelopment	0
21	Public transportation access	21
2	Heat island effect	0
1	Construction management	0
5	Pollution during construction	0
4	Noise from building equipment	4
1	Building user handbook	0
	Water Efficiency	
2	Innovative wastewater technologies	0
1	Metering and controls	1
4	Water quality	2
2	Water recycling	0
	Energy Use	
3	Improvement of the average U-value	3
3	Building orientation	0
1	CO_2 emission due to energy consumption in public areas	0
1	Renewable energy	0
2	Clothes drying facilities	2
9	Natural ventilation	4
11	Energy efficient lighting in public areas	11
3	Energy efficient appliances	0
1	Building systems commissioning	0
1	Energy consumption on site	0
1	Metering and monitoring	1

Possible Points	Assessed Issues	Score achieved
1	Operation and maintenance manual	0
	Materials & Resources	
1	Recycled materials	0
1	Resource reuse	0
1	Rapidly renewable materials	0
1	Local/regional materials	1
1	Sustainable forest products	0
1	Green building materials	0
3	Ozone depletion	1
1	Off-site fabrication	0
63	No asbestos	63
2	Adaptability and deconstruction	0
2	Modular and standardized design	0
2	Construction waste management	0
2	Storage of recyclables and waste disposal	0
	Indoor Environmental Quality	
11	Ventilation effectiveness	0
173	**Group Sub-total**	**114**
	PRECINCT LEVEL	
	Sustainable Site	
3	Contaminated land	0
7	Local transportation and amenities	4
2	Heat island effect	0
2	Ecological impact	0
4	Landscaping and planters	2
1	Microclimate around buildings	1
1	Overshadowing and views	0
2	Vehicular access	2
2	Stormwater management	0
1	Light pollution reduction	1
1	Low environmental impact pest management policy	1
3	Pollution during construction	0
	Water Efficiency	
5	Water efficient landscaping	5
	Energy Use	
16	Energy efficient lighting in external areas	16
	Materials & Resources	
2	Storage of recyclables and waste disposal	0
	Indoor Environmental Quality	
2	IAQ in car parks	0
54	**Group Sub-total**	**32**
	INNOVATION	
5	Innovation & performance enhancements	0
305	**Grand Total**	**167**

However, there is a lot of room for improvement, particularly under the section of "indoor environmental quality". The assessment results reflect that the indoor environmental quality of Building One does not meet more than 10% of the credits' requirements at any of the three Levels. Besides, the low score on section of "water efficiency" and "energy use" at Unit Level, "water efficiency" at Block Level, "sustainable site" and "materials & resources" at Precinct Level indicates that improvement in these areas should also be looked into.

Table 7. 3 Summary of environmental assessment for Building One using new developed protocol

Assessed Issues	Maximum score achievable	Score achieved	Percentage
UNIT LEVEL (total)	**73**	**21**	**29%**
Water Efficiency	3	1	33%
Energy Use	40	17	43%
Indoor Environmental Quality	30	3	10%
BLOCK LEVEL (total)	**173**	**114**	**66%**
Sustainable Site	35	25	71%
Water Efficiency	9	3	33%
Energy Use	37	21	57%
Materials & Resources	81	65	80%
Indoor Environmental Quality	11	0	0%
PRECINCT LEVEL (total)	**54**	**32**	**59%**
Sustainable Site	29	11	38%
Water Efficiency	5	5	100%
Energy Use	16	16	100%
Materials & Resources	2	0	0%
Indoor Environmental Quality	2	0	0%
Grand Total	**300**	**167**	**56%**
INNOVATION (total)	**5**	**0**	**0%**
Innovation & performance enhancements	5	0	0%

7.4 Assessment of Building Two Using the New Protocol

Table 7.5 sets out the environmental assessment of the existing design of Building Two under unit level, block level, precinct level, and innovation, respectively.

7.4.1 Unit Level

7.4.1.1 Water Efficiency

- **Water Efficient Devices ─** The indoor measurement results show that the average flow rate of showerheads and faucet aerators in surveyed units of Building Two are 11.1 l/min and 11.2 l/min respectively. The average capacity of water cisterns is 4.5 l and all surveyed units install duel flush water cisterns. Therefore, one credit is achieved.

7.4.1.2 Energy Use

- **CO_2 Emission Due To Energy Consumption ─** Building Two is a 4Room block, the measured average electricity consumption is 55.83 kWh/m^2/year, which meets the credit requirement.

- **Natural Ventilation ─** The only code that controls ventilation is the Building Code, which specifies minimum 10% ventilation for every room. HDB flats all comply with this 10% natural ventilation requirement. However, according to the architect, there was no airflow simulation and sketches indicating the airflow pattern done by mechanical engineer during the design stage for this building. Hence, sixteen credits are awarded.

- **Hot Water Supply ─** According to the architect, there is no installation of energy efficiency hot water supply equipment and devices in this building.

- **Energy Efficient Appliances ─** In the surveyed units of Building Two, there are 33.3% of refrigerators labeled under the Singapore's Energy Efficiency Labeling scheme (2 credits are achieved), while there are 25% of air-conditioners labeled under the Singapore's Energy Efficiency Labeling scheme. There is no use of other energy efficient appliances in these units.

7.4.1.3 Indoor Environmental Quality

- **Ventilation Effectiveness ─** According to the architect, there was no modeling or commissioning test provided in occupied or habitable rooms, neither was any airflow simulation and sketches indicating the airflow pattern done by mechanical engineer during the design stage for this building.

- **Cooker Hood ─** It is observed that 100% of surveyed units have cooker hoods. However all of them do not extract cooking smoke to the outdoor air.

- **Thermal Comfort ─** The worse case peak operative temperature and mean operative temperature without mechanical cooling in Building Two are 31.0^{o}C and 30.7^{o}C respectively. It only meets the credit requirement of worse case peak operative temperature.

- **Daylight & Views ─**

  Room depth criteria

  There are two types of living rooms in Building Two. The dimensions of living rooms in corner units are 5.7m(d) x 3.5m(w), and window head height is 2.6m. The dimensions of living rooms in corridor units are 7.3m(d) x 6.5m(w), and window head height is 2.6m. The living rooms all have light color walls therefore

R_B = 0.5 is used. The calculation results show that all living rooms in Building Two meet the room depth criteria.

Average daylight factor

Table 7.4 shows the dimension and average daylight factor (DF) of rooms in Building Two. Corridor units constitute 66.6% of all residential units in Building Two, while corner units constitute 33.3% of all residential units. All the rooms have light color walls therefore R_B = 0.5 is used. The results reflect that Building Two fulfill the requirement that at least 80% of living rooms achieve DF of 1.5%, at least 80% of bedrooms achieve DF of 1%, and 100% of kitchens achieve DF of 2%.

Table 7. 4 Dimension and average daylight factor of rooms in Building Two

Rooms		θ	T	W (m^2)	A (m^2)	DF (%)
Corridor units (66.7%)	Living room	1.31/1.22	0.88	5.6	160.5	3.0/2.8
	Master bedroom	1.31/1.13	0.88	1.43	83.1	1.5/1.3
	Bedroom 2	1.31/1.13	0.88	1.43	56.5	2.2/1.9
	Bedroom 3	1.31/1.22	0.88	4.48	58.7	6.6/6.1
	Kitchen	1.31	0.88	1.43	60.5	2.0
Corner units (33.3%)	Living room	1.31/1.22	0.88	7.4	174.6	3.7/3.4
	Master bedroom	1.31	0.88	3.8	71.1	4.6
	Bedroom 2	1.31/1.13	0.88	3.8	63.1	5.5/4.5
	Bedroom 3	1.31/1.13	0.88	1.4	55.4	2.2/1.9
	Kitchen	1.31	0.88	1.43	55.9	2.2

- **Room Acoustics** — The measured results show that the average indoor noise level is 57.7dBA, which is noisier than the credit requirements.

- **Noise Isolation** — HDB has no control on noise isolation between rooms, premises or floors.

- **Indoor Sources of Air Pollution** —

Adhesives & sealants

There is no control on VOC emission level for adhesives and sealants.

Central rubbish chutes

It is observed that central rubbish chutes are provided in Building Two.

Paints and coating

All HDB approved paints and coatings have to comply with PSB standard SS 150:1998 for interior applications and SS 345:1990 for exterior applications. In addition, primers for painting metal have to comply with SS 494:2001 to be lead and chromate free. Exact VOC emission levels cannot be obtained from product brochures, but all of them do not contain lead or mercury.

Composite wood

There is no control on composite wood.

7.4.2 Block Level

7.4.2.1 Sustainable Site

- **Urban Redevelopment ─** The building development does not use redeveloped or reclaimed land.

- **Public Transportation Access ─** The project site is located within 300m radius from a LRT station and within 200m radius from bus stops. Building Two has a proximity to food shops and a post box within 500m, and has a proximity to bank, school, medical centre, community centre, public house, and children's play area within 1000m.

- **Heat Island Effect** ─ The building's roof is made of RC and Ferrocement which are not highly reflective and high emissivity materials, and there is no green (vegetated) area on the roof.

- **Construction Management** ─ According to the architect, there was no implementation of an environmental management plan for the project.

- **Pollution During Construction** ─ Information is not available to demonstrate that the project met the credit requirement during construction.

- **Noise from Building Equipment** ─ Building Two meets the credit requirement.

- **Building User Handbook** ─ Building user handbook is not provided to building users.

7.4.2.2 Water Efficiency

- **Innovative Wastewater Technologies** ─ No innovative wastewater technology is applied in Building Two.

- **Metering and Controls** ─ It is observed that water meters are installed for every unit. One credit is achieved.

- **Water Quality ─** According to Public Utilities Board, potable water meets WHO drinking water quality standards. However, no measure is installed for treatment of potable water supplies to ensure quality to WSD (WHO) drinking water quality standards at point of use.

- **Water Recycling ─** Water recycling facilities are not provided in Building Two.

7.4.2.3 Energy Use

- **Improvement of the Average U-value ─** The average U-value of external building surfaces is 0.84W/m^{2}K, and the average roof U-value of Building Two is 0.5384W/m^{2}K. Both of them meet the credit requirements.

- **Building Orientation ─** According to the drawings of Building Two, total area of external building surfaces facing N-S is only 1% more than total area of external building surfaces facing W-E. One credit is achieved.

- **CO_2 Emission due to Energy Consumption in Public Areas ─** The energy consumption of the operation of lifts, lighting and other services in public areas of Building Two is not available.

- **Renewable Energy ─** All building energy use is not generated from renewable energy sources.

- **Clothes Drying Facilities ─** It is observed that all units have a set of standard cloth hanging rack for residents to place bamboo poles and dry cloth. This drying facility consists of two cloth hanging rack facing each other; one is fixed on the external wall of the kitchen and the other on the external wall of bedroom, so residents can place bamboo poles with wet clothes on them.

- **Natural Ventilation —** None of the required two analyses was undertaken. However, all public/circulation areas (corridors and staircases) are open areas and capable of providing adequate ventilation. Therefore, 4 credits are awarded.

- **Energy Efficient Lighting in Public Areas —** Site survey results show that energy efficient lighting equipments are installed in public areas, and under the control of town council with time switching and photoelectric switching lighting control for the lamps in areas where daylight is available.

- **Energy Efficient Appliances —** No certified energy efficient appliance is used in Building Two.

- **Building Systems Commissioning —** HDB has implemented the following fundamental best practice commissioning procedures:
    - Engage a commissioning team that does not include individuals directly responsible for project design or construction management.
    - Review the design intent and the basis of design documentation.
    - Incorporate commissioning requirements into the construction documents.
    - Develop and utilize a commissioning plan.
    - Verify installation, functional performance, training and operation and maintenance documentation.

There is no commissioning report, only the commissioning result e.g. “approval”.

- **Energy Consumption on Site ─** No information indicates that a firm commitment is made to require the constructor to set up systems to monitor and report energy consumption resulting from energy use on site and fuel consumption resulting from transport to and from site on a monthly basis.

- **Metering and Monitoring ─** Water, gas and electrical sub metering are installed for every unit, and metering for landlord’s electricity consumption in common space/public areas is installed as well.

- **Operation and Maintenance Manual ─** No operations and maintenance manual is provided.

7.4.2.4 Materials & Resources

- **Recycled materials ─** No recycled material was used in this building.

- **Resource Reuse ─** No resource was reused in the project.

- **Rapidly Renewable Materials ─** No rapidly renewable material was used in the project.

- **Local/Regional Materials ─** Concrete and sand used by the contractor in this project are from Malaysia and Indonesia, which are within the 800km radius. And concrete constitutes more than 80% of the whole materials used in the project.

- **Sustainable Forest Products —** According to HDB, this project used durable and reusable formwork systems to replace timbers formwork, and timber formwork, where used, was properly maintained during the construction.

- **Green Building Materials —** Building Two did not meet the credit requirement that choosing building materials for 50% of key building elements which have been labeled under the Singapore Green Labeling scheme.

- **Ozone Depletion —** According to HDB architect, not all thermal insulation in building fabric and services are made only from materials with zero ozone depletion potentials. In Singapore, environmental pollution control (ozone depleting substances) regulations were issued by government in 2001 to prohibit importation and exportation of CFC and HCFC (National Environment Agency, 2001). Singapore has already successfully phased out the consumption of CFCs and Halons, and the government will work closely with local industries to move away from HCFC technologies as soon as practically possible (Ministry of the Environment, 1999). Hence one credit is achieved in “Banned by Government”.

- **Off-site Fabrication —** According to HDB, standardized prefabricated building elements were used in this project to reduce the use of formwork.

- **No Asbestos —** According to the architect, no asbestos was used in Building Two. Therefore, this project meets all the credits’ requirements.

- **Adaptability and Deconstruction —** The Design of Building Two did not provide spatial flexibility that can adapt spaces for different uses, nor provide flexibility through the choice of building structural system that allows for change in future use.

- **Modular and Standardized Design —** According to HDB, modular and standardized design was used in this project.

- **Construction Waste Management —** HDB does not impose an active waste management system on the building contractor at construction stage.

- **Storage of Recyclables and Waste Disposal —** It is observed that neither central waste recycling space at ground level of building nor recycling bin in each floor level is provided in Building Two.

7.4.2.5 Indoor Environmental Quality

- **Ventilation Effectiveness —** The building is located in isolation, and two longer sides of building face to open space.

7.4.3 Precinct Level

7.4.3.1 Sustainable Site

- **Contaminated Land—** The site is not on a contaminated land.

- **Local Transportation and Amenities —** It is observed that there exist sheltered pedestrian access to a LRT system and local urban center. Sufficient local amenities are provided for basic needs of building occupants. There are covered storage facilities for securing six bicycles on the ground floor of this building, and cycling path is provided. Only car parking for disable persons is provided close to the building, and centralized car parking is provided in multi-storey carpark.

- **Heat Island Effect ─** The site meets the credit requirements that it provides shade for at least 30% of the site's non-roof impervious surfaces. It is observed that "green" (vegetated) roof for more than 50% of the roof area of multi-storey car park is installed.

- **Ecological Impact ─** The site is not a low ecological value site, nor Greenfield or brownfield site.

- **Landscaping and Planters ─** The plants provided in the site are tolerant of climate, soils, and natural water availability. Planting area is more than 30% of the site area.

- **Microclimate around Buildings ─** It is observed that no pedestrian area is subject to excessive wind velocities caused by amplification due to the site layout and/or building design.

- **Overshadowing and Views ─** The building is isolated. Hence it meets the credit requirements: consideration of the solar access for individual building to minimize overshadowing, and optimization of view potential for the site whilst preserving the views of surrounding developments.

- **Vehicular Access ─** It is observed that access is provided for deliver vehicles and waste collection vehicles to the service areas of the building which lies within the site boundary and are or segregated from pedestrian access routes.

- **Stormwater Management ─** According to the architect, HDB does not track the volume of the stormwater discharged from the project site. There is no stormwater treatment facility required on-site as the stormwater is collected across the whole-catchment area to be treated at the local reservoirs.

- **Light Pollution Reduction ─** Survey results show that Building Two fulfilled the credit requirements: all the exterior luminaries do no exceed 1.5 times the recommended maintained illuminance; the maximum candela value of all interior lighting fall within the building; the maximum candela value of all the exterior lighting falls within the property because the lamps are all faced towards the property and appropriately shielded such that there is no spill over to adjacent property.

- **Low Environmental Impact Management Policy ─** The National Environment Agency and town councils are all involved in establishing/maintaining a low impact site and building exterior pest management.

- **Pollution During Construction ─** According to the architect, there was no implementation of an environmental management plan for the project.

7.4.3.2 Water Efficiency

- **Water Efficient Landscaping ─** The landscaping is irrigated by rain. There is no potable water used for the irrigation. Permanent landscape irrigation system is not installed on the site.

7.4.3.3 Energy Use

- **Energy Efficient Lighting in External Areas ─** Site survey results show that energy efficient lighting equipments are installed, and under the control of town council with time switching and photoelectric switching lighting control for the lamps in areas where daylight is available.

7.4.3.4 Materials & Resources

- **Storage of Recyclables and Waste Disposal ─** It is observed that no storage of recyclables and waste disposal is provided in the precinct.

7.4.3.5 Indoor Environmental Quality

- **IAQ in Multi-storey Car Parks ─** IAQ in multi-storey car park complies with the design requirements specified in SS CP 13: 1999.

7.4.4 Innovation

- **Innovation & Performance Enhancements ─** No information indicates that Building Two has exceptional performance above the requirements set in this protocol, or innovative performance in green building categories not specifically addressed in the protocol.

Table 7. 5 Environmental assessment for Building Two using new developed protocol

Possible Points	Assessed Issues	Score achieved
	UNIT LEVEL	
	Water Efficiency	
3	Water efficient devices	1
	Energy Use	
1	CO_2 emission due to energy consumption	1
32	Natural ventilation	16
2	Hot water supply	0
5	Energy efficient appliances	2
	Indoor Environmental Quality	
6	Ventilation effectiveness	0
1	Cooker hood	0
7	Thermal comfort	3
8	Daylight & views	8
2	Room acoustics	0
2	Noise isolation	0
4	Indoor sources of air pollution	2
73	**Group Sub-total**	**33**
	BLOCK LEVEL	
	Sustainable Site	
1	Urban redevelopment	0
21	Public transportation access	18
2	Heat island effect	0
1	Construction management	0
5	Pollution during construction	0
4	Noise from building equipment	4
1	Building user handbook	0
	Water Efficiency	
2	Innovative wastewater technologies	0
1	Metering and controls	1
4	Water quality	2
2	Water recycling	0
	Energy Use	
3	Improvement of the average U-value	3
3	Building orientation	1
1	CO_2 emission due to energy consumption in public areas	0
1	Renewable energy	0
2	Clothes drying facilities	2
9	Natural ventilation	4
11	Energy efficient lighting in public areas	11
3	Energy efficient appliances	0
1	Building systems commissioning	0
1	Energy consumption on site	0
1	Metering and monitoring	1

Possible Points	Assessed Issues	Score achieved
1	Operation and maintenance manual	0
	Materials & Resources	
1	Recycled materials	0
1	Resource reuse	0
1	Rapidly renewable materials	0
1	Local/regional materials	1
1	Sustainable forest products	1
1	Green building materials	0
3	Ozone depletion	1
1	Off-site fabrication	1
63	No asbestos	63
2	Adaptability and deconstruction	0
2	Modular and standardized design	2
2	Construction waste management	0
2	Storage of recyclables and waste disposal	0
	Indoor Environmental Quality	
11	Ventilation effectiveness	11
173	**Group Sub-total**	**127**
	PRECINCT LEVEL	
	Sustainable Site	
3	Contaminated land	0
7	Local transportation and amenities	7
2	Heat island effect	2
2	Ecological impact	0
4	Landscaping and planters	4
1	Microclimate around buildings	1
1	Overshadowing and views	1
2	Vehicular access	2
2	Stormwater management	0
1	Light pollution reduction	1
1	Low environmental impact pest management policy	1
3	Pollution during construction	0
	Water Efficiency	
5	Water efficient landscaping	5
	Energy Use	
16	Energy efficient lighting in external areas	16
	Materials & Resources	
2	Storage of recyclables and waste disposal	0
	Indoor Environmental Quality	
2	IAQ in car parks	2
54	**Group Sub-total**	**42**
	INNOVATION	
5	Innovation & performance enhancements	0
305	**Grand Total**	**202**

7.4.5 Summary of Building Two

Table 7.6 shows that Building Two has achieved 67% of the total number of the new protocol's credits, hence is awarded Gold Grade. The performance of Building Two is above average at Block Level (73%) and Precinct Level (78%), but slightly below average at Unit Level (45%). Overall, the environmental performance of Building Two is above average. However, the assessment results reveal that improvement should be looked into in the following areas: "water efficiency", "energy use" and "indoor environmental quality" at Unit Level, "water efficiency" at Block Level, and "materials & resources" at Precinct Level.

Table 7. 6 Summary of environmental assessment for Building Two using new developed protocol

Assessed Issues	Maximum score achievable	Score achieved	Percentage
UNIT LEVEL (total)	**73**	**33**	**45%**
Water Efficiency	3	1	33%
Energy Use	40	19	48%
Indoor Environmental Quality	30	13	43%
BLOCK LEVEL (total)	**173**	**127**	**73%**
Sustainable Site	35	22	63%
Water Efficiency	9	3	33%
Energy Use	37	22	59%
Materials & Resources	81	69	85%
Indoor Environmental Quality	11	11	100%
PRECINCT LEVEL (total)	**54**	**42**	**78%**
Sustainable Site	29	19	66%
Water Efficiency	5	5	100%
Energy Use	16	16	100%
Materials & Resources	2	0	0%
Indoor Environmental Quality	2	2	100%
Grand Total	**300**	**202**	**67%**
INNOVATION (total)	**5**	**0**	**0%**
Innovation & performance enhancements	5	0	0%

7.5 Comparison of new protocol assessment results of Building One and Building Two

The comparison of new protocol assessment results of Building One and Building Two is shown in Table 7.7. It is observed that Building Two has better environmental performance than Building One at all the three Levels. However, Building One has better performance than Building Two under section "sustainable site" at Block Level. Besides, the two buildings have achieved same scores in "water efficiency" at all the three Levels, "energy use" and "material & resources" at Precinct Level. Both buildings' environmental performances are above average.

According to the assessment results, Building Two has great improvement compared to Building One under the section "indoor environmental quality" at Unit Level. The better environmental performance of Building Two is reflected especially in the higher use rate of energy efficient appliances and better daylight & views.

Other than the improvement of indoor environmental quality, the comparison results also demonstrate the improvement of outdoor environment in public housing in Singapore especially in the enlargement of open space and greenery in the precinct, reduction of heat island effect by centralizing car parking into multi-storey carpark, and bicycle storage provision on the ground floor of HDB blocks.

However, the assessment results of the two HDB blocks reveal common problems in local public housing: the limited attention to analyses/simulation of indoor environmental quality including ventilation, noise control and thermal comfort, as well as the limited attention to environmental sustainability of water, material and energy, especially the waste water technology, water recycling, energy efficient appliances, renewable/green energy, and renewable/recycled material.

Table 7. 7 Comparison of environmental assessment results of Building One and Building Two using new developed protocol

Assessed Issues	Score achieved	
	Building One	Building Two
UNIT LEVEL (total)	**21**	**33**
Water Efficiency	1	1
Energy Use	17	19
Indoor Environmental Quality	3	13
BLOCK LEVEL (total)	**114**	**127**
Sustainable Site	25	22
Water Efficiency	3	3
Energy Use	21	22
Materials & Resources	65	69
Indoor Environmental Quality	0	11
PRECINCT LEVEL (total)	**32**	**42**
Sustainable Site	11	19
Water Efficiency	5	5
Energy Use	16	16
Materials & Resources	0	0
Indoor Environmental Quality	0	2
Grand Total	**167**	**202**
INNOVATION (total)	**0**	**0**
Innovation & performance enhancements	0	0

7.6 Evaluation of the New Developed Environmental Assessment Criteria and Protocol

The new developed environmental assessment criteria and protocol take into consideration of environmental issues relevant to Singapore's tropical and high density living city context especially the critical environmental issues regarding local residential developments with the focus on public housing. The new protocol adopts a weighting network which gives different parameters different weights in relation to local priority, and addresses a balance between global, local and indoor issues.

One main objective of the assessment of the two HDB buildings using the new protocol is to use the assessment as two case studies to evaluate the applicability of the new protocol for assessing local residential developments. The evaluation reveals that the new protocol is

- Simple and practical – the new protocol adopts local building code and regulations which are easy to access and follow for local building industry. For example, Credit BSS-5 and PIEQ-1 adopt local regulations and building code as the credit requirements.
- Transparent and credible – the criteria's requirements are described in detail and clear in the new protocol, which are easy for local building industry to understand, e.g., Credit UWE-1, Credit BSS-2, and etc.
- Challenging – some criteria have higher requirements than local standard level, which need more effort to achieve. For example, Credit UIEQ-2 requires installation of a cooker hood with extract fan ducted to the outdoor air, while under local stand level cooker hoods with extract fan ducted to elsewhere in the kitchen are installed.
- Covers essential environmental and resource issues – the new protocol covers the five essential environmental and resource issues categories: sustainable site, water efficiency, energy use, material & resources, and indoor environmental quality.
- Versatile - some criteria's requirements are very open and could be achieved by different methods/solutions, e.g. different simulation models, different building performance, installation of different facilities. For example, Credit UEU-2 could be achieved by undertake an analysis of the building design using different simulation models or using wind tunnel test.

- Encourages innovation – the new protocol awards up to additional 5 points to innovation and performance enhancement in the Credit IPE-1.
- Useful as design tool - the new protocol could be used as design tool during the planning and design stage of a project. For example, Credit BEU-2 could be used as design tool during the design stage and Credit PSS-2 could be used as design tool during the planning stage of a project.
- Ability to offer different levels of assessment/output - the new protocol offers three levels (unit, block and precinct) of assessment/output.
- Weighting of criteria - the new protocol gives different criteria different weights according to local priority.

The evaluation results demonstrate that the new developed environmental assessment criteria and protocol could be considered as a satisfactory building environmental assessment method for local residential developments.

7.7 Conclusion

The assessment results reveal that Building Two has better environmental performance than Building One. Building Two has achieved Gold Grade and fulfilled 67% of the new protocol's requirements. Building One has achieved 56% of the total number of the new protocol's credits, hence is awarded Silver Grade. The performance of both buildings is above average at Block Level and Precinct Level, but below average at Unit Level.

However, there is a lot of room for improvement for local residential developments, particularly in the areas of analyses/simulation of indoor environmental quality including ventilation, noise control and thermal comfort, and environmental sustainability of water, material and energy.

To evaluate the applicability of new protocol for assessing local residential developments, the environmental performance of two HDB buildings is assessed as two case studies. The evaluation results reveal that the new protocol could be considered as a satisfactory building environmental assessment method for local residential developments.

CHAPTER 8 CONCLUSION

8.1 Introduction

This study aims to develop environmental assessment criteria and protocol for residential developments relevant to Singapore and tropical context. The main research achievements include:

- Identification of a set of sustainable criteria which are relevant to Singapore and the tropical context with respect to residential developments
- Indoor survey and measurement of two HDB residential buildings
- Environmental assessment of two HDB residential buildings using LEED-NC
- Survey on local building experts regarding environmental sustainable issues of local residential developments
- Generation of weights of environmental issues in relation to local priority
- Development of a new environmental assessment criteria and protocol for residential developments
- Environmental assessment of the two HDB blocks using the new developed environmental assessment protocol, and the evaluation of the new protocol

8.2 Research Finding

8.2.1 Indoor survey and measurement

In order to determine the indoor environmental quality of public housing in Singapore, two HDB public housing buildings, Building One built in 1971 and Building Two built in 2001, are selected to conduct indoor survey and measurement. The indoor survey and measured results are summarized in Table 8.1.

Table 8. 1Comparison of indoor survey and measured results of Building One and Building Two

Surveyed items and measured parameters		Building One	Building Two
Electricity consumption (kWh/m^2/year)		51.3	55.83
Air-conditioner usage		46.4%	69.5%
Water efficiency	Water consumption (l/household/day)	400.25	536.1
	Water flow rate of faucets (l/s)	0.315	0.187
	Water flow rate of showerheads (l/s)	0.11	0.185
	Capacity of water cisterns (l)	12	4.5
	Duel flush water cisterns	20%	100%
Cooker hood		20%	100%
Sky visibility of living room		46.7%	70%
Cloth drying facilities		Bamboo slots	Hanging rack
Energy efficient appliances	Air-conditioner	14.3%	25%
	Refrigerator	0	33.3%
Indoor thermal environment	Air temperature (mean) (^oC)	29.95	30.47
	Relative humidity (mean)	65.2%	56.8%
	Air Velocity (mean) (m/s)	0.13	0.28
	Mean radiant temperature (^oC)	31.18	31.1
Noise level (mean) (dBA)		57	57.7
Satisfied rate of living condition of the unit		46.7%	22%
Satisfied rate of living environment of the neighborhood		40%	27%

The indoor survey and measured results indicate that Building Two has more sustainable indoor environment in the aspects of energy efficient appliances, water flow rate of showerheads, water efficient water cisterns, cooker hood usage, sky visibility in living room, cloth drying facilities, and indoor thermal environment. On the other hand, Building One is slightly quiet and cooler, and consumes less electricity and water which may be due to different life style of residents.

8.2.2 Environmental assessment of Two HDB residential buildings using LEED-NC

To examine the sustainability of Building One and Building Two, these two buildings are assessed using LEED-NC. The environmental performance of the two buildings is assessed under six categories: sustainable sites, water efficiency energy & atmosphere, materials & resources, indoor environmental quality, and innovation & design process.

The environmental sustainable assessment results of two HDB buildings are summarized in Table 8.2. The assessment results indicate that Building Two has better environmental performance than Building One. Building Two achieved 24% of the total number of credits possible in LEED-NC assessment, while Building One achieved 20% of the total number of credits possible in LEED-NC assessment. However, both buildings have failed to achieve average scores in the assessments.

Table 8. 2 Summary of environmental assessment of the two HDB buildings using LEED-NC

	Building One		Building Two	
	Scored achieved	Percentage achieved	Scored achieved	Percentage achieved
LEED-NC assessment				
Sustainable Sites	4	29%	6	43%
Water Efficiency	2	40%	2	40%
Energy & Atmosphere	1	14%	1	14%
Materials & Resources	2	15%	2	15%
Indoor Environmental Quality	2	18%	2	18%
Innovation & Design Process	0	0%	0	0%
Total	11	20%	13	24%

8.2.3 Building expert survey

A local building expert survey is conducted to investigate local building experts' opinions towards the importance of identified environmental sustainable issues which are relevant to Singapore and the tropical context with respect to residential developments.

From local building experts' point of views, "no asbestos" is the most important environmental issue in residential buildings, while "local/regional materials" is the least important environmental issue. Eleven issues are considered as "more important":

- **Unit level**

Natural ventilation, ventilation effectiveness, thermal comfort, and daylight & views

- **Block level**

Public transportation access, natural ventilation, energy efficient lighting in public areas, no asbestos, and ventilation effectiveness

- **Precinct level**

Local transportation and amenities, and energy efficient lighting in external areas

8.2.4 Environmental assessment of Two HDB residential buildings using the new developed protocol

Environmental sustainability of the same two HDB blocks is assessed using the new developed environmental assessment criteria and protocol at three levels: unit level, block level and precinct level, and under six categories: sustainable sites, water efficiency, energy use, materials & resources, indoor environmental quality, and innovation & design process.

The environmental sustainable assessments results of two HDB buildings are summarized in Table 8.3. The assessment results also reveal that Building Two has better environmental performance than Building One. Building Two has achieved Gold Grade and fulfilled 67% of the new protocol's requirements. Building One has achieved 56% of the total number of possible credits possible of the new protocol, hence is awarded Silver Grade. The performance of both buildings is above average at Block Level and Precinct Level, but below average at Unit Level.

8.3 Future Research Development

Due to time limitation, only two case studies have been conducted to test the new environmental assessment criteria and protocol for residential developments. In future,

Table 8. 3 Summary of environmental assessment of the two HDB buildings using new protocol

	Building One		Building Two	
	Scored achieved	Percentage achieved	Scored achieved	Percentage achieved
UNIT LEVEL (total)	**21**	**29%**	**33**	**45%**
Water Efficiency	1	33%	1	33%
Energy Use	17	43%	19	48%
Indoor Environmental Quality	3	10%	13	43%
BLOCK LEVEL (total)	**114**	**66%**	**127**	**73%**
Sustainable Site	25	71%	22	63%
Water Efficiency	3	33%	3	33%
Energy Use	21	57%	22	59%
Materials & Resources	65	80%	69	85%
Indoor Environmental Quality	0	0%	11	100%
PRECINCT LEVEL (total)	**32**	**59%**	**42**	**78%**
Sustainable Site	11	38%	19	66%
Water Efficiency	5	100%	5	100%
Energy Use	16	100%	16	100%
Materials & Resources	0	0%	0	0%
Indoor Environmental Quality	0	0%	2	100%
INNOVATION (total)	**0**	**0%**	**0**	**0%**
Innovation & performance enhancements	0	0%	0	0%
Grand Total	**167**	**56%**	**202**	**67%**
Grade Awarded	**Silver**		**Gold**	

more case studies should be conducted to test the protocol. These case studies could include test on occupied and un-occupied HDB residential buildings, test on condominiums, and test on residential buildings in the tropical region.

Since the collective knowledge that constitutes environmentally sustainable residential buildings will continue to develop, this new environmental assessment criteria and protocol will need to respond accordingly. Therefore, the protocol will be a dynamic system, and further research could be done to make this protocol to incorporate periodic changes and updates of criteria and their weights in the future.

BIBLIOGRAPHY

Acuity Brands Lighting. (2005). United States. *EQc8 – daylight and views*. Retrieved 28 November, 2005 from the World Wide Web: http://www.acuitybrandslighting.com/sustainability/LEED/EQ-C8.asp.

Auty, R. M., and Brown, K. (Ed.). (1997). *Approaches to Sustainable Development*. New York: Printer.

Briffett, C., Mathur, K., and Ofori, G. (1998). Sustainable development and the built environment in Singapore. *Proceedings of Buildings and the Environment in Asia*. Singapore: National University of Singapore.

Building Research Establishment. (2005). England. *EcoHomes: the environmental rating for home*. Retrieved 28 November, 2005 from the World Wide Web: http://www.breeam.org/ecohomes.html.

Building Energy Efficiency Research. (2000). Hong Kong. *Sustainable architecture*. Retrieved 07 February, 2007 from the World Wide Web: http://www.arch.hku.hk/research/BEER/sustain.htm
.

Cao, S. Q., and Fei, L. (Ed.). (2001). Urban housing design in China. Beijing: China Planning Press.

Chiang, C. M., Su, H. J., Li, Y. Y., Chou, P. C., and Shao, W. C. (2001). *Stride forward to sustainable healthy building, past, present and future - from global view to local action in Taiwan*, International Conference on Planning and Design, Tainan, TAIWAN.

Cole, R.J. (1998). Emerging trends in building environmental assessment methods. *Building Research & Information*, *26*(1), 3-16.

Cole, R.J. (2001). A Building Environmental Assessment Method for British Columbia Final Report. University of British Columbia, Canada.

Cole, R.J., Rousseau, D., and Theaker, I.T. (1993). *Building environmental performance assessment criteria: version 1 – office buildings*. Paper presented at the BEPAC Foundation, Vancouver.

Collaborative for High Performance School. (2001). United States. *High performance schools best practices manual*. Retrieved 28 November, 2005 from the World Wide Web: http://www.chps.net/manual/documents/2002_updates/CHPSvIII.pdf.

De Dear, R.J., Leow K.G., and Foo S.C. (1991). Thermal comfort in the humid tropics: 4eld experiments in air conditioned and naturally ventilated buildings in Singapore. *International Journal of Biometeorology*, *34*, 259–265.

Feraidi, H. (2004). *Thermal comfort for naturally ventilated residential buildings in tropical climate.* Unpublished doctoral dissertation, Department of Building, National University of Singapore.

Green Building Challenge. (2002). Canada. Retrieved 28 November, 2005 from the World Wide Web: http://www.greenbuilding.ca/iisbe/gbc2k2/gbc2k2-start.htm.

Green Building Council. (2005). United States. *LEED: leadership in energy and environmental design*. Retrieved 28 November, 2005 from the World Wide Web: http://www.usgbc.org/DisplayPage.aspx?CategoryID=19.

Green Building Council of Australia. (2008). Australia. *Green Star*. Retrieved 15 May, 2008 from the World Wide Web: http://www.gbca.org.au/green-star/.

HK BEAM Society. (2003). Hong Kong. *HK-BEAM: Hong Kong building environmental assessment method*. Retrieved 28 November, 2005 from the World Wide Web: http://www.hk-beam.org.hk/general/home.php.

Housing and Development Board. (2006). *Annual report*. Housing and Development Board, Singapore.

Japan Sustainable Building Consortium. (2008). Japan. *Comprehensive Assessment System for Building Environmental Efficiency*. Retrieved 15 May, 2008 from the World Wide Web: http://www.ibec.or.jp/CASBEE/english/index.htm.

Lee, S.E. (2001). *An integrated building environmental assessment method using total building performance approach.* Unpublished research project report, Department of Building, National University of Singapore.

Lee, S.E., and Ho, K. M. (1996). *Survey on noise in HDB estates report 1 acceptable indoor noise levels of HDB apartments and summary report*. Unpublished research project report, Department of Building, National University of Singapore.

Levin, H., Boerstra, A., and Ray, S. (1995). *Scoping U.S. inventory flows and environmental impacts in life cycle assessment*. Paper presented at Society for Environmental Toxicology and Chemistry (SETAC) World Congress, Vancouver, B.C.

Ministry of the Environment. (1999). *Singapore's commitment to the montreal Protocol*. Singapore.

National Environment Agency. (2001). Singapore. *Environmental pollution control (ozone depleting substances) regulations*. Retrieved 28 November, 2005 from the World Wide Web: http://app.nea.gov.sg/cms/htdocs/category_sub.asp?cid=193.

Priyadarsini, R., Cheong, K. W., and Wong, N. H. (2004). Enhancement of natural ventilation in high-rise residential building using stack system. *Energy and Buildings*, *36*(15 January), 61-71.

Public Utilities Board. (2005). Singapore. Retrieved 28 November, 2005 from the World Wide Web: http://www.pub.gov.sg/conservation/ConservWaterSaving-Devices.aspx?l1=3&l2=19&l3=19.

Sustainability Reporting Program. (2004). Canada. *A brief history of sustainable development*. Retrieved 06 February, 2007 from the World Wide Web: http://www.sustreport.org/background/history.html.

Toh, E.S. (1997). *An environmental assessment method for buildings*. Unpublished undergraduate dissertation, Department of Building, National University of Singapore.

Ullah, M. B. (2001). *Study of daylight attenuation through windows in urban environments*. Unpublished research project report, Department of Building, National University of Singapore.

Ullah, M. B., and Liaw, W. L. (2003). Daylight distribution in the living rooms of four types of public housing building in Singapore. *Lighting Research and Technology*, *35*(2), 91–100.

Wittkopf, S. K. (2003). *I-light 2 design guide for energy efficient qualitative lighting design in urban housing*. Unpublished research project report, Department of Building, National University of Singapore.

Wong, N. H. (2002). *Natural ventilation studies of public housing in Singapore*. Unpublished research project report, Department of Building, National University of Singapore.

Wong, N. H. (2004). *Thermal performance of façade materials and design and the impacts on indoor and outdoor environment*. Unpublished research project report, Department of Building, National University of Singapore.

Wong, N. H., Feraidi, H., Lim, P.Y., Tham, K. W., Sekhar, S. C., and Cheong, K. W. (2002a). Thermal comfort evaluation of naturally ventilated public housing in Singapore. *Building and Environment, 37*(12), 1267-1277.

Wong, N. H., Feriadi, H., Tham, K. W., Sekhar, S. C., Cheong, K. W., and K. Y. O. (2002b). The impact of multi-storey car parks on wind pressure distribution and air change rates of surrounding high rise residential buildings in Singapore. *International Journal on Architectural Science, 3*(1), 30-42.

Wong, N. H., and Huang, B. (2004). Comparative study of the indoor air quality of naturally ventilated and air-conditioned bedrooms of residential buildings in Singapore. *Building and Environment, 39*(8 January), 1115-1123.

World Commission on the Environment and Development. (1987). *From one earth to one world: an overview*, Oxford: Oxford university press.

Yoon, K. P., and Hwang, C. L. (1995). *Multiple attribute decision making: an introduction*, Thousand Oaks, CA : Sage Publications.

APPENDIX A

Summary of LEED-NC Criteria Requirements

Points	Criteria
	Sustainable Sites
Prereq	**Erosion & Sedimentation Control** Design a sediment and erosion control plan, specific to the site, that conforms to United States Environmental Protection Agency (EPA) Document No. EPA 832/R-92-005 (September 1992), Storm Water Management for Construction Activities, Chapter 3, OR local erosion and sedimentation control standards and codes, whichever is more stringent. The plan shall meet the following objectives: • Prevent loss of soil during construction by stormwater runoff and/or wind erosion, including protecting topsoil by stockpiling for reuse. • Prevent sedimentation of storm sewer or receiving streams. • Prevent polluting the air with dust and particulate matter.
1	**Site Selection** Do not develop buildings, roads or parking areas on portions of sites that meet any one of the following criteria: • Prime farmland as defined by the United States Department of Agriculture in the United States Code of Federal Regulations, Title 7, Volume 6, Parts 400 to 699, Section 657.5 (citation 7CFR657.5). • Land whose elevation is lower than 5 feet above the elevation of the 100-year flood as defined by the Federal Emergency Management Agency (FEMA). • Land which is specifically identified as habitat for any species on Federal or State threatened or endangered lists. • Within 100 feet of any water including wetlands as defined by United States Code of Federal Regulations 40 CFR, Parts 230-233 and Part 22, and isolated wetlands or areas of special concern identified by state or local rule, OR greater than distances given in state or local regulations as defined by local or state rule or law, whichever is more stringent. • Land which prior to acquisition for the project was public parkland, unless land of equal or greater value as parkland is accepted in trade by the public landowner (Park Authority projects are exempt).
1	**Development Density** Increase localized density to conform to existing or desired density goals by utilizing sites that are located within an existing minimum development density of 60,000 square feet per acre (two story downtown development).
1	**Brownfield Redevelopment** Develop on a site documented as contaminated (by means of an ASTM E1903-97 Phase II Environmental Site Assessment) OR on a site classified as a brownfield by a local, state or federal government agency. Effectively remediate site contamination.

Points	Criteria
1	**Alternative Transportation ─ Public Transportation Access** Locate project within 1/2 mile of a commuter rail, light rail or subway station or 1/4 mile of two or more public or campus bus lines usable by building occupants.
1	**Alternative Transportation ─ Bicycle Storage & Changing Rooms** For commercial or institutional buildings, provide secure bicycle storage with convenient changing/shower facilities (within 200 yards of the building) for 5% or more of regular building occupants. For residential buildings, provide covered storage facilities for securing bicycles for 15% or more of building occupants in lieu of changing/shower facilities.
1	**Alternative Transportation ─ Alternative Fuel Vehicles** Provide alternative fuel vehicles for 3% of building occupants AND provide preferred parking for these vehicles, OR install alternative-fuel refueling stations for 3% of the total vehicle parking capacity of the site. Liquid or gaseous fueling facilities must be separately ventilated or located outdoors.
1	**Alternative Transportation ─ Parking Capacity** Size parking capacity to meet, but not exceed, minimum local zoning requirements AND provide preferred parking for carpools or vanpools capable of serving 5% of the building occupants; OR add no new parking for rehabilitation projects AND provide preferred parking for carpools or vanpools capable of serving 5% of the building occupants.
1	**Reduced Site Disturbance ─ Protect or Restore Open Space** On greenfield sites, limit site disturbance including earthwork and clearing of vegetation to 40 feet beyond the building perimeter, 5 feet beyond primary roadway curbs, walkways and main utility branch trenches, and 25 feet beyond constructed areas with permeable surfaces (such as pervious paving areas, stormwater detention facilities and playing fields) that require additional staging areas in order to limit compaction in the constructed area; OR, on previously developed sites, restore a minimum of 50% of the site area (excluding the building footprint) by replacing impervious surfaces with native or adapted vegetation.
1	**Reduced Site Disturbance ─ Development Footprint** Reduce the development footprint (defined as entire building footprint, access roads and parking) to exceed the local zoning's open space requirement for the site by 25%. For areas with no local zoning requirements (e.g., some university campuses and military bases), designate open space area adjacent to the building that is equal to the development footprint.
1	**Stormwater Management ─ Rate and Quantity** If existing imperviousness is less than or equal to 50%, implement a stormwater management plan that prevents the post-development 1.5 year, 24 hour peak discharge rate from exceeding the pre-development 1.5 year, 24 hour peak discharge rate. OR If existing imperviousness is greater than 50%, implement a stormwater management plan that results in a 25% decrease in the rate and quantity of stormwater runoff.

Points	Criteria
1	**Stormwater Management ─ Treatment** Construct site stormwater treatment systems designed to remove 80% of the average annual post-development total suspended solids (TSS) and 40% of the average annual post-development total phosphorous (TP) based on the average annual loadings from all storms less than or equal to the 2-year/24- hour storm. Do so by implementing Best Management Practices (BMPs) outlined in Chapter 4, Part 2 (Urban Runoff), of the United States Environmental Protection Agency's (EPA's) *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*, January 1993 (Document No. EPA-840-B-92-002) or the local government's BMP document (whichever is more stringent).
1	**Heat Island Effect ─ Non-Roof** Provide shade (within 5 years) and/or use light-colored/high-albedo materials (reflectance of at least 0.3) and/or open grid pavement for at least 30% of the site's non-roof impervious surfaces, including parking lots, walkways, plazas, etc.; OR place a minimum of 50% of parking spaces underground or covered by structured parking; OR use an open-grid pavement system (less than 50% impervious) for a minimum of 50% of the parking lot area.
1	**Heat Island Effect ─ Roof** Use ENERGY STAR® compliant (highly reflective) AND high emissivity roofing (emissivity of at least 0.9 when tested in accordance with ASTM 408) for a minimum of 75% of the roof surface; OR install a "green" (vegetated) roof for at least 50% of the roof area. Combinations of high albedo and vegetated roof can be used providing they collectively cover 75% of the roof area.
1	**Light Pollution Reduction** Meet or provide lower light levels and uniformity ratios than those recommended by the Illuminating Engineering Society of North America (IESNA) *Recommended Practice Manual: Lighting for Exterior Environments* (RP-33-99). Design exterior lighting such that all exterior luminaires with more than 1000 initial lamp lumens are shielded and all luminaires with more than 3500 initial lamp lumens meet the Full Cutoff IESNA Classification. The maximum candela value of all interior lighting shall fall within the building (not out through windows) and the maximum candela value of all exterior lighting shall fall within the property. Any luminaire within a distance of 2.5 times its mounting height from the property boundary shall have shielding such that no light from that luminaire crosses the property boundary.
	Water Efficiency
1	**Water Efficient Landscaping ─ Reduce by 50%** Use high-efficiency irrigation technology OR use captured rain or recycled site water to reduce potable water consumption for irrigation by 50% over conventional means.
1	**Water Efficient Landscaping ─ No Potable Use or No Irrigation** Use only captured rain or recycled site water to eliminate all potable water use for site irrigation (except for initial watering to establish plants), OR do not install permanent landscape irrigation systems.

Points	Criteria
1	**Innovative Wastewater Technologies** Reduce the use of municipally provided potable water for building sewage conveyance by a minimum of 50%, OR treat 100% of wastewater on site to tertiary standards.
1	**Water Use Reduction ─20% Reduction** Employ strategies that in aggregate use 20% less water than the water use baseline calculated for the building (not including irrigation) after meeting the Energy Policy Act of 1992 fixture performance requirements.
1	**Water Use Reduction─30% Reduction** Employ strategies that in aggregate use 30% less water than the water use baseline calculated for the building (not including irrigation) after meeting the Energy Policy Act of 1992 fixture performance requirements.
	Energy & Atmosphere
Prereq	**Fundamental Building Systems Commissioning** Implement or have a contract in place to implement the following fundamental best practice commissioning procedures. • Engage a commissioning team that does not include individuals directly responsible for project design or construction management. • Review the design intent and the basis of design documentation. • Incorporate commissioning requirements into the construction documents. • Develop and utilize a commissioning plan. • Verify installation, functional performance, training and operation and maintenance documentation. • Complete a commissioning report.
Prereq	**Minimum Energy Performance** Design the building to comply with ASHRAE/IESNA Standard 90.1-1999 (without amendments) or the local energy code, whichever is more stringent.
Prereq	**CFC Reduction in HVAC&R Equipment** Zero use of CFC-based refrigerants in new base building HVAC&R systems. When reusing existing base building HVAC equipment, complete a comprehensive CFC phase-out conversion.
10	**Optimize Energy Performance** Reduce design energy cost compared to the energy cost budget for energy systems regulated by ASHRAE/IESNA Standard 90.1-1999 (without amendments), as demonstrated by a whole building simulation using the Energy Cost Budget Method described in Section 11 of the Standard. New Bldgs. Existing Bldgs. Points 15% 5% 1 20% 10% 2 25% 15% 3 30% 20% 4 35% 25% 5 40% 30% 6

Points	Criteria
	45% 35% 7 50% 40% 8 55% 45% 9 60% 50% 10 Regulated energy systems include HVAC (heating, cooling, fans and pumps), service hot water and interior lighting. Non-regulated systems include plug loads, exterior lighting, garage ventilation and elevators (vertical transportation). Two methods may be used to separate energy consumption for regulated systems. The energy consumption for each fuel may be prorated according to the fraction of energy used by regulated and non-regulated energy. Alternatively, separate meters (accounting) may be created in the energy simulation program for regulated and non-regulated energy uses. If an analysis has been made comparing the proposed design to local energy standards and a defensible equivalency (at minimum) to ASHRAE/IESNA Standard 90.1-1999 has been established, then the comparison against the local code may be used in lieu of the ASHRAE Standard. Project teams are encouraged to apply for innovation credits if the energy consumption of non-regulated systems is also reduced.
1	**Renewable Energy — 5%** Supply at least 5% of the building's total energy use (as expressed as a fraction of annual energy cost) through the use of on-site renewable energy systems.
1	**Renewable Energy — 10%** Supply at least 10% of the building's total energy use (as expressed as a fraction of annual energy cost) through the use of on-site renewable energy systems.
1	**Renewable Energy — 20%** Supply at least 20% of the building's total energy use (as expressed as a fraction of annual energy cost) through the use of on-site renewable energy systems.
1	**Additional Commissioning** In addition to the Fundamental Building Commissioning prerequisite, implement or have a contract in place to implement the following additional commissioning tasks: • A commissioning authority independent of the design team shall conduct a review of the design prior to the construction documents phase. • An independent commissioning authority shall conduct a review of the construction documents near completion of the construction document development and prior to issuing the contract documents for construction. • An independent commissioning authority shall review the contractor submittals relative to systems being commissioned. • Provide the owner with a single manual that contains the information required for re-commissioning building systems. • Have a contract in place to review building operation with O&M staff, including a plan for resolution of outstanding commissioning-related issues within one year after construction completion date.
1	**Ozone Depletion** Install base building level HVAC and refrigeration equipment and fire suppression systems that do not contain HCFCs or Halons.

Points	Criteria
1	**Measurement & Verification** Install continuous metering equipment for the following end-uses: • Lighting systems and controls • Constant and variable motor loads • Variable frequency drive (VFD) operation • Chiller efficiency at variable loads (kW/ton) • Cooling load • Air and water economizer and heat recovery cycles • Air distribution static pressures and ventilation air volumes • Boiler efficiencies • Building-related process energy systems and equipment • Indoor water risers and outdoor irrigation systems Develop a Measurement and Verification plan that incorporates the monitoring information from the above end-uses and is consistent with Option B, C or D of the 2001 *International Performance Measurement & Verification Protocol (IPMVP) Volume I: Concepts and Options for Determining Energy and Water Savings.*
1	**Green Power** Provide at least 50% of the building's electricity from renewable sources by engaging in at least a two-year renewable energy contract. Renewable sources are as defined by the Center for Resource Solutions (CRS) Green-e products certification requirements.
	Materials & Resources
Prereq	**Storage & Collection of Recyclables** Provide an easily accessible area that serves the entire building and is dedicated to the separation, collection and storage of materials for recycling including (at a minimum) paper, corrugated cardboard, glass, plastics and metals.
1	**Building Reuse ─ Maintain 100% of Existing Walls, Floors and Roof** Maintain an additional 25% (100% total) of existing building structure and shell (exterior skin and framing, excluding window assemblies and nonstructural roofing material).
1	**Building Reuse ─ Maintain 75% of Existing Walls, Floors and Roof** Maintain at least 75% of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material).
1	**Building Reuse ─ Maintain 100% of Shell/Structure and 50% of Non-Shell/Non Structure** Maintain 100% of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material) AND at least 50% of non-shell areas (interior walls, doors, floor coverings and ceiling systems).

Points	Criteria
1	**Construction Waste Management — Divert 50% From Landfill** Develop and implement a waste management plan, quantifying material diversion goals. Recycle and/or salvage at least 50% of construction, demolition and land clearing waste. Calculations can be done by weight or volume, but must be consistent throughout.
1	**Construction Waste Management — Divert 75% From Landfill** Develop and implement a waste management plan, quantifying material diversion goals. Recycle and/or salvage an additional 25% (75% total) of construction, demolition and land clearing waste. Calculations can be done by weight or volume, but must be consistent throughout.
1	**Resource Reuse — 5%** Use salvaged, refurbished or reused materials, products and furnishings for at least 5% of building materials.
1	**Resource Reuse — 10%** Use salvaged, refurbished or reused materials, products and furnishings for at least 10% of building materials.
1	**Recycled Content — 5% (post-consumer + 1/2 post-industrial)** Use materials with recycled content such that the sum of post-consumer recycled content plus one-half of the post-industrial content constitutes at least 5% of the total value of the materials in the project. The value of the recycled content portion of a material or furnishing shall be determined by dividing the weight of recycled content in the item by the total weight of all material in the item, then multiplying the resulting percentage by the total value of the item. Mechanical and electrical components shall not be included in this calculation. Recycled content materials shall be defined in accordance with the Federal Trade Commission document, *Guides for the Use of Environmental Marketing Claims, 16 CFR 260.7 (e)*, available at www.ftc.gov/bcp/grnrule/guides980427.htm.
1	**Recycled Content — 10% (post-consumer + 1/2 post-industrial)** Use materials with recycled content such that the sum of post-consumer recycled content plus one-half of the post-industrial content constitutes at least 10% of the total value of the materials in the project. The value of the recycled content portion of a material or furnishing shall be determined by dividing the weight of recycled content in the item by the total weight of all material in the item, then multiplying the resulting percentage by the total value of the item. Mechanical and electrical components shall not be included in this calculation. Recycled content materials shall be defined in accordance with the Federal Trade Commission document, *Guides for the Use of Environmental Marketing Claims, 16 CFR 260.7 (e)*, available at www.ftc.gov/bcp/grnrule/guides980427.htm.

Points	Criteria
1	**Local/Regional Materials ─20% manufactured regionally** Use a minimum of 20% of building materials and products that are manufactured* regionally within a radius of 500 miles. * Manufacturing refers to the final assembly of components into the building product that is furnished and installed by the tradesmen. For example, if the hardware comes from Dallas, Texas, the lumber from Vancouver, British Columbia, and the joist is assembled in Kent, Washington; then the location of the final assembly is Kent, Washington.
1	**Local/Regional Materials ─50% extracted regionally** Of the regionally manufactured materials documented for last credit, use a minimum of 50% of building materials and products that are extracted, harvested or recovered (as well as manufactured) within 500 miles of the project site.
1	**Rapidly Renewable Materials** Use rapidly renewable building materials and products (made from plants that are typically harvested within a ten-year cycle or shorter) for 5% of the total value of all building materials and products used in the project.
1	**Certified Wood** Use a minimum of 50% of wood-based materials and products, certified in accordance with the Forest Stewardship Council's Principles and Criteria, for wood building components including, but not limited to, structural framing and general dimensional framing, flooring, finishes, furnishings, and nonrented temporary construction applications such as bracing, concrete form work and pedestrian barriers.
	Indoor Environmental Quality
Prereq	**Minimum IAQ Performance** Meet the minimum requirements of voluntary consensus standard ASHRAE 62-1999, Ventilation for Acceptable Indoor Air Quality, and approved Addenda (see ASHRAE 62-2001, Appendix H, for a complete compilation of Addenda) using the Ventilation Rate Procedure.
Prereq	**Environmental Tobacco Smoke (ETS) Control** Zero exposure of non-smokers to ETS by EITHER: • prohibiting smoking in the building and locating any exterior designated smoking areas away from entries and operable windows; OR • providing a designated smoking room designed to effectively contain, capture and remove ETS from the building. At a minimum, the smoking room must be directly exhausted to the outdoors with no recirculation of ETS-containing air to the non-smoking area of the building, enclosed with impermeable deck-to-deck partitions and operated at a negative pressure compared with the surrounding spaces of at least 7 PA (0.03 inches of water gauge).

Points	Criteria
	• Performance of the smoking rooms shall be verified by using tracer gas testing methods as described in the ASHRAE Standard 129-1997. Acceptable exposure in non-smoking areas is defined as less than 1% of the tracer gas concentration in the smoking room detectable in the adjoining non-smoking areas. Smoking room testing as described in ASHRAE Standard 129-1997 is required in the contract documents and critical smoking facility systems testing results must be included in the building commissioning plan and report or as a separate document.
1	**Carbon Dioxide (CO_2) Monitoring** Install a permanent carbon dioxide (CO_2) monitoring system that provides feedback on space ventilation performance in a form that affords operational adjustments. Refer to the CO_2 differential for all types of occupancy in accordance with ASHRAE 62-2001, Appendix D.
1	**Ventilation Effectiveness** For mechanically ventilated buildings, design ventilation systems that result in an air change effectiveness (Eac) greater than or equal to 0.9 as determined by ASHRAE 129-1997. For naturally ventilated spaces demonstrate a distribution and laminar flow pattern that involves not less than 90% of the room or zone area in the direction of air flow for at least 95% of hours of occupancy.
1	**Construction IAQ Management Plan, During Construction** Develop and implement an Indoor Air Quality (IAQ) Management Plan for the construction and pre-occupancy phases of the building as follows: • During construction meet or exceed the recommended Design Approaches of the Sheet Metal and Air Conditioning National Contractors Association (SMACNA) IAQ Guideline for Occupied Buildings under Construction, 1995, Chapter 3. • Protect stored on-site or installed absorptive materials from moisturedamage. • If air handlers must be used during construction, filtration media with a Minimum Efficiency Reporting Value (MERV) of 8 must be used at each return air grill, as determined by ASHRAE 52.2-1999. • Replace all filtration media immediately prior to occupancy. Filtration media shall have a Minimum Efficiency Reporting Value (MERV) of 13, as determined by ASHRAE 52.2-1999 for media installed at the end of construction.
1	**Construction IAQ Management Plan, Before Occupancy** Develop and implement an Indoor Air Quality (IAQ) Management Plan for the pre-occupancy phase as follows: • After construction ends and prior to occupancy conduct a minimum two-week building flush-out with new Minimum Efficiency Reporting Value (MERV) 13 filtration media at 100% outside air. After the flushout, replace the filtration media with new MERV 13 filtration media, except the filters solely processing outside air. OR • Conduct a baseline indoor air quality testing procedure consistent with the United States Environmental Protection Agency's current *Protocol for Environmental Requirements, Baseline IAQ and Materials, for the Research Triangle Park Campus, Section 01445.*

Points	Criteria
1	**Low-Emitting Materials ─ Adhesives & Sealants** The VOC content of adhesives and sealants used must be less than the current VOC content limits of South Coast Air Quality Management District (SCAQMD) Rule #1168, AND all sealants used as fillers must meet or exceed the requirements of the Bay Area Air Quality Management District Regulation 8, Rule 51.
1	**Low-Emitting Materials ─ Paints** VOC emissions from paints and coatings must not exceed the VOC and chemical component limits of Green Seal's Standard GS-11 requirements.
1	**Low-Emitting Materials ─ Carpet** Carpet systems must meet or exceed the requirements of the Carpet and Rug Institute's Green Label Indoor Air Quality Test Program.
1	**Low-Emitting Materials ─ Composite Wood** Composite wood and agrifiber products must contain no added urea-formaldehyde resins.
1	**Indoor Chemical & Pollutant Source Control** Design to minimize pollutant cross-contamination of regularly occupied areas: • Employ permanent entryway systems (grills, grates, etc.) to capture dirt, particulates, etc. from entering the building at all high volume entryways. • Where chemical use occurs (including housekeeping areas and copying/ printing rooms), provide segregated areas with deck to deck partitions with separate outside exhaust at a rate of at least 0.50 cubic feet per minute per square foot, no air re-circulation and maintaining a negative pressure of at least 7 PA (0.03 inches of water gauge). • Provide drains plumbed for appropriate disposal of liquid waste in spaces where water and chemical concentrate mixing occurs.
1	**Controllability of Systems ─ Perimeter** Provide at least an average of one operable window and one lighting control zone per 200 square feet for all regularly occupied areas within 15 feet of the perimeter wall.
1	**Controllability of Systems ─ Non-Perimeter** Provide controls for each individual for airflow, temperature and lighting for at least 50% of the occupants in non-perimeter, regularly occupied areas.
1	**Thermal Comfort ─ Comply with ASHRAE 55-1992** Comply with ASHRAE Standard 55-1992, Addenda 1995, for thermal comfort standards including humidity control within established ranges per climate zone. For naturally ventilated buildings, utilize the adaptive comfort temperature boundaries, using the 90% acceptability limits as defined in the California High Performance Schools (CHPS) Best Practices Manual, Appendix C – A Field Based Thermal Comfort Standard for Naturally Ventilated Buildings, Figure 2.

Points	Criteria
1	**Thermal Comfort ─ Permanent Monitoring System** Install a permanent temperature and humidity monitoring system configured to provide operators control over thermal comfort performance and the effectiveness of humidification and/or dehumidification systems in the building.
1	**Daylight & Views ─ Daylight 75% of Spaces** Achieve a minimum Daylight Factor of 2% (excluding all direct sunlight penetration) in 75% of all space occupied for critical visual tasks. Spaces excluded from this requirement include copy rooms, storage areas, mechanical plant rooms, laundry and other low occupancy support areas. Other exceptions for spaces where tasks would be hindered by the use of daylight will be considered on their merits.
1	**Daylight & Views ─ Views for 90% of Spaces** Achieve direct line of sight to vision glazing for building occupants in 90% of all regularly occupied spaces. Examples of exceptions include copy rooms, storage areas, mechanical, laundry and other low occupancy support areas. Other exceptions will be considered on their merits.
	Innovation & Design Process
1 to 4	**Innovation in Design** In writing, identify the intent of the proposed innovation credit, the proposed requirement for compliance, the proposed submittals to demonstrate compliance, and the design approach (strategies) that might be used to meet the requirements.
1	**LEED™ Accredited Professional** At least one principal participant of the project team that has successfully completed the LEED Accredited Professional exam

APPENDIX B

Building Expert Survey Form

Section A: Survey Questions

Please tick (√) in appropriate cells: 1 = least important; 2 = less important; 3 = important; 4 = more important; and 5 = most important

UNIT LEVEL

Environmental Issues	Importance Rating				
WATER EFFICIENCY					
Water Efficient Devices Employ strategies that reduce water consumption in dwellings (e.g. use showerheads and faucet aerator with lower flow rate or use dual flush WCs)	**1**	**2**	**3**	**4**	**5**
ENERGY USE					
CO_2 Emission Due To Energy Consumption Emission of carbon dioxide (CO_2) to the atmosphere due to the energy consumption of the operation of a home and its services	**1**	**2**	**3**	**4**	**5**
Natural Ventilation Utilize natural ventilation to reduce reliance on mechanical ventilation for indoor environmental control	**1**	**2**	**3**	**4**	**5**
Hot Water Supply Install energy efficiency hot water supply equipment and devices (e.g. hot water is supplied by gas or solar energy)	**1**	**2**	**3**	**4**	**5**
Energy Efficient Appliances Provide or purchase energy efficient appliances (e.g. refrigerators and air-conditioners have been labeled under the Singapore's Energy Efficiency Labeling scheme)	**1**	**2**	**3**	**4**	**5**
INDOOR ENVIRONMENTAL QUALITY					
Ventilation Effectiveness Provide for the effective delivery and mixing of fresh air to support the safety, comfort and well-being of unit residents (e.g. a minimum air change rate)	**1**	**2**	**3**	**4**	**5**
Cooker Hood Install a cooker hood to minimize the spread of moisture, pollutants and odors within the kitchen and from the kitchen to the rest of the unit	**1**	**2**	**3**	**4**	**5**

Environmental Issues	Importance Rating				
Thermal Comfort Provide thermally comfortable environment for unit residents (e.g. worse case peak temperatures without mechanical cooling is within adaptive comfort temperature boundaries)	**1**	**2**	**3**	**4**	**5**
Daylight & Views Provide unit residents a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the unit (e.g. average daylight factor)	**1**	**2**	**3**	**4**	**5**
Room Acoustics Control ambient internal noise of habitable rooms at levels appropriate for living (e.g. indoor noise level, or locate condenser unit of air-con away from bedrooms)	**1**	**2**	**3**	**4**	**5**
Noise Isolation Improve the noise isolation of rooms to reduce impact of unwanted noise (e.g. airborne sound insulation values)	**1**	**2**	**3**	**4**	**5**
Indoor Sources of Air Pollution Reduce the quantity of indoor air contaminants that are odorous, potentially irritating and/or harmful to the comfort and well-being of unit residents (e.g. the quantity of VOCs, formaldehyde and radon in habitable rooms)	**1**	**2**	**3**	**4**	**5**
OTHER ENVIRONMENTAL ISSUES					
Other Environmental Issues Is there any other environmental issue of local residential development that you think is important and should be included in the environmental assessment criteria and protocol? If "Yes", please specify.					

BLOCK LEVEL

Environmental Issues	Importance Rating				
SUSTAINABLE SITE					
Urban Redevelopment Building development uses land and that has been redeveloped or reclaimed	1	2	3	4	5
Public Transportation Access Provide easy access to a mainstream mass transport system or public bus lines for the users of the building development	1	2	3	4	5
Heat Island Effect Use highly reflective and high emissivity roofing for the roof surface, or install a "green" (vegetated) roof for part of the roof area	1	2	3	4	5
Construction Management Implement an Environmental Management Plan by the main contractor, including provisions for environmental monitoring and auditing and reporting to the client representative	1	2	3	4	5
Pollution During Construction Apply adequate measures to reduce the emissions to air and waters during the construction, and reduce the considerable annoyance from construction related noise	1	2	3	4	5
Noise from Building Equipment Control unwanted sound from equipment on and around buildings contributes to noise pollution with potential impacts on neighboring properties (e.g. the level of the noise is in compliance with the recommended criteria)	1	2	3	4	5
Building User Handbook Provide building users a handbook giving details about the facilities within the building and a guide on environmental friendly use and operation of building	1	2	3	4	5
WATER EFFICIENCY					
Innovative Wastewater Technologies Reduce the use of municipally provided potable water for building sewage conveyance	1	2	3	4	5
Metering and controls Install water meters at key supply branches which permits the monitoring and audit of fresh water consumption	1	2	3	4	5
Water Quality Install measures for treatment of potable water supplies to ensure quality to WHO drinking water quality standards at point of use	1	2	3	4	5

Environmental Issues	Importance Rating				
Water Recycling Install systems to recycle grey water and rain water (e.g. provide systems for the collection of rainwater or condensate for use in cleaning, toilet flushing or otherwise, which will reduce consumption of potable water)	**1**	**2**	**3**	**4**	**5**
ENERGY USE					
Improvement of the Average U-value Improve the average U-value of external walls and the average roof U-value of the dwellings	**1**	**2**	**3**	**4**	**5**
Building Orientation Total area of walls facing N-S is more than total area of walls facing W-E	**1**	**2**	**3**	**4**	**5**
CO_2 Emission Due To Energy Consumption in Public Areas Emission of carbon dioxide (CO_2) to the atmosphere due to the energy consumption of the operation of lifts, lighting and other services in public areas (e.g. lift lobby and corridor)	**1**	**2**	**3**	**4**	**5**
Renewable Energy Part of building energy use is generated from renewable energy sources, or supply part of the building energy use through the use of on-site renewable energy systems (e.g. using solar energy)	**1**	**2**	**3**	**4**	**5**
Clothes Drying Facilities Provide suitable clothes drying facilities which utilize the natural environment for the majority of residential unit, or provide space and posts/footings/fixings for drying clothes in a secure environment for each unit on the site	**1**	**2**	**3**	**4**	**5**
Natural Ventilation Undertake an analysis of building design, assess wind pressures on building facades to inform detailed building design on best locations to locate windows/openings to achieve cross ventilation	**1**	**2**	**3**	**4**	**5**
Energy Efficient Lighting in Public Areas Install energy efficient lighting equipment in public areas (e.g. compact fluorescent lamps luminaires, time switching or photoelectric switching lighting control for the lamps)	**1**	**2**	**3**	**4**	**5**
Energy Efficient Appliances Install certified energy efficient appliances (e.g. energy efficient lifts)	**1**	**2**	**3**	**4**	**5**
Energy Consumption on Site The constructor sets up systems to monitor and report energy consumption resulting from energy use on site and fuel consumption resulting from transport to and from site on a monthly basis	**1**	**2**	**3**	**4**	**5**

Environmental Issues	Importance Rating				
Building Systems Commissioning Ensure full and complete commissioning of all systems, equipment and components that impact on energy use and indoor environmental quality, and provide fully detailed commissioning report	1	2	3	4	5
Metering and Monitoring Install metering for landlord's electricity consumption in common space/public areas, and install gas sub metering and electrical sub metering for every unit	1	2	3	4	5
Operation and Maintenance Manual Provide a fully documented instructions that enables systems to operate at a high level of energy efficiency, and provide a fully documented operations and maintenance manual to the minimum specified	1	2	3	4	5
MATERIALS & RESOURCES					
Recycled Materials Use materials which contain recycled or reused materials or waste materials or by-products such as pulverized-fuel, or materials with recycled content in the project.	1	2	3	4	5
Resource Reuse Use salvaged, refurbished or reused materials, products and furnishings for part of building materials	1	2	3	4	5
Rapidly Renewable Materials Use rapidly renewable building materials and products (made from plants that are typically harvested within a ten-year cycle or shorter) for part of building materials and products	1	2	3	4	5
Local/Regional Materials Use part of building materials and products that are extracted, harvested or recovered or manufactured regionally (Manufacturing refers to the final assembly of components into the building product that is furnished and installed by the tradesmen)	1	2	3	4	5
Sustainable Forest Products Use solid and composite timber products which are entirely from well managed sustainable sources, including reuse of salvaged timber, or use of durable and reusable formwork and hoarding systems to replace timbers formwork and hoardings	1	2	3	4	5
Green Building Materials Choose building materials for part of key building elements which have been labeled under the Singapore Green Labeling scheme	1	2	3	4	5
Off-site Fabrication The manufacture of part of building elements has been off-site	1	2	3	4	5

Environmental Issues	Importance Rating				
Ozone Depletion Thermal insulation materials and products in the building fabric and services are made only from materials with zero ozone depletion potentials	**1**	**2**	**3**	**4**	**5**
No Asbestos There is no asbestos in the structure, services, lifts, etc. of new buildings; or for existing buildings where an asbestos survey has been carried out and all asbestos either removed or identified and contained	**1**	**2**	**3**	**4**	**5**
Adaptability and Deconstruction Designs provide flexibility through the choice of building structural system that allows for change in future use; or provide spatial flexibility that can adapt spaces for different uses	**1**	**2**	**3**	**4**	**5**
Modular and Standardized Design Apply modular design in buildings and use standardized prefabricated building elements to reduce the use of formwork	**1**	**2**	**3**	**4**	**5**
Construction Waste Management Construction waste is monitored, sorted and recycled on site. Develop and implement a waste management plan, quantifying material diversion goals (e.g. recycle and/or salvage part of construction, demolition and land clearing waste)	**1**	**2**	**3**	**4**	**5**
Storage of Recyclables and Waste Disposal Provide an easily accessible area that is dedicated to the separation, collection and storage of materials for recycling (e.g. provide central waste recycling spaces at ground level of building, or recycling bins in each floor level, or waste recycling bins for each household, or partition recycle bins to collect different waste materials such as paper, glass, plastics, metals separately)	**1**	**2**	**3**	**4**	**5**
INDOOR ENVIRONMENTAL QUALITY					
Ventilation Effectiveness For natural ventilation in public areas, demonstrate that each common area has ventilation opening capable, under prevailing wind conditions, of providing adequate ventilation	**1**	**2**	**3**	**4**	**5**
OTHER ENVIRONMENTAL ISSUES					
Other Environmental Issues Is there any other environmental issue of local residential development that you think is important and should be included in the environmental assessment criteria and protocol? If "Yes", please specify.					

PRECINCT LEVEL

Environmental Issues	Importance Rating				
SUSTAINABLE SITE					
Contaminated Land Implement measures for the rehabilitation of previously contaminated land (i.e. land previously used for industrial purposes, or adjacent to landfills), or proper preparation of sites adjacent to landfill sites	**1**	**2**	**3**	**4**	**5**
Local Transportation and Amenities Provide sheltered pedestrian access to a mainstream mass transport system or shuttle services to public transport networks and local urban centre. Provide secure bicycle storage (parking) or cycling paths which link to local cycling pathways. Provide sufficient local services and amenities for basic needs of the users of the building development (e.g. food shop, post box, children's play area)	**1**	**2**	**3**	**4**	**5**
Heat Island Effect Provide shade or use light-colored/high-albedo materials or open grid pavement for the site's non-roof impervious surfaces; use highly reflective and high emissivity roofing or install a vegetated roof for multi-storey car parks	**1**	**2**	**3**	**4**	**5**
Ecological Impact Landscaping and other site design minimize ecological impact on Greenfield sites, or contributes positively to the ecological value of Brownfield sites	**1**	**2**	**3**	**4**	**5**
Landscaping and Planters Preserve or expend urban greenery on the site by using plants tolerant of climate, soils, and natural water availability and using pervious materials for hard landscaped area	**1**	**2**	**3**	**4**	**5**
Microclimate Around Buildings No pedestrian areas will be subject to excessive wind velocities caused by amplification due to the site layout or building design	**1**	**2**	**3**	**4**	**5**
Overshadowing and Views The master planning considers the solar access for individual buildings to minimize overshadowing, optimization of view potential for the site whilst preserving the views of surrounding developments	**1**	**2**	**3**	**4**	**5**
Vehicular Access Providing access for deliver vehicles and waste collection vehicles to the service areas of the building which lies within the site boundary and are enclosed or segregated from pedestrian access routes	**1**	**2**	**3**	**4**	**5**
Stormwater Management Use rainwater holding facilities or sustainable drainage techniques to attenuate water run-off at peak time to municipal drainage systems	**1**	**2**	**3**	**4**	**5**

Environmental Issues	Importance Rating				
Light Pollution Reduction Ensure exterior lighting not to create unwanted and unnecessary light pollution such as light trespass from the building and site, and impact on nocturnal environments	**1**	**2**	**3**	**4**	**5**
Low Environmental Impact Pest Management Policy Provide management plan for establishing/maintaining a low impact site and building exterior pest management (e.g. use physical controls such as blocking entry paths, removing nesting sites and food sources, or reduce usage of potentially hazardous chemical, biological and particle contaminants)	**1**	**2**	**3**	**4**	**5**
Pollution During Construction Apply adequate measures to reduce the emissions to air and waters during the construction, and reduce the considerable annoyance from construction related noise	**1**	**2**	**3**	**4**	**5**
WATER EFFICIENCY					
Water Efficient Landscaping Limit the use of potable water for landscape irrigation (e.g. use high-efficiency irrigation technology or use captured rain or recycled site water for irrigation or do not install permanent landscape irrigation systems)	**1**	**2**	**3**	**4**	**5**
ENERGY USE					
Energy Efficient Lighting in External Areas Install energy efficient lighting equipment (e.g. compact fluorescent lamps (CFL) luminaires or strip lights or time switching or photoelectric switching lighting control)	**1**	**2**	**3**	**4**	**5**
MATERIALS & RESOURCES					
Storage of Recyclables and Waste Disposal Provide adequate facilities for the collection, sorting, storage and disposal of waste (e.g. partition recycle bins to collect different waste materials such as paper, glass, plastics, metals separately)	**1**	**2**	**3**	**4**	**5**
INDOOR ENVIRONMENTAL QUALITY					
IAQ in Car Parks Meet the minimum requirements of performance in respect of air quality in multi-storey car parks	**1**	**2**	**3**	**4**	**5**
OTHER ENVIRONMENTAL ISSUES					
Other Environmental Issues Is there any other environmental issue of local residential development that you think is important and should be included in the environmental assessment criteria and protocol? If "Yes", please specify.					

Section B: Respondents Details

Please tick in appropriate cells by double click the check box and choose "checked" under default value.

1. Respondent's age group

☐ 20 to 29 ☐ 30 to 39 ☐ 40 to 49 ☐ 50 to 59 ☐ ≥ 60

2. Respondent's gender

☐ Male ☐ Female

3. Respondent's professional background

   A. Occupation

   ☐ Architect ☐ Civil engineer ☐ M&E engineer ☐ Building manager

   ☐ Faculty of educational institute ☐ Government officer ☐ HDB officer

   B. Year of working experience

   ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 15 ☐ 16 to 20 ☐ 21 to 25 ☐ > 25

4. Respondent's educational background

   A. The highest education degree

   ☐ Diploma ☐ Bachelor ☐ Master ☐ PhD

   B. Background

   ☐ Architecture ☐ Building ☐ Civil engineering ☐ M&E engineering

   ☐ Real estate ☐ Management ☐ Other (please specify) ______

   C. Where did you receive your education?

   ☐ Local ☐ Overseas ☐ Local & overseas

5. Respondent's residential background

   A. Residential location

   ☐ HDB apartment ☐ Condominium ☐ Semidetached house ☐ Detached house

   B. How many years have you lived in your present residential location?

   ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 15 ☐ 16 to 20 ☐ 21 to 25 ☐ > 25

   C. HDB apartment living experience in Singapore

   ♠ Have you lived in HDB apartment in Singapore?

   ☐ Yes ☐ No

   ♠ If "Yes", how many years have you lived in HDB apartment in Singapore?

   ☐ < 1 ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 15 ☐ 16 to 20 ☐ 21 to 25 ☐ > 25