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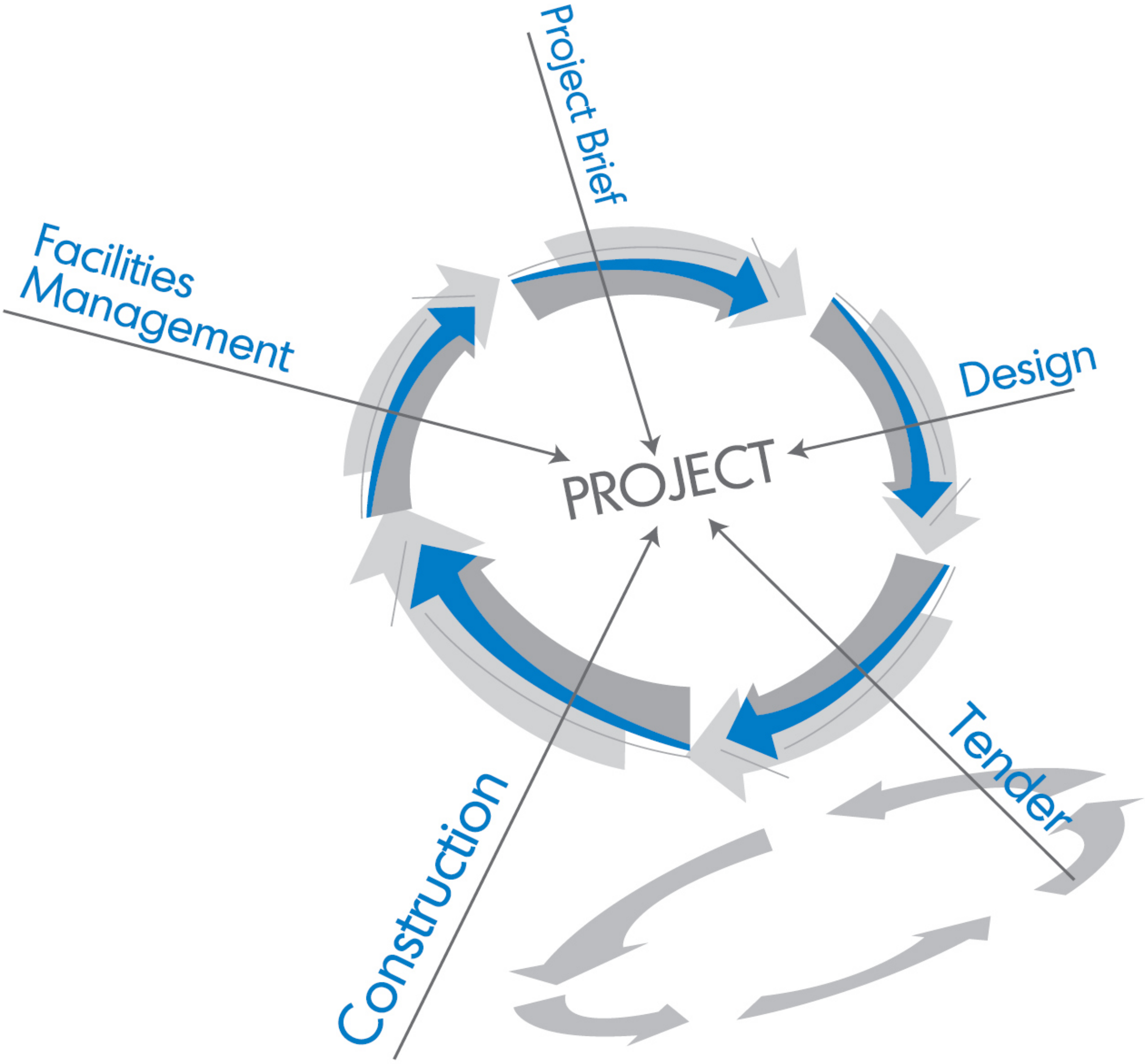

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Contents

Editorial Advisory Board

Editorial

Welcome from the Editors

Welcome to the fourteenth issue of Malaysian Construction Research Journal (MCRJ). In this issue, we are pleased to include another six papers that cover wide range of research area in construction industry. The editorial team would like to express our sincere gratitude to all contributing authors and reviewers for their contributions, continuous support and comments. It is hope that readers will find informative articles from this edition of MCRJ. In this issue;

Zuhairi Abd. Hamid, ***et. al.*** presents the comparative review of four green building rating tools found in Malaysia, namely GBI, PH JKR, Green PASS and GreenRE. Comparisons were made across a number of sustainability issues and suggestions on ways of merging both PH JKR and Green PASS were made. The study not only provides a deep insight into the Malaysian green rating tools but to act as guidance for both Malaysian authorities in establishing a standardised national green building rating system.

Siti Akhtar Mahayuddin and Joy Jacqueline Pereira study the identification of generation and management of waste residential construction. Improper waste management is due to the lack of understanding and little information known about the quantity and characteristics of construction waste generated and its management. A series of site audit has been carried out in several on-going housing projects as a basis of the study. The total construction waste quantity was generated and the calculated rate is proposed to be disseminated to all parties involved in construction. Several recommendations are made in order to improve construction waste management.

AbdulLateef Ashola Olanrewaju, ***et.al.*** provides an overview of the literature on issues of sustainability concerning the Nigerian built environment. They investigate the understanding of the professionals in the Nigerian built environment on sustainable construction. Six sustainable criteria were addressed to the respondents to evaluate their frequency in the procurement of construction projects. The paper concludes with a recommendation that construction practitioners should take leading roles to apply sustainable criteria in the design, construction, and maintenance and operations of construction projects to increase project performance and the well-being of the users.

Mustafa Zakaria and Anwar Salem Omair Musaibah examine the competitive priorities, competitive advantage and performance of real estate firms in

Dubai. The data analysis indicated that the firms in the study emphasized competitive priorities that include flexibility, cost, quality and delivery. In addition, the results of the study showed that quality, cost and delivery are positively related to competitive advantage. This paper adds support to the idea that there exist relationships between competitive priorities, competitive advantage, and performance of real estate firms in Dubai.

Narayanan S.P. and Mathews M.S. propose the roofing sheets systems for industrial sheds in cyclone prone areas based on dynamic testing. The roofing systems were subjected to simulated dynamic tests which simulate low-high-low load cycles during a cyclone, ensuring that the frequency of load application does not coincide with natural frequency of roofing sheet system. Roofing systems with different spans were tested. Suitable reduced spans were recommended for these zones based on the test results. General guidelines to be followed while fixing asbestos cement and galvanized iron roofing sheet systems are also given.

In their second contribution, **Narayanan S.P. and Mathews M.S.** present the results of static uplift load tests on asbestos cement and galvanized iron corrugated roofing sheet systems used in India using gravity load method. Full-scale tests were carried out on roofing sheet systems with different connections. The ultimate loads obtained from the tests are used to evaluate the maximum permissible wind speeds. The values are compared with design wind speeds for critical and interior regions of the roof for different wind zones. The suitability of a particular roofing sheet system for a particular wind zone is then assessed.

Editorial Committee

TOWARDS A NATIONAL GREEN BUILDING RATING SYSTEM FOR MALAYSIA

Zuhairi Abd. Hamid[1], Maria Zura Mohd Zain[1], Foo Chee Hung[1], Mohd Syarizal Mohd Noor[1], Ahmad Farhan Roslan[1], Nurulhuda Mat Kilau[1] and Mukhtar Che Ali[2]

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Abstract

The paper presents the comparative review of four green building rating tools found in Malaysia, namely GBI, PH JKR, Green PASS, and GreenRE. The review process was done by comparing these rating tools across a number of sustainability issues. With the insights drawn from the comparative review, suggestions on ways of merging both PH JKR and Green PASS are made, in orderto formulate a national green building rating system that may facilitate its implementation in all government projects.The outcome of the study provides a deep insight into the Malaysian green rating tools.It is able to function as a reference for the potential toolusers when choosing among the existing rating tools, or to act as guidance for both the *Jabatan Kerja Raya* (Public Works Department) and Construction Industry Development Board (CIDB) in establishing a standardized national green building rating system.

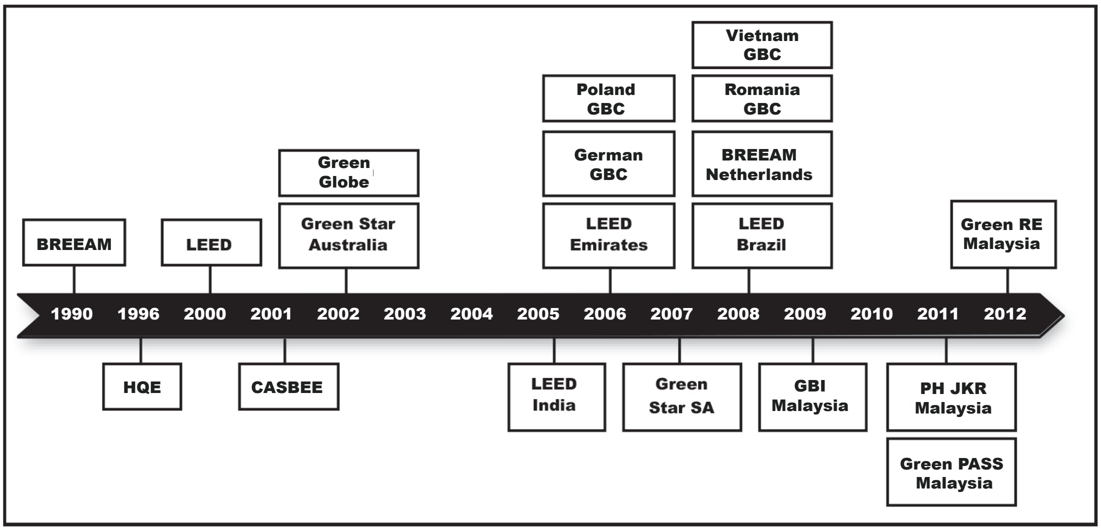
Keywords: *Green Building, Sustainability, Green Rating Tools, Merging, Malaysia*

INTRODUCTION

As like many other countries around the world, construction industry functions as a key economic driver in Malaysia, contributing to the country's development agenda through supporting social development and meeting the needs of basic infrastructure requirements in a host of other economic sectors. The expansion of construction industry in Malaysia is largely driven by domestic demand that boosted by the government through spending in national infrastructure projects. For example, in the 10th Malaysian Plan (10MP), a total of RM230 billion was allocated for development fund,while an amount of RM20 billion is aimed for facilitation fund. 60% of the development fund (or RM138 billion) will be spent on physical development to benefit the construction sector directly and the RM20 billion facilitation fund is open to the private sector.

While being position as an enabler of growth in other sectors, the construction industry is also responsible for a significant amount of resource use and carbon emissions. Rapid economic growth and the increasing level of urbanization have led to the extensive development of buildings and infrastructures. Since buildings and other structures are normally planned to last for 50 to 100 years, the impact on climate change posed by these constructions should not be overlooked.In fact, researches have shown that buildings (as well as built environment) are one of the major CO_2 emitters and contribute substantially to climate change due to their high energy and water consumption, raw material employment, and the usage of land (Reed and Wilkinson, 2008; Wilkinson et al., 2008; Reed et al., 2009). About 40% of the total world energy consumption is initiated from built environment, while the property industry was found to contribute to about 20% of CO_2 emissions via energy use, waste and water production (Mustaffa& Ahmad Baharum, 2009). Only by encouraging the development of more efficient buildings or through improving energy efficiency in the buildings, harmful impact of the buildings to the surroundings can be mitigated, and issues related to climate change can then be addressed. Thus, knowledge on trends of climatic development as well as the estimated amount of CO_2 contributed by the buildings and constructions are crucial, as these may help the engineers and other related professions in minimizing the negative environmental effects (Jamilus, et.al, 2009).

It is under this circumstance that green building ratings were developed, to assist architects, designers, builders, government bodies, building owners, developers, and other end users in understanding the impact of each design choice and solution. Ever since its first introduction in 1990 (i.e. BREEAM), the adoption of green building ratings has proliferated around the world. Many countries have introduced and areadvocating their own rating systems, with measurable criteria covering the socio, economic, and environmental parameters of design that can function as a positive tool in guidingthem towards sustainable developments. Amongst the typical examples of these rating systems are BREEAM (Building Research Establishment's Environmental Assessment Method) in the United Kingdoms, LEED (The Leadership in Energy and Environmental Design) in the United States, CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) in Japan, and Green Star in Australia (Figure 1).



(*Source: Adapted from Reed et al., 2009*)

Figure 1. Timeline of the development of rating tools in different countries

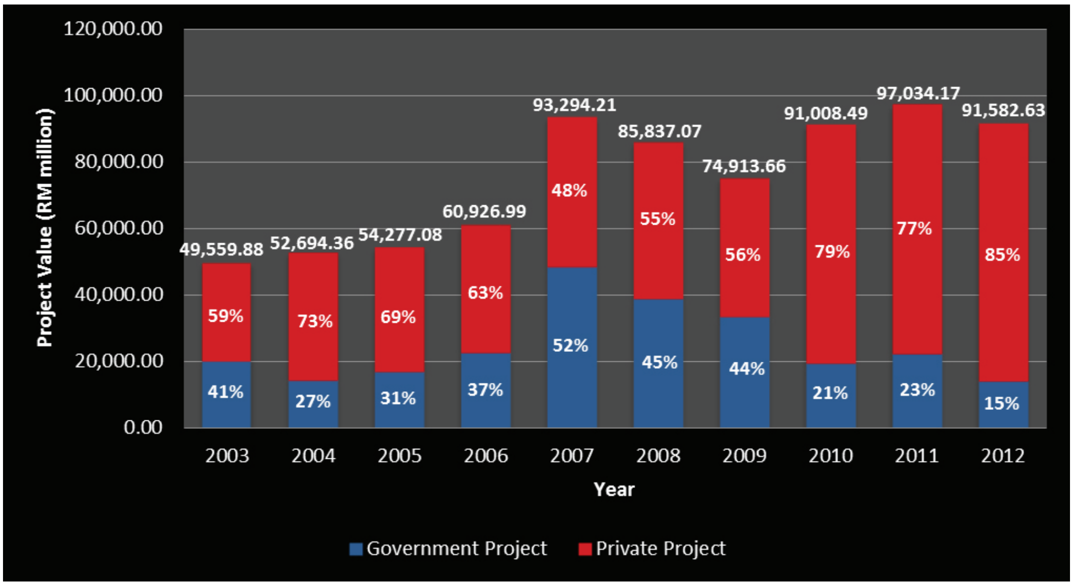
Background of the Study

As Malaysia heads towards higher level of urbanization, the country is expected to face the accelerated demand on housing and the associated environmental impacts.Existing studies indicated that Malaysia is experiencing an increase in construction waste material generation, energy waste, decimation of water catchment, soil erosion, deforestation and landslides, and destruction of endangered flora and fauna (ZainulAbidin et al., 2012).Meanwhile, increasing population during the past decades has inevitably generated intensive demands on houses. It is estimated that Malaysia needs a total of 8,850,554 houses between years 1995 to 2020, with an average of 1,790,820 units to be built for every 10 years (Chen, 2000). All these,eventually,may causethe rise in energy costs and the threat to global warming.In order to realize the vision set by the Construction Industry Master Plan (CIMP) (2006 – 2015), which is to incorporate green technology into the country's construction industry and to embark on the green building practices, as well as to commit to the reduction of 40% of the CO_2 emission nationwide, it is imperative to have an assessment method that can provide insights into the sustainability of a building throughout the whole cycle of construction work.

In this sense, Malaysia has developed its very own green building rating tools,which are Green Building Index (GBI) (2009), GREEN PASS (Green Performance Assessment System) (2012), PH JKR(*Skim Penilaian Penarafan Hijau JKR*) (2012), and GreenRE(Green Real Estate) (2013). Each of these tools has demonstrated its capacity in showing the sustainability level of a building. However, differences in nature and assessment characteristics have caused complications for stakeholders in comparing the green performances of each building that utilizing different rating tools.Moreover, each of these rating tools aimed to be applied in different stages of construction works (i.e. design, construction, operation and maintenance) and none of them cover the whole process cycle, resulting the necessity of adopting different assessment methodsto evaluate the same project at different stages.

The most typical example isobserved from the PH JKR and Green PASS, wherethey are developed to specifically measure the sustainability level of government projects administered by both the JKR (*Jabatan Kerja Raya Malaysia*) or Public Works Department and Construction Industry Development Board (CIDB), respectively, but covering different stages that may somehow confuse the rating tool users. Besides, some of their assessment areas with regard to the construction phase are overlapping with each other. Users who are adopting these two rating tools for the same project may need to decide which one to be used when evaluating the green performance of the building during the construction phase. Apart from that, government projects have been contributing a significant portion to the total project value awarded to local contractors. As shown in Figure 2, the value of government project accounted for an average of 34% of the total project value from 2003 to 2012, and even achieved as high as 52% due to the higher budgets allocated to the physical development. With this given amount, an average of 95% of the total government project value is mainly awarded to the local contractors, as compared to the foreign contractors where the percentage share was seldom more than 10% (Table 1).

In realizing how profound the impact of government projects is on the whole construction eco-system, coupled with the commitments shown by the government in embarking on the green building practices, one can expect that more and more green initiatives will be implemented by the government. These green initiatives are likely to be made compulsory by incorporating them into various government programs and projects. As such, the formulation of a national green rating system that aimed to be implemented in government projects throughout the whole construction cycle, as to functions as the building sustainability evaluator, is deemed necessary.



(*Data source: CIDB Construction Quarterly Statistical Bulletin; Own calculation*)

Figure 2. Value of project awarded by status of project, 2003 – 2012

Table 1. Value of government project awarded by status of contractor, 2003 – 2012

Value of government project awarded to	**Year**				
	2003	**2004**	**2005**	**2006**	**2007**
Local Contractor (RM million)	17,537.37	14,080.69	16,830.63	21,377.16	44,775.29
Foreign Contractor (RM million)	2,541.35	54.60	0	1,077.81	3,475.32
% of project value awarded to Local Contractor	87.3	99.6	100	95.2	92.8

Value of government project awarded to	**Year**				
	2008	**2009**	**2010**	**2011**	**2012**
Local Contractor (RM million)	33,964.26	31,937.37	19,154.69	20,656.86	13,881
Foreign Contractor (RM million)	4,851.83	1,313.99	316.22	1,610.74	169
% of project value awarded to Local Contractor	87.5	96.0	98.4	92.8	98.8

(Data source: CIDB Construction Quarterly Statistical Bulletin; Own calculation)

The main objective of the study is to evaluate the characteristics of both PH JKR and Green PASS, thereby suggesting ideas of merging them to formulate a national green building rating systemthat may facilitate its implementation in all government projects. In order to ensure the outcome of the study is of beneficial to wider readers, the scope of the study is not only limited to PH JKR and Green PASS. The study begins with a comparative review on the Malaysian green building rating tools, covering GBI, PH JKR, Green PASS, and GreenRE. It then proceeds to the comparison of these rating tools across a number of sustainability issues.

With the insights drawn from the comparative review, suggestions on ways of merging both PH JKR and Green PASS are made.

METHODOLOGY

A combination of research techniques was adopted. Primary data was collected through interviewsand focus group discussion, while secondary data was gathered from various reliable sources, such as journal, conference papers, international magazines, online database, government/business association publications, and the internet. Data collected through interview and focus group discussion are mainly for the understanding of the characteristics of each rating tool and to obtain feedbacks from the industry regarding ways of merging PH JKR and Green PASS. Meanwhile, secondary research were done to understand the trends of international green rating tool development as well as the sustainability issues normally used in evaluating green rating tools. All these data are then integrated and analysed, to meet the objective of the study.

Assessment Criteria for the Comparative Review

Inspired by the BRE (2004) study, the assessment criteria selected for the comparative reviewin this study are (i) date of development, (ii) establishers, (iii) certification process, (iv) nature of assessment, (v) phase of assessment, (vi) mode of assessment, (vii) rating system, and (viii) themes of coverage, whichcan be categorized into three broad areas: (i) development, (ii) application, and (iii) measurement system (Figure 3). Apart from past literature review, the selection of these criteria have also been discussed and confirmed through focus group discussion organized by the Construction Research Institute of Malaysia (CREAM) and *Jabatan Kerja Raya*.

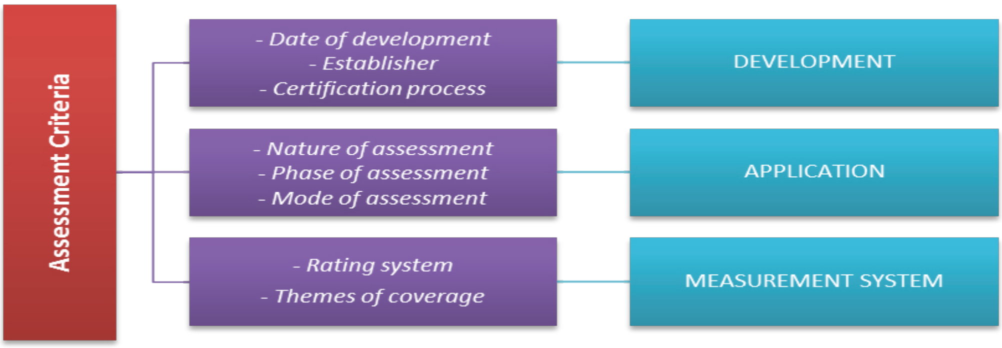


Figure 3. Assessment criteria

Assessment Checklist on Sustainability Coverage

To investigate the sustainability coverageof each Malaysian green building rating tool, an assessment checklist that involved all the major sustainability themes was constructed, by reviewing some selected international green rating tools, such asGreen Globes, LEED, Green Star, and NABERS. The justification of selecting these tools for review is due to the fact thatthey arenotable, widely adopted internationally, and have been used as reference during the process of formulating the Malaysian own green rating tools. Besides, they are the only few rating tools that really set a recognizable standard for sustainable development (Nguyen and Altan, 2011).

Table 2 shows the major themes of sustainability addressed by each of the selected international green rating tools, together with the associated priority ranking. These themes are decided by consolitating similar criteria together. As one can observe, energy efficiency and atmosphere, water efficiency, and indoor environmental quality (IEQ) management are the most common theme of sustainability that appeared in all the selected tools, followed by the sustainable site management & planning, land use, and ecology, material & resources, and waste & emission. Themes that ranked as 3rd and 4th are both the project management and innovation, and transport, respectively. Among these four rating tools, only Green Star covers all the listed themes of sustainability.

Table 2. Major themes of sustainability by the selected international green rating tools

Major Themes of Sustainability	Selected International Green Rating Tool				Rank
	Green Globes	LEED	Green Star	NABERS	
Energy efficiency and atmosphere	✓	✓	✓	✓	1
Water efficiency	✓	✓	✓	✓	1
Indoor environmental quality (IEQ) management	✓	✓	✓	✓	1
Sustainable site management & planning, land use, and ecology	✓	✓	✓		2
Material & resources	✓	✓	✓		2
Waste & emission	✓		✓	✓	2
Project management	✓		✓		3
Innovation		✓	✓		3
Transport			✓		4

RESULTS AND DISCUSSIONS

Comparative Reviewon GBI, Green PASS, PH JKR, and GreenRE

A brief introduction on each Malaysian green building rating tool is given in this section. The info on each of these tools were obtained either from the manual published by their establishers, or through interview with the associated working groups that are responsible for the formulation of these tools. The outcomes of the comparative review are summarized in Table 3.

GBI

Green Building Index (GBI) is formed under the initiative of Malaysian Institute of Architect (PAM) and Association of Consulting Engineer Malaysia (ACEM), as to promote sustainability in the built environment and raise awareness among the industry players about environment issues. GBI provides an opportunity for developers and building owners to design and construct green, sustainable buildings that can provide energy savings, water savings, a healthier indoor environment, better connectivity to public transport and the adoption of recycling and greenery for their projects and reduce our impact on the environment.Building will be awarded GBI Malaysia rating score based on six key criteria including energy efficiency, indoor environment quality, sustainable site planning, material and resources, water efficiency and innovation.

Since its establishment, GBI keep expanding the types of building assessment. It is now covering non-residential new construction, residential new construction, non-residential existing building, industrial new construction, industrial existing building, non-residential new construction, non-residential existing building, and township.

PH JKR

PH JKR or *Skim Penilaian Penarafan Hijau JKR* is a green rating tool developed based on the performance of the existing building towards sustainability with the consideration of latest requirement by the government. JKR (*Jabatan Kerja Raya Malaysia*) or Public Works Department started to practice green initiative in projects implemented since the 8th Malaysian Plan. PH JKR is introduced and applied by JKR for evaluating the sustainability level of its construction projects. PH JKR focuses on the design stage and the assessment is based on the a list of set criteria. It coversfour types of building, including non-residential new building, non-residential existing building, non-residential without air conditioner, and the health service building.

Green PASS

Green Performance Assessment System (Green PASS) in construction is developed and managed by the Construction Industry Development Board of Malaysia (CIDB). The tool aims to encourage a sustainable construction by focusing on the construction and operation stage through the reduction of CO_2.Green PASS estimates the carbon emission from construction phase to operation throughout the building's lifecycle for 50 years. Figure 5 shows an overview on the structure of Green PASS.

An achievement of 100 % carbon reduction is designated carbon neutral, represented by six diamonds. The carbon emission baseline is the calculation of the sum of embodied and operational carbon conducted or projected in a Business As Usual (BAU) scenario. In any given project, the percentage of carbon reduction is based on the difference between the CO_2 emission of the BAU scenario and the CO_2 emission of the new/ retrofitted building.

The assessment of Building Construction begins from site possession until the issuance of certificate of completion and compliance (CCC). Renovation works involving major structural changes and with more than 50 % materials replacement will be considered major construction therefore qualifying for applicability of the Green PASS building construction award. The assessment of Building Operations will only be eligible upon meeting two conditions specified below:

a) Receipt of certificate of completion and compliance (CCC) for newly completed building; and
b) 12 months of operations with a minimum of 70 % occupancy for newly completed building and retrofitted buildings.

GreenRE

Green Real Estate (GreenRE) is launched by the Real Estate and Housing Developers' Association (REHDA) in year 2013, with the aim of driving Malaysia's real estate industry towards a more sustainable and liveable built environment. The rating tool assesses a building's performance, in terms of energy efficiency, water efficiency, environmental protection, indoor environmental quality, and carbon emissions of the development, commencing from the conceptualization and design stage, construction and up to post completion. The tool is currently aimed for high rise residential building and landed houses.

The assessment criteria are broadly classified into two main groups, namely Energy Related Requirements and Other Green Requirements. The Energy Related Requirements consist of Energy Efficiency where credits are allocated for the various energy efficient designs, practices and features used. A minimum of 30 credits is required from this group in order to be eligible for certification.Other Green Requirements consist of Water Efficiency, Environmental Protection, Indoor Environmental Quality, Other Green Features, and Carbon Emission of Development. Credits are allocated for the water efficient features, environmentally friendly design practices, innovative green features used and carbon emission of development. A minimum of 20 credits are required from this group for certification.

In general, four green building rating tools were developed in Malaysia since 2009; two of them (i.e. GBI and GreenRE) were established by the professional associations, while another two (i.e. PH JKR and Green PASS) are government-driven. All the certifications are on the voluntary basis. These tools are attempting to optimize building performance while reducing the associated environmental impact through the provision of measurement on the building's environment effect and a set of standards that allow for the building to be judged objectively.

At present, only GBI has achieved maturity as it continuously releasing various tools for specific building types and applications. The others are believed to have relatively lower awareness among the users (or public) as they were newly launched or still in the final stage of refinement before released to the public. Except for Green PASS, which the mode of green assessment is based on the real-time measurement of carbon emission, the rest of the rating tools are based on the criteria checklist.In terms of application, GreenRE, PH JKR, and GBI are aimed to be implemented during the design and construction stages. Only Green PASS is designed to measure the environmental impact of building's construction and operational performance, as a reward scheme that based on the reduction of carbon emission.Throughout the comparative review, one may observe that GreenRE, PH JKR, and GBI are tools for assessment by evaluating performance against criteria, while Green PASS is considered as a tool for measurement by identifying variables measuring sustainable development and collecting relevant data.

Table 3. Characteristics of Malaysian Green Rating Tools

Criteria	GreenRE	Green PASS	PH JKR	GBI
Date of establishment	2013	2012	2012	2009
Developed by	REHDA	CIDB	JKR	PAM and ACEM
Certification process	Voluntary	Voluntary	Voluntary	Voluntary
Nature of assessment	Design based (No operation)	Performance based (No design consideration)	Design based (No operation)	Design based (No operation)
Phase of assessment	Design & Construction	Construction & Operation	Design & Construction	Design & Construction
Mode of assessment	Criteria checklist	Based on CO_2 emission	Criteria checklist	Criteria checklist
Rating system	Score (*by credits*): • 90 to 150 = GreenRE Platinum • 85 to < 90 = GreenRE Gold • 75 to < 85 = GreenRE Silver • 50 to < 75 = GreenRE Bronze	Diamond rating (100% carbon neutral) – percentage of CO_2 reduction: • 100% CO_2 reduction = 6 diamond • 70-100% CO_2 reduction = 5 diamond • 50-70% CO_2 reduction = 4 diamond • 30-50% CO_2 reduction = 3 diamond • 30-5%0 CO_2 reduction = 3 diamond • 10-30% CO_2 reduction = 2 diamond • 1-10% CO_2 reduction = 1 diamond	Star rating (*by percentage*): • 40-49% = 2 star • 50-69% = 3 star • 70-84% = 4 star • 85-100% = 5 star	Score (*by points*): • 86+ points = Platinum • 76-85 points = Gold • 66-75 points = Silver • 50-65 points = Certified
Themes of coverage	• *Energy Related Requirements:* ✓ Energy efficiency • *Other green requirements:* ✓ Water efficiency ✓ Environmental protection ✓ Indoor environmental quality ✓ Other green features ✓ Carbon emission of development	• *Building construction*: ✓ Site ✓ Material ✓ Energy ✓ Water ✓ Waste • *Building operation*: ✓ Indoor environmental quality (pre-requisite) – 80% satisfaction of occupants ✓ Energy ✓ Water	• Sustainable site planning & management • Energy efficiency • Indoor environmental quality (IEQ) • Material & resources management • Water efficiency • Innovation	• Energy efficiency • Indoor Environmental Quality (IEQ) • Sustainable site planning and management • Material and resources • Water efficiency • Innovation

Sustainability Coverage in GBI, Green PASS, PH JKR, and GreenRE

While the use of green rating tools is mainly for determining whether a development is sustainable, or whether progress is being made towards sustainable development, different tools have different emphasis on the issues of sustainability.When the four Malaysian rating tools were compared across a number of sustainability issues (as identified in Section 2.2), all these tools are biased towards criteria for energy efficiency, water efficiency, IEQ, site management, and resources (Table 4). None of these tools coversissue related to project management. Nevertheless, some of the project management elements may have been incorporated into other assessment criteria. Being a newly launched rating tool targeted for the design and construction phases, GreenRE is said to cover a wide range of sustainability issues, where it requires the tool users to perform carbon emission calculation which is not being considered by PH JKR and GBI.

Table 4. Different rating tools and their sustainability coverage

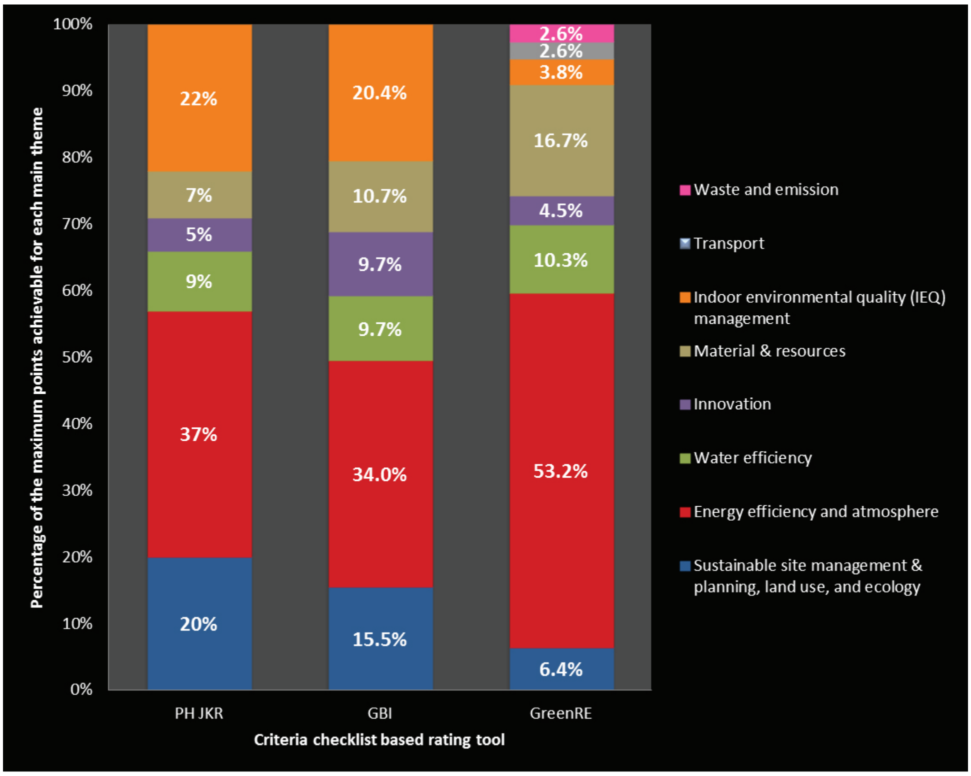
Sustainability Coverage	Malaysian Green Rating Tool				Rank
	Green PASS	PH JKR	GBI	GreenRE	
Energy efficiency and atmosphere	✓	✓	✓	✓	1
Water efficiency	✓	✓	✓	✓	1
Indoor environmental quality (IEQ) management	✓	✓	✓	✓	1
Sustainable site management & planning, land use, and ecology	✓	✓	✓	✓	1
Material & resources	✓	✓	✓	✓	1
Innovation		✓	✓	✓	2
Transport	✓		✓	✓	2
Waste &emission	✓			✓	3
Project management					4

A further analysis on the weighting schemeof these rating tools provide their degree of emphasis on each of these sustainability issues. Table 5shows the weighting distribution of each rating tool on different sustainability issues. It should be noted that Green PASS is not included in this table as it is based on real-time measurement of carbon emission. By calculating the percentage distribution for each sustainability theme (Figure 4), one may find variation in the standards of each scheme regarding the assessment on non-residential building. For example, GreeRE allocates scores for transport and waste & emission, while PH JKR and GBI do not. PH JKR and GBI, on the other hand, give higher scores on site management than GreenRE. Also, both PH JKR and GBI allocate almost equivalent scores for IEQ while GreenRE falls behind. Nevertheless, one may also find similarities among these rating tools. For example, the issue of energy has been given the most concern than any other criteria, while water efficiency is given the more or less equivalent emphasis in all these tools. Such similarities aremainly due to the nature of the tools' development, where these tools were established to promote standards that reflect local sustainability issues, environmental conditions, and certain climatic zone.

Table 5. Weighting distribution on major sustainability themes in PH JKR, GBI, and GreenRE (for the assessment on non-residential building)

Sustainability Coverage	**PH JKR**	**GBI**	**GreenRE**
Sustainable site management & planning, land use, and ecology	20	16	10
Energy efficiency and atmosphere	37	35	83
Water efficiency	9	10	16
Innovation	5	10	7
Material & resources	7	11	26
Indoor environmental quality (IEQ) management	22	21	6
Transport			4
Waste and emission			4
Total Score	**100**	**103**	**156**

(Note 1: Green PASS is not included as it is based on real-time measurement of carbon emission)



(*Note 1: Green PASS is not included as it is based on real-time measurement of carbon emission*)

Figure 4. Degree of emphasis on major sustainability themes in PH JKR, GBI, and GreenRE

RECOMMENDATIONS ON FORMULATING THE NATIONAL GREEN BUILDING RATING SYSTEM

Although the comparative review on Malaysian green rating tools may provide a clear picture on which sustainability themes to be covered when formulating the national green building rating system (i.e. Energy Efficiency, Water Efficiency, IEQ, Site Management, Material & Resources, Innovation, Transport, Waste & Emission, Project Management), there are still other issues that required for deep consideration, particularly (i) the nature and mode of the proposed rating system (i.e. criteria checklist, or measurement of carbon emission), (ii) phases of implementation (i.e. design, construction, or operation), and (iii) certification process of the proposed rating system, as these issues, to some extent, may affect its role, function and adoptability.

Nature and Mode of Green Rating System

As the proposed national green building rating system is aimed to be used in the future, its establishment should take into consideration the trends of global rating tool evolution. As pointed out by Wild (2011), the global trend of green rating tool development is approaching towards calculating the total carbon and water footprint (Figure 5). Since the launching of BREEAM in 1990, the focus of green rating toolshas moved from design to actual. It is expected that the focus of green rating tools will shift from actual to performance in the near future, and finally evolve to become full carbon and water accounting. As such, the formulation of the proposed national green building rating system should bein linewith this evolution trend, in which more emphasis is necessary to be given on measuring the carbon and water footprint that are accountable for the international audit measurement standards.

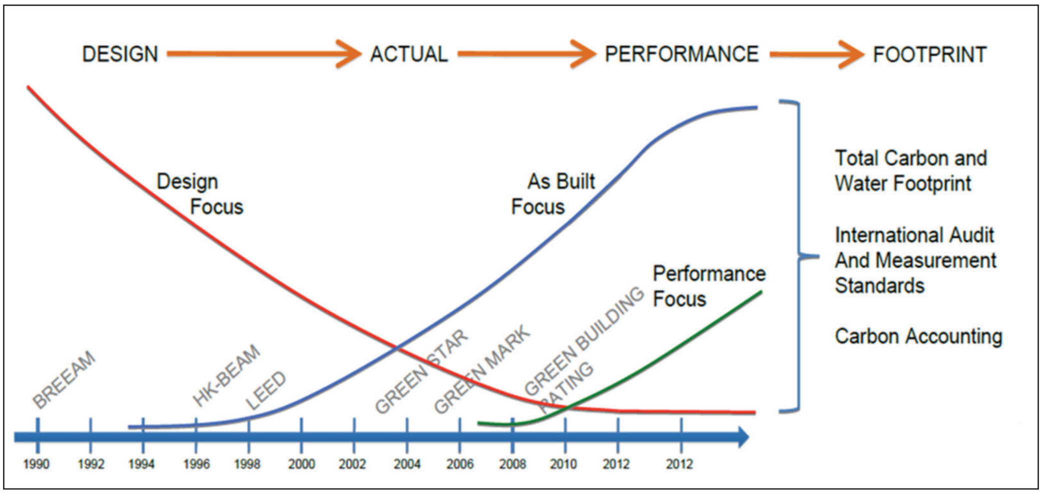


Figure 5. Green Rating Tool Comparison Evaluation and Future (Wild, 2011)

Phases of Implementation

Figure 6 shows the phases of implementation of both PH JKR and Green PASS. PH JKR focuses on design and construction phase, while Green PASS focuses on construction and operational &maintenance phases. As a result, overlapping of assessment criteria was found at the construction phase.It is suggested that synchronization of assessment criteria has to be done between pH JKR and Green PASS.In this sense, criteria checklist-basedmethod can be used in the design phase,while the actual performance measurement on carbon emissioncan be implemented at the construction and operational &maintenance phases. In terms of the sustainability coverage at each phase,it is as suggested in Figure 7. As such, the proposednational green rating system will cover the overall construction work cycle, starting from design to operational phases.

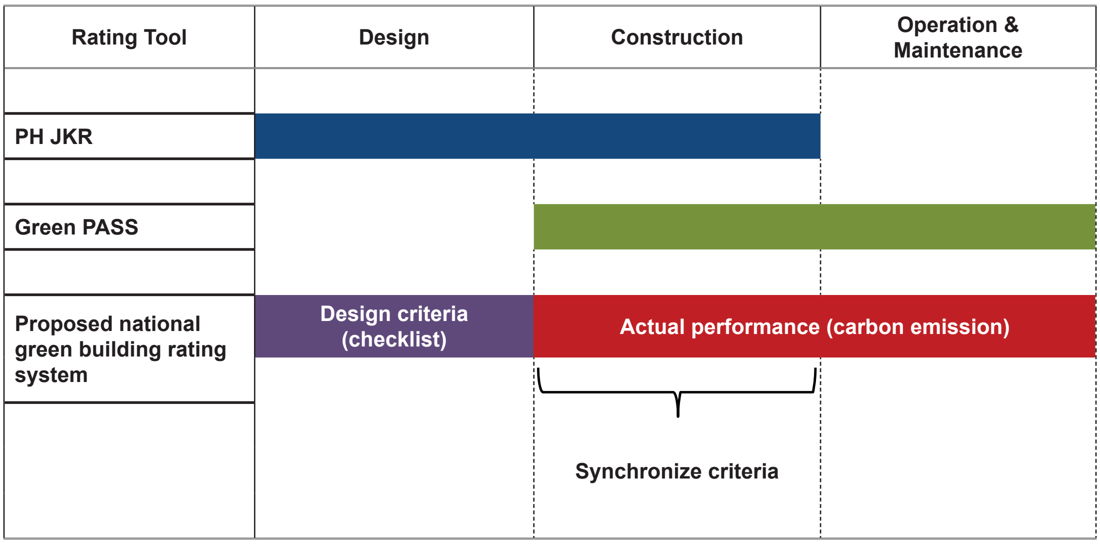


Figure 6. Synchronization path for PH JKR and Green PASS to develop national green building rating system

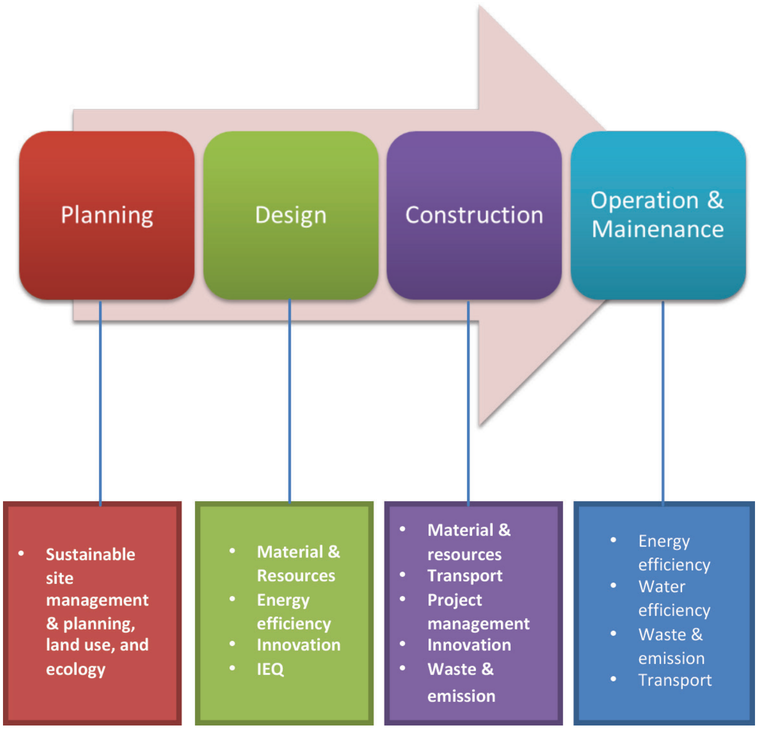


Figure 7. Proposed assessment criteria for the national green building rating system at different phases

Certification Process

A strategic certification process upon green building assessment should be established as to ensure the successful implementation of the proposed national green rating system. The suggested certification process can be divided into two categories: (i) certification by stages (multiple certification), and (ii) certification by weightages (single certification) (Figure 8). Both of these certification options consider similar assessment criteria, sustainability coverage, as well as the nature and mode of assessment (i.e. criteria checklist and actual measurement of CO_2 emission). Besides, the phases of implementation adopted in these two certification options are also same with each other, where criteria checklist is applied in the design phase, while actual measurement of CO_2 is implemented in the construction phase and the operation & maintenance phase. The only difference between these options is how frequent the certification process is to be conducted.

In the case of certification by stages, a separate certificate will be awarded in each different phase. For example, during the design phase, a certificate of 'Green Design' will be awarded to those who complied all the stated design requirements. Meanwhile, the certificate of 'Green Performance Construction' and 'Green As-built & Actual Building' will be awarded to the eligible users, both during the construction phase and operation & maintenance phase, respectively. In the case of certification by weightages, only one certificate is issued towards the end of the assessment process. A user is only considered to be eligible after such user has gone through the whole cycle by complying all the specified requirements.

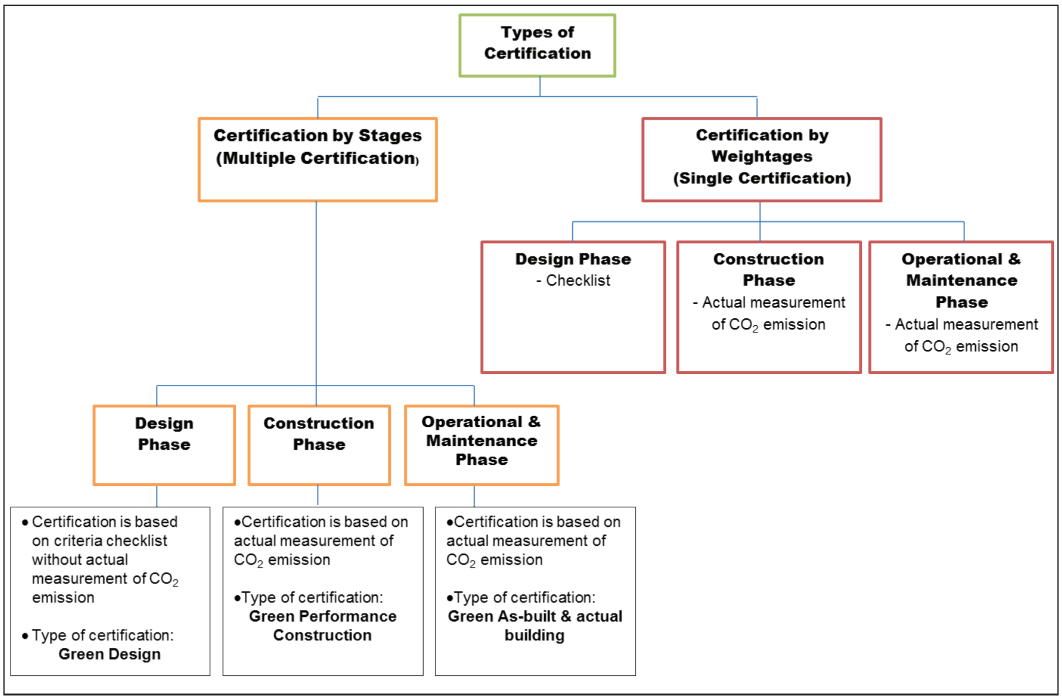


Figure 8. Certification implementation of green assessment

CONCLUSIONS

In this paper, four Malaysian green building rating tools (i.e. GBI, PH JKR, Green PASS, and GreenRE) were analysed with regard to their development, application, and measurement system. The sustainability coverage of each tool is also assessed, and it is found that the common themes to be covered in every tool are Energy Efficiency, Water Efficiency, IEQ, Site Management, Material & Resources, Innovation, Transport, and Waste & Emission. Despite having the similar aim of approaching sustainability, there are differences in how these tools pursue this aim. This is mainly due to the differences in how, where, and why these tools were developed and applied.

Besides, the paper explores the ideas of merging both PH JKR and Green PASS as to formulate a national green building rating system that may facilitate its implementation in all government projects. Three main conditions are suggested to be incorporated into the formulation of the proposed national green building rating system. First, the nature and mode of the proposed rating system should be following the trends of global rating tool evolution, where emphasis should be given on measuring the performance of the building through calculating total carbon and water footprint.In addition, the proposednational green rating system should cover the overall construction work cycle, starting from design to operational phases. Criteria checklist-based assessment approach can be applied during the design phase, while the actual measurement of CO_2 emission can be implemented in both the construction and operation & maintenance phases. Future research on synchronizing the overlapping of assessment criteria in the construction phase should be carried out for sake of standardization. The certification process of the proposed national green building rating system can be done either by multiple certification or single certification. In the case ofmultiple certification,a separate certificate will be awarded in each different phase (i.e. design, construction, and operation & maintenance), while in terms of single certification, only one certificate is issued after the whole construction cycle is gone through.

The outcome of the study provides a deep insight into the Malaysian green rating tools. It is able to function as a reference for the potential tool users when choosing among the existing rating tools, or acting as guidance for both the *Jabatan Kerja Raya* (Public Works Department) and Construction Industry Development Board (CIDB) in establishing a standardized national green building rating system.

REFERENCES

BRE. (2004). Assessment of Sustainability Tools. BRE, Glasgow.
Chen, E.L.L. (2000). An overview of the Malaysian property market. Paper presented at the UPM Workshop – Environment Friendly Township for Developing Countries, Universiti Putra Malaysia, Serdang, Malaysia.
CIDB (2012). CIS 20:2012 Green Performance Assessment System in Construction.
CIDB (2007). Construction Industry Master Plan (2006 – 2015).
Green Building Index www.greenbuildingindex.org
GreenRE Design Reference Guide – Residential Building and Landed Home, Version RES 1.0, 1st June 2013.
Jamilus, H., Zuhairi, A.H., Mohd. Khairolden, G., Maria Zura, M.Z. (2009). Towards sustainable construction: Malaysian Construction Initiatives. *The Ingeniur*, Board of Engineers Malaysia.
Manual Penarafan Hijau JKR – Sektor Bangunan, Jabatan Kerja Raya
Mustaffa, M.M. and Ahmad Baharum, Z. (2009). Paradigm shift in property management practice in Malaysian office buildings, *8th Annual Conference and Meeting of the Management in Construction Researchers Association (MiCRA), 2009, USM, Penang*, pp. 180 – 189.
Nguyen, B.K. and Altan, H. (2011). Comparative review of five sustainable rating systems. *Procedia Engineering*, 2011 International Conference on green Buildings and Sustainable Cities.
Reed, R.G., Bilos, A., Wilkinson, S.J. and Schulte, K.W. (2009). International comparison of sustainable rating tools.*JOSRE*, 1(1): 1 – 22.
Reed, R.G. and Wilkinson, S.J. (2008). *How green can you go? Increasing the value of your home through sustainability*. John Wiley and Sons, Brisbane.
The 10th Malaysia Plan (10MP) 2011 – 2015 (CIMP).
Wild, S. (2011). *Green Building Rating Tools Comparison, Evolution, and Future*. CUNDALL; [cited 2013 March 2]. Available from:http://files-asia.gbca.org.au/greencities/2011/presentations/GC2011_RatingToolEvolution_SimonWild.pdf
Wilkinson, S.J., Reed, R.G. and Cadman, D. (2008). *Property Development*. Taylor and Francis, London.
ZainulAbidin, N. Yusof, N. and Awang, H. (2012). A foresight into green housing industry in Malaysia. *World Academy of Science, Engineering and Technology*, 67, 440 – 448.

GENERATION AND MANAGEMENT OF WASTE IN RESIDENTIAL CONSTRUCTION

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Abstract
Construction waste profile is important to assess the viability of good waste management practices. However, little information known about the quantity and characteristics of construction waste generated and its management. Lack of understanding, results in improper waste management practiced. The generation and characterisation of construction waste has to be identified together with the current waste management practiced. Therefore, a series of site audit has been carried out in several on-going housing projects in Ipoh, Malaysia. The calculation of the total construction waste quantity and the floor area constructed gives a generation rate of 16.55 kg/m^2. This rate should be disseminated to all parties involved in construction with a view towards widespread use in future construction waste estimation. It will be an incentive to the development of an integrated waste management system and the implementation of good practices for managing construction waste. Recommendations are made in order to improve construction waste management in Ipoh.

Keywords: *Construction Waste, Waste Management, Residential Construction*

INTRODUCTION

An increase in construction activities bring negative impacts to the environment through the generation of waste, ecological imbalance, changes in living environment through the generation of waste, sewage, reduction in environmental resources and energy usage (Yip 2000). Solid and chemical wastes are found to be the most common contamination source from the construction site (Pun et al. 2001). Construction waste is generated during the construction process such as during site clearance, material use, material damage, material non-use, excess procurement and human error (Macozoma 2002). The composition and quantity of construction waste generated depends on the construction methods and materials used during construction activities (Formoso et al. 2002).

The generation of construction waste is predictable, based on the building design and procurement of the building materials; thus it can be expected and hence controlled. However, the avoidance of waste generation in construction site is unpredictable due to lack of readily available data on construction waste from previous projects (Garas et al 2001). Furthermore, construction company could not provide relevant and appropriate data because they are not obliged to record and report the quantitative characteristics of waste generated at their sites (Fatta et al. 2003). In addition, ineffective waste management practiced at construction site increases the generation of construction waste.

A critical step to develop comprehensive waste management system is by categorization and quantification of construction waste (Gavilan & Bernold 1994). The quantification of construction waste needs to be done early in the construction project. However, it is difficult to determine the exact quantity generated as well as the exact composition of construction waste at construction sites. The occurrences of fly tipping or illegal dumping also give challenge to the estimation of construction waste quantity (Kofoworola & Gheewala 2009). The natural characteristic of construction waste which is highly variable in its compositions also brings difficulty in waste quantity estimation (Gavilan & Bernold 1994).

Without the ability to specifically identify the characteristics of construction wastes being generated on construction sites, the site management would be unable to accurately track, monitor and quantify the total amount of wastes generated. Hence, accurate waste measurement would provide an effective method to evaluate the production system performance as it shows the improvement potential and identification of the major inefficient factors (Formoso et al. 2002). Construction waste quantity acts as an indicator to benchmark the construction waste management practices whether standard, good or best practices.

The construction waste can be estimated by the building area, building demolition works and converting the construction and demolition waste quantitative data (Fatta el a. 2003). Another method of estimation is through the use of a construction waste index (Poon et al. 2001a). In Malaysia, the construction waste quantity are required for the planning and provision of capacity, location and total facilities and equipment to achieve Solid Waste National Strategic Plan target (MHLG 2005). Then, monitoring system and continuous performance assessment could be implemented. However, very little information known about the volume and characteristics of construction waste generated and its management at local level. Therefore, a study has been conducted in one of the city in Malaysia to access the current status of construction waste management. This study was based in Ipoh, the capital city of the state of Perak in northern Malaysia. Ipoh covers an area of 387.63 square kilometres with a population of 562,500 in 2005 (Town and Regional Planning Department (JPBD) Perak 1998). In comparison to the other areas in Perak, construction activities in Ipoh are higher due to its function as the main administrative centre where the major industrial, commercial and residential areas are concentrated. The study focused on estimating waste generation at housing construction sites and identifying the current practices of waste management by the local contractors. Thus better understanding of construction waste profile at local level enhances the promotion of good practices of construction waste management.

RESEARCH METHODOLOGY

To meet the research objectives, a series of site audit has been conducted at nine fairly similar private housing construction sites in Ipoh. All these sites were at superstructure stage, comprised of terraced house, constructed with conventional reinforced concrete and brick wall. Thus enable a standard observation and collection of data and uniform comparison between the sites. The distribution of data are not influenced by the geographical situation but depends on the types of house, specific practice by the contractors and lack of uniform standard in disposal and storage of the waste sample (Franklin Associates 1998).

An audit form was used during the site audit which was developed based on a review of literature, results of an earlier visit to several housing construction sites and interviews with site managers and site supervisors in Ipoh to identify current waste management practices at construction sites. The form has four major sections, namely general information on respondents, housing project profile, construction waste data and construction waste control.

The quantities of waste were estimated by the transportation records of waste disposed off from the construction sites (Poon et al. 2004). The estimation of waste quantity was calculated based on the waste transportation trip record, truck load and frequency of waste disposal activities. All the data gathered from the site audit were computed in MS Excel for the calculation of estimated quantity of construction waste generated at every site. Therefore, the waste was estimated by using Equation 1 adopted from Poon et al. (2004). However, this study estimates the waste quantity according to weight different from earlier study by Poon et al. (2004). This is consistent with the landfill charges imposed in Malaysia and the unit used in National Strategic Plan for Solid Waste Management (MHLG 2005).

$$W = V \, x \, N \qquad \text{Equation 1}$$

where:

V = truck load (tonne)

N = total no of truck for waste disposal

W = total waste generated from the project (tonne)

The construction waste index was then calculated by using Equation 2, adopted from Poon et al. (2004).

$$C = \frac{W}{GFA} \qquad \text{Equation 2}$$

where:

V = truck load (tonne)

N = total no of truck for waste disposal

W = total waste generated from the project (tonne) = $V \, x \, N$

GFA = gross floor area

C = waste index (i.e construction of 1 m^2 gross floor area generates C tonne of waste)

Data on the ccurrent practices of waste management at housing sites in Ipoh were analyzed using the Statistical Package for Social Sciences (SPSS) and Microsoft Excel. Simple descriptive analysis such as frequency and mean had been calculated for all the variables. Meanwhile, relative importance index had been calculated to identify the ranking of statements regarding current practices of construction waste management at the audited sites. To determine the relative ranking of factors, the scores were transformed to important indices based on Equation 3 (Kometa et al. 1994; Tam et al. 2000; Tam 2008).

$$\text{RII} = \frac{\Sigma w}{AN} \qquad \text{Equation 3}$$

Where w is the weighting given to each factor by the respondent, ranging from 1 to 5 in which '1' is the least important and '5' the most important; A is the highest weight which is '5' in this study; N is the total number of samples and RII is the relative important index, $0 \leq \text{RII} \leq 1$. The higher the index value means the higher is the ranking.

RESULTS AND DISCUSSION

Construction Site Profile

Table 1 presents the profile of the housing construction sites involved in this site audit. Most of the housing projects' duration is 24 months, with an average work progress of 59.4% completed. The number of constructed houses at the nine sites varies from 18 units to 235 units with an average total gross floor area for one site is 9650.7 m^2.

Table 1. Housing construction site profile in Ipoh

Site	Location	Project duration (month)	Work progress	Project cost value	Total constructed house (unit)	Total gross floor area (m^2)
TB1	Jalan Gopeng	24	80%	> MYR10 million	108	16524
TB2	Pasir Puteh	-	75%	MYR5-10 million	100	16560
TB3	Jalan Gopeng	24	60%	MYR5-10 million	50	6750
TB4	Gunung Rapat	24	70%	MYR5-10 million	84	11854.08
TB5	Seri Rapat	18	30%	MYR1-3 million	58	7308
TB6	Jelapang	24	55%	MYR500,000-MYR1 million	18	2494.8
TB7	Chemor	-	85%	MYR1-3 million	33	4395.6
TB8	Lahat	30	40%	MYR1-3 million	235	17730
TB9	Klebang	132*	40%*	> MYR10 million *	24	3240

** This information refers to the whole housing project for TB9. The total gross area reflects 24 units of terraced house under construction only.*

Waste Generation at Housing Construction Sites

During the site audit, only seven sites were able to provide information on waste transportation trip for the estimation of waste quantity as shown in Table 2. These estimations were used to calculate the construction waste index in this study. Five of the seven sites had disposed off their construction waste regularly. Meanwhile the other two sites, TB1 and TB3 have provided their estimation for the composition and quantity of waste expected to be disposed off from their projects. TB8 and TB9 were excluded from the estimation as they were unable to estimate the quantity of waste generated from their sites. In addition, TB9 divulged that all the construction waste generated at their site will be disposed off at the allocated areas on the site itself.

Table 2. Estimated waste quantity at the project sites in Ipoh

	TB1	TB2	TB3	TB4	TB5	TB6	TB7
Total waste transportation trip	0	4	0	10	10	6	30
Truck load (tonne)	10	3	1	10	10	10	10
Waste estimated quantity (tonne)	10*	12	1*	100	100	60	300

** Early estimation due to lack of construction waste disposal activities during site audit exercise*

Figure 1 shows the different level of work progress among the construction sites and the estimated quantity of waste generated at the sites. The TB7 site with a construction work progress of 85% had disposed 300 tonnes of waste. But TB1 site with similar work progress estimates to dispose 10 tonnes of waste. Therefore, the average quantity of waste generated from the two sites is 83.3 tonnes with an average work progress of 65%. The variability in the quantity of construction waste generated depends on the efficiency of site management and work practices during construction activities.

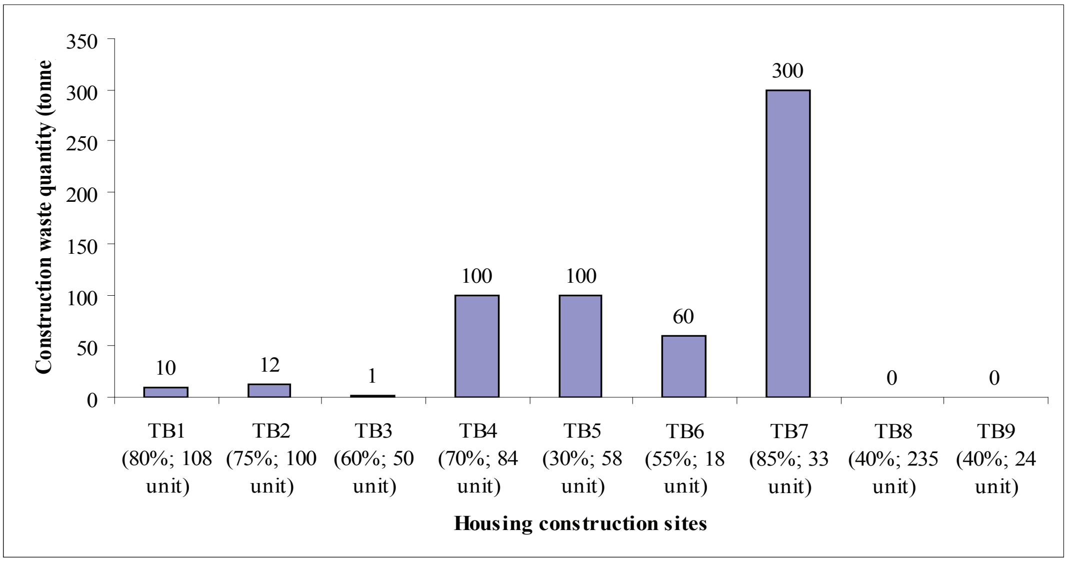

Figure 1. Estimated waste quantity according to construction work progress, among the audited sites.

Figure 2 shows the types and composition of construction waste at the selected project sites in Ipoh. The major composition of construction waste generated at the studied site are soil, aggregates and sand; with an average of 44.3%. This is followed by wood (12%) and insulation material for ceiling (9.3%).

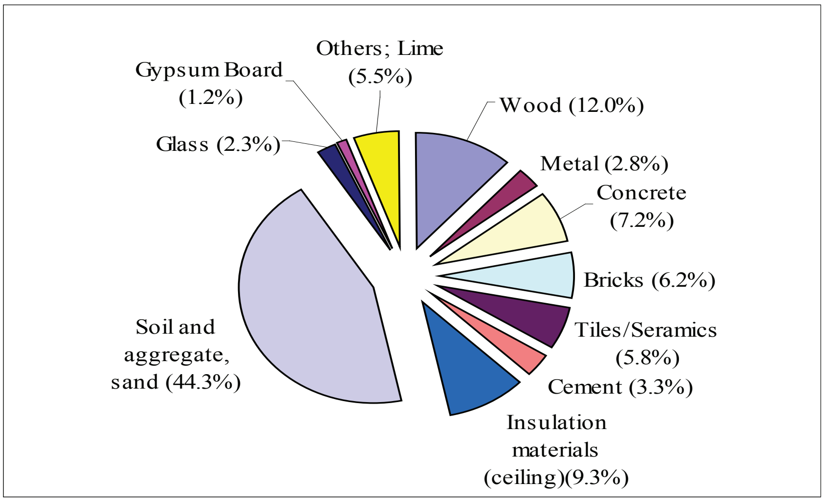

Figure 2. Average composition of construction waste at the selected project sites in Ipoh

The estimation of waste quantity from Table 2 and the total gross floor area (Table 1) produce the generation rate for construction waste as shown in Table 3. The average construction waste generation rate for the seven housing sites is 16.55 kg/m^2. Therefore, the estimated quantity of waste from one unit of house with an average floor area of 146.1 m^2 will be 2418 kg.

Table 3 Construction waste generation rate at housing projects in Ipoh

Site	Total gross floor area (m^2) (A)	Estimated waste quantity (tonne) (B)	Construction waste generation rate (tonne/m^2) (C=B/A)	Construction waste generation rate kg/m^2
TB1	16524	10	0.000605	0.60
TB2	16560	12	0.0007246	0.72
TB3	6750	1	0.00015	0.15
TB4	11854.1	100	0.0084359	8.44
TB5	7308	100	0.0136836	13.68
TB6	2494.8	60	0.02405	24.05
TB7	4395.6	300	0.0682501	68.25
Average construction waste generation rate kg/m^2			16.55	

The generation rate found from this study is almost similar to the findings by NAHB (1995). They had performed an evaluation and estimation on three housing construction sites in the United States of America. The waste generation rate from the study was 21.5 kg/m^2 and the total estimated quantity for a typical residential unit with an area of 186 square metres was 4000 kg. Meanwhile, the waste generation rate for different types of buildings in the United States of America was found to be between 20 to 30 kg/m^2 (Peng et al. 1997). It is difficult to compare directly the waste generation rate between countries because of the various techniques, work procedures and construction practices employed (Yahya and Boussabaine 2006). For example, the generation of construction waste in Kuwait is higher than the total international quantity due to the Gulf War and the lack of material management in the construction industry (Kartam et al. 2004). The composition and quantity of construction waste generated on sites depend on the construction methods and materials used during construction activities (Formoso et al. 2002). The difference in waste composition is also caused by the different construction methods and technology used, workers' skill and building designs (Poon et al. 2001b). Hence, experience, information and technologies related to the management of construction waste from various countries can be shared in order to overcome the problems caused by the generation of construction waste.

The construction waste generation rate found from this study is beneficial to local contractors and housing developers in Ipoh to estimate the generation of waste for their future housing projects. The index also indicates the benchmark of the waste management practices at housing sites. Thus, the construction sector and local authorities can plan for an effective waste management strategy early. However, the index from this study is not conclusive due to small number of audited sites. The index will be subject to change once additional waste data is available from other projects. Therefore more sites are needed for the waste audit to develop a construction waste index that is more representative of the local construction industry.

Current Practices of Waste Management at Housing Construction Sites

The site audit has identified the current practices of waste management at housing construction sites in Ipoh. The practices include the waste management sources and facilities, waste management hierarchy and disposal of waste from the construction sites.

Sources and Waste Management Facilities in Housing Construction Sites in Ipoh

The waste management sources and facilities at the audited sites include an action plan, specific worker and waste record as shown in Table 4. Meanwhile the waste management facilities consist of equipment and location for collection and sorting of waste, condition of waste collected and re-use and recycling facilities. It is found that 67% of the site audited provide a waste reduction action plan and appoint a specific worker to manage waste. There is also lack of waste record as only 22% of the construction sites record the generation of waste at their sites. Most of the sites record the waste transportation trip by keeping the transportation charges receipt. Other sites keep the tipping receipt from the MBI landfill as their record. This shows that no formal recording activities applied for the management of waste.

The site audits found that 67% of the sites allocate a specific area for waste collection. But TB6 and TB9 also used that area for construction waste disposal. Mostly the allocated area is still undeveloped. Sometimes the allocated area is used for temporary collection before final disposal to the Bercham landfill. Normally the disposal actvities at the sites are managed by the housing developer with their own transportation vehicle. During the site audit, construction waste can be found everywhere near the working area. It is found that 56% of the sites temporarily pile the construction waste scatteredly. Meanwhile 22% of the audited site provide bin for waste collection and 33% of the audited site provide a spesific area for waste sorting activities. The other 22% of the audited sites provide bins for waste recycling and re-using. Piles of unsorted waste at the audited sites lead to the mixed of different types of construction waste. Thus makes reuse and recycling of construction waste difficult.

The large number of sub-contractors involved in construction works at one site makes waste management activities complicated. For example, there are 11 sub-contractors involved in one of the audited site for various trades such as aluminium works, ceiling works, tiling works and painting works. This makes the identification of the responsible party for the waste generated from each work trade difficult. Nonetheless the main contractor and the housing developer are unable to identify the actual waste management practices by the sub-contractor. However every sub-contractor is responsible to manage the construction waste generated from their own work trade. Sub-contractor played an important role to reduce the generation of waste on construction sites (Gavillan & Bernold 1994). For example, two different contractors who do a same trade may produce different quantity of construction waste due to various factors such as work skill, attitude and construction method used.

Table 4. Sources and waste management facilities in housing construction sites in Ipoh

Sources and facilities in construction sites	No of construction sites		Percentage of construction sites	
	Yes	No	Yes	No
Company have an action plan to reduce waste	6	3	67%	33%
The construction site appoint special/specific workers to manage waste	6	3	67%	33%
The construction site record the quantity of waste generated	2	7	22%	78%
Provision of special bin for waste collection before final disposal	2	7	22%	78%
Provision of specific area for construction waste collection	6	3	67%	33%
Construction waste are collected randomly at the construction sites (no specific area provided)	5	4	56%	44%
Provision of specific area for waste sorting	3	6	33%	67%
All types of construction waste are mixed and collected together	6	3	67%	33%
The construction site provides bin for reusing and recycling of material waste	2	7	22%	78%

Waste Management Hierarchy at Housing Sites

Table 5 shows the waste management hierarchy at the audited sites. The highest rank is reuse on site with RII of 0.582, followed by recycle on site at 0.473 RII. Then disposal of construction waste become the third rank and leave waste on site is the fourth rank. This finding indicates low level of waste management practices at construction sites in Ipoh according to the waste management hierarchy outlined in the Solid Waste National Strategic Plan.

Table 5. Waste management hierarchy at housing construction sites in Ipoh

	Σw	RII	Ranking
Reuse on site	32	0.582	1
Recycle on site	26	0.473	2
Dispose	19	0.345	3
Leave on site	16	0.291	4
Reuse off site	15	0.273	5
Sell to third party (sell to others)	15	0.273	5
Recycle off site	14	0.254	7
Others	11	0.200	8
Give to others	10	0.182	9

The disposal activities for the site audit has been divided into dispose offsite and leave on sites. Dispose offsite means that all the construction waste will be transported out from the site for final disposal. Majority of the disposed waste found in the site audit consist of excavated soil from land levelling, sewerage, drain, underground pipe and piling works. Meanwhile, leaving waste on sites involved burying waste or pile the waste scattered around the sites. This site audit has estimate 1-30% of waste generated will be left on sites after the completion of construction works. For example, wood will be left to rot at TB6 site. Wastes were buried at TB7 and CCC3 sites. Rocks and aggregates were dumped into the excavated hole at the isolated area of the construction sites. This practice is preferable due to minimal cost involved and it is difficult to be noticed.

The fifth waste management activity is reuse of waste off sites. The housing developer brings the building material surplus from the completed housing project to another projects which is still under construction. The last sixth and seventh rank of the waste management activities is selling the waste to the other parties and recycling of waste. Steel found to be the most collected waste and were sold to other parties. It is estimated that 1-30% of waste generated will be recycled offsite. One of the contractor at the audited site admitted that recycling are costly since it involved cleaning of concrete, mortar and nail from the wood waste. The third party only accept cleaned wood waste to be used as burning material in ceramic manufacturing. Therefore, the wood waste surface give constraint to the selling and recycling of wood waste offsite.

The findings reveals that another least method practiced on site is burn the damaged wood for about 1-30% of the wood waste generated. Burning of wood found to be the easiest and cheapest way by the site management of TB6 and TB5. They admitted that they burn the wood waste in small quantity by stages to avoid being spotted by the Department of Environment. Packaging material was also openly burned at the construction site. Meanwhile, the least waste management practiced on-site is giving away the construction waste to others especially the building material surplus. This practice is unpopular among the contractors because it is not profitable.

Disposal of Construction Waste from the Housing Sites

The site audit found that the construction waste transportation trip record were poor among the construction sites audited. Only 3 sites (37.5 %) of the sites keep transportation record of the waste being transported out from their sites. Majority of the construction sites (62.5 %) do not have a fixed schedule and will transport the construction waste after completion of the project. The other two sites transport the waste every month. Only one site will transport the waste after completion of work by trade.

Table 6 shows the selection method and rate of transportation cost for construction waste disposal from the audited sites. Most construction sites (87.5%) rent a lorry for waste disposal transportation. Meanwhile the average lorry rental charge per day is MYR 335.

Table 6. Selection of method and transportation cost rate for construction waste disposal from housing construction site in Ipoh

	Priority to construction site								**No. and percentage (%)**
Method used	**TB1**	**TB2**	**TB3**	**TB4**	**TB5**	**TB6**	**TB7**	**TB8**	
Rent a lorry	1	-	1	1	1	1	1	1	7 (87.5%)
Solid waste contractor	-	3	-	-	-	-	-	4	2 (25%)
Building material supplier	-	1	-	-	-	-	-	3	2 (25%)
Own transport	-	2	-	-	-	2	2	2	4 (50%)
Transportation cost rate									**Average**
Lorry rental charge per day	MYR 450	-	*NA*	MYR 300	MYR 350	MYR 260	MYR 250	MYR 400	RM 335
Lorry rental charge per distance	-	MYR 300	-	-	-	-	-	-	RM 300

Notes - TB3 unable to provide lorry rental charge rate due to confidential and its managed by the housing developer

The physical condition of construction waste before being transported out from the housing construction site in Ipoh is shown in Table 6. It is found that 50% are mixed waste from various construction activities. Meanwhile 25% of waste collected are mixed but according to the types of construction activities. And 25% of the audited site sort the construction waste according to the types of building materials.

Table 7. Construction waste physical condition collected before being transported out from the housing construction site in Ipoh

Waste condition	No of sites	Percentage (%)
All construction waste are mixed (various material and construction activities)	4	50
All construction waste are mixed (according to types of construction activities)	2	25
Construction waste are sorted according to the types of building materials	2	25

The waste transported out from the housing site in Ipoh has been sent to several destinations as shown in Table 8. Dispose at the allocated dumpsite which is Bercham Landfill become the first rank with RII of 0.473. This is followed by reuse of building waste. Meanwhile, other method such as burning found to be the last ranked.

Table 8. Construction waste destination after being transported out from the housing construction site in Ipoh

	ΣW	RII	Ranking
Dispose at the allocated dumpsite	26	0.473	1
Reuse	22	0.400	2
Dispose to other area (outside the allocated dumpsite)	18	0.327	3
Recycle	18	0.327	3
Sell	14	0.254	5
Other method – Burning (wood/bags)	9	0.164	6

Recommendations for Improvement of Current Waste Management Practices at Housing Construction Sites in Ipoh.

This study has identified the current status of construction waste management at several housing construction sites in Ipoh focussing on the waste generation, waste management sources and facilities, waste management hierarchy and waste disposal practices. The findings show that local contractors need to improve their current construction waste management practices. In order to achieve that, three recommendations are made.

The first recommendation is to increase the level of education and knowledge of good waste management practices of the construction workers. The increment could enhance awareness among the workers on the importance of good waste management practices. Provision of regular talk on good practices of construction waste management would stimulate the workers awareness.

Second recommendation is to increase the construction waste management facilities. Information on the generation and characterization of construction waste found in this study could be used to plan the provision of the facilities such as transportation and collection network, allocation of specific area for waste disposal to prevent illegal dumping or public filling at the ex-mining pond and set up of reuse and recycling centre. Thus, construction industry will have proper channel and support for better management of construction waste.

To improve the current practices, a suitable and local construction waste management plan is needed. So the last last recommendation is to provide a waste management plan for the local construction company. The proposed plan consist of five elements namely company administration, guidelines for management plan, prevention and reduction, optimisation of waste disposal and evaluation of good practices. So this plan acts as guidelines for good waste management at sites. To succeed, it should be precise, simple and practical to be implemented on site. Later, the plan could be used by the local authorities to monitor and control the generation and management of construction waste.

CONCLUSION

This study has identified the current status of construction waste management at several housing construction sites in Ipoh in terms of the waste management sources and facilities, waste management hierarchy and waste disposal practices. The present scenario shows that waste management practiced in Ipoh are below the good practices standard. However, the results obtained shall help improve current waste management practices in Ipoh by providing useful information regarding construction waste characteristics and the potential of construction waste generation rate as a reference for future projects to promote waste minimisation. In conclusion, better understanding of construction waste characteristics helps in proper planning and implementation of good waste management practices.

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REFERENCES

Fatta, D., Papadopoulos, A., Avramikos, E., Sgourou, E., Moustakas, K., Kourmoussis, F., Mentzis, A. & Loizidou, M. 2003. Generation and management of construction and demolition waste in Greece--an existing challenge. *Resources, Conservation and Recycling* 40(1): 81-91.

Formoso, C.T., Soibelman, L., De Cesare, C. & Isatto, E.L. 2002. Material waste in building industry: main causes and prevention. *Journal of Construction Engineering & Management* 128(4): 316.

Franklin Associates. 1998. Characterization of Building Related Construction and Demolition Debris in the United States. US EPA. EPA530-R-98-010.

Garas, G.L., Anis, A.R. & El-Gammal, A. 2001. Material waste in the Egyptian construction industry. Chua, D. B., Glenn. *Proceedings of the 9th International Group for Lean Construction Conference*.Kent Ridge Crescent, Singapore

Gavilan, R.M. & Bernold, L.E. 1994. Source evaluation of solid waste in building construction. *Journal of Construction Engineering and Management* 120(3): 536-552.

JPBD. 1998. *Draf Rancangan Struktur Ipoh (Penggubahan) 1998-2020.*

Kartam, N., Al-Mutairi, N., Al-Ghusain, I. & Al-Humoud, J. 2004. Environmental management of construction and demolition waste in Kuwait. *Waste Management* 24(10): 1049-1059.

Kofoworola, O.F. & Gheewala, S.H. 2009. Estimation of construction waste generation and management in Thailand. *Waste Management* 29(2): 731-738.

Kometa, S.T., Olomolaiye, P.O. & Harris, F.C. 1994. Attributes of UK construction clients influencing project consultants' performance. *Construction Management & Economics* 12(5): 433.

Macozoma, D.S. 2002. International report - construction site waste management and minimisation. International Council for Research and Innovation in Building and Construction (CIB). Report No. BOU/C361.

Ministry of Housing and Local Government (MHLG). 2005. National Strategic Plan for Solid Waste Management. Volume 2 Main Report.

NAHB. 1995. Residential Construction Waste: From Disposal to Management. NAHB Research Centre. www.toolbase.org/tertiaryT.asp [16 April 2006]

Peng, C.-L., Scorpio, D.E. & Kibert, C.J. 1997. Strategies for successful construction and demolition waste recycling operations. *Construction Management & Economics* 15(1): 49-58.

Poon, C.S., Ann, T.W.Y. & Ng, L.H. 2001b. On-site sorting of construction and demolition waste in Hong Kong. *Resources, Conservation and Recycling* 32(2): 157-172.

Poon, C.S., Ann, T.W.Y., Wong, S.W. & Cheung, E. 2004b. Management of construction waste in public housing projects in Hong Kong. *Construction Management & Economics* 22(7): 675-689.

Poon, C.S., Yu, A.T.W. & Ng, L.H. 2001a. A Guide for Managing and Minimizing Building and Demolition Waste. The Hong Kong Polytechnic University.

Pun, K.F., Hui, I.K. & Lee, W.K. 2001. An EMS approach to environmentally-friendly construction operations. *The TQM Magazine* 13(2): 112-119.

Tam, C.M., Deng, Z.M., Zeng, S.X. & Ho, C.S. 2000. Quest for continuous quality improvement for public housing construction in Hong Kong. *Construction Management and Economics* 18(4): 437-446.

Tam, V.W.Y. 2008. On the effectiveness in implementing a waste-management-plan method in construction. *Waste Management* 28(6): 1072-1080.

Yahya, K. & Boussabaine, A.H. 2006. Eco-costing of construction waste. *Management of Environmental Quality: An International Journal* 17(1): 6-19.

Yip, J.S.L. 2000. New directions of environmental management in construction: accepted levels of pollution. *Structural Survey* 18(2): 89-98.

SUSTAINABLE CONSTRUCTION PROCUREMENT: A CASE STUDY OF NIGERIA

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Abstract
This paper has the double objectives of first providing an overview of the literature on issues of sustainability concerning the Nigerian built environment. The second objective is to investigate the understanding of the professionals in the Nigerian built environment on sustainable construction. This objective is sought through the administration and subsequent analysis of survey questionnaires. Six sustainable criteria were addressed to the respondents to evaluate their frequency in the procurement of construction projects. Out of the total of the 120 distributed questionnaires administered to construction practitioners, a total of 83 responses were completed and useable. By means of inference based on these results, the sampled practitioners have only a passive understanding of sustainable construction practices. The paper concludes with a recommendation that construction practitioners should take leading roles to apply sustainable criteria in the design, construction, and maintenance and operations of construction projects to increase project performance and the well-being of the users. Moreover, given the importance of the measures designed to promote sustainable development, the government should make greater efforts to promote its application.

Keywords: *Sustainability; Construction; Passive Procurement; Nigeria*

INTRODUCTION

The construction industry is fundamental to the growth of a country irrespective of whether the country is undeveloped, developing, or developed, due to the industry's micro-economic contribution to the Gross Domestic Product, Gross National Product, and Gross Fixed Capital Formation. The outputs of the construction industry are capital or investment goods. If the construction industry is inefficient, the country cannot witness any meaningful development. Therefore, a major factor that could impede the economic prosperity of a nation is shortage in the necessary building and infrastructural facilities. However, the performance of the industry is measured by critical success factors (CSF) or client / users value system, i.e. the value system of client needs and wants.

The criteria within the client value system are cost of construction, project duration, safety, aesthetic, function, and quality. In other words, the success or performance of projects is measured based on the achievements of these criteria. However, it is now understood that for projects to be successful, all the stakeholders (i.e. consultants, contractors, suppliers, clients) must be satisfied, and that this satisfaction cannot come at the cost of the success of other stakeholders. Although, CSF is used to measure project performance, the need to include sustainability criteria has also became a fundamental requirement.

Today's clients and users are more knowledgeable and are conscious of the impact of their investments on the environment. The rise in energy cost is also making the sustainability issue a client/user requirement. Clients now procure buildings with the full understanding of the building's sustainability requirements. As such, given the rise in interest in sustainability, this research examines sustainability procurement indicators.

It is often maintained that sustainable design and construction cost more compared to conventional design and construction. However, this is not entirely true. The capital cost may be more, but not the operational cost. This is apart from the environmental, social, and community benefits. There are many definitions for sustainable construction. Sustainable construction has different connotations under different considerations. As a result, it is very unlikely that a common definition will be agreed upon even among those that have a stake in sustainability issues. Therefore, one method of considering sustainability issues in the built environment sector is to consider the way projects are procured. In other words, it is to look at the elements that are considered at the design and construction phases of the projects. Governments are now launching various strategies and initiatives necessary to achieve economic growth that at the same time enhance social and environmental standards. Government effort to achieve transition to the sustainable economy risk being curtailed, unless the process and practices involved in the procurement and operation of a construction project are adequately geared towards this direction.

Interests in sustainable development have heightened in the construction industry, which has a unique role to play in reducing the impact on environmental and resource degradation. Sustainability criteria need assimilation into the management of building/construction projects at the design and construction phases to reduce the building's impact in its use phase. To determine how sustainability considerations are integrated into the construction industry in Nigeria, primary data are collected through surveys with construction experts in Nigeria. The paper commences with an introduction in section 1 followed by a description of construction clients in section 2. The meaning of procurement of construction projects is explained in section 3, sustainability or sustainable development is considered in section 4, while in section 5, sustainable procurement is contextualised by bringing together sustainability indicators in order to provide appropriate industry specific measurements of sustainability. Efforts by the Nigerian government to promote sustainability are examined in section 6. The outline of the research method is presented in section 7, and section 8 reports the data analysis. Section 9 presents the results of the survey and offers a discussion of the findings, followed by a conclusion of the study.

CONSTRUCTION CLIENTS

Construction clients set the need for the projects and while some of the clients are experienced, others are not (Marsh, 2003). The recent past has seen some large construction clients demand carbon-offsetting projects with overall levels of business delivery. Clients are now realising that investing a little more to offset the carbon emission from their investment is necessary to provides value for money invested.

Clients are becoming more demanding and sophisticated compared to how they used to be in terms of how they measure the performance of their projects. The kinds of buildings that today's clients require are increasingly complex and sophisticated both in terms of volume and quality. The client wants a project that will be completed on schedule and within their budget, yet with highest standards of quality. They also want the building they can readily operate and maintain and to be cited at their choice of location. It is no longer a simple case of considering the capital cost of the project but the all-involving cost of acquiring the facility as well as that for maintaining and operating the facility on completion (Olanrewaju and Khairuddin, 2007b).

Clients that have continuous projects in their portfolios and that have procured projects regularly are more experienced and sometime have even prepared their projects' briefs in-house (Olanrewaju and Khairuddin, 2006a). This is because such clients are better informed on what they actually want (Ashworth and Hogg, 2002) as well as on how the construction industry operates. However, the majority of the industry's clients are the one off, namely those that build only once in their lifetime. Such clients do not know what they actually want and do not have adequate knowledge of the construction industry (Marsh, 2003). Usually, such clients have conflicting requirements, which need to be vigorously monitored from time to time for the projects to be completed on time, within budget, with high quality and to meet other criteria within the client value system.

PROCUREMENT

Even within the construction industry, procurement has been defined differently. In this paper, procurement is defined as the entire process of acquiring construction projects (Khairuddin, 2002 and Ashworth and Hogg, 2002). This process could pertain to new works or for maintenance, refurbishment, conversion, or extension. Procurement is not a pure science; it is more technology or engineering management rather than natural science or hard engineering. The skills required of a procurement expert cover history, politics, economics, management, business, psychology, engineering, technology, administration, sociology as well as science.

A few decades, ago, there were just few types of procurement methods available to the clients that had interest in acquiring construction projects can be procured for to choose from, either for procuring a new facility or for maintenance, rehabilitation or reconstruction or as the case may be. The various types of procurement strategies reflect the extent to which the client is willing and able to bear certain levels of risk measured in terms of cost, quality, and time and other criteria within the client value system. The selected procurement strategy must ensure that risk is transferred to the best parties that can manage it efficiently and effectively. The types of risk include financial, time, quality, function, technical, legal, operational, political and/or performance risk. Risk in any project is expected; this is unlike *uncertainty*. Therefore, it should be efficiently managed by any capable party. Risk is not bad *per se;* it simply denotes *responsibilities and duties*.

Perry (1985) classified procurement into two main types, namely; "design separated from construction" and "design combined with construction". Following this classification, another type that should be added is design combined with construction, operation and maintenance. This will represent a sort of private finance initiative or PFI strategy (and its various forms). Perhaps, Perry did not include the design combined with construction, operation, and maintenance in his classification because PFI (at least in its present organised forms) only appeared on the construction scene around 1992. Based on Perry's classification, methods like the lump sum contract, construction management, and management contracting fall to the design separate from the construction (Cheung, *et. al,* 2001), while design and construct, package deal, and turnkey falls under the design combined with construction. Hence, the PFI (and its various forms) can be classified under the design combined with construction, operation, and maintenance.

Selecting the wrong procurement strategy could lead to poor projects delivery in terms of cost and time overrun, poor quality and inability to consider the sustainability issue in the project (Love, et al., 1998 and Taylor, 2000). In other words, among the various types of procurement options available to a client towards achieving best value, only one of the procurement strategies is suitable for a particular set of client requirements. For instance, some procurement strategies place greater emphasis on a criterion or on some particular criteria within the client value system. As an illustration, the traditional strategy is most suitable for a project where time is not of essential priority. Under this strategy, tenders are usually selected on the basis of the lowest tender price. The type of procurement selected for a project could define the extent to which of the CSF can be considered as well as the extent to which sustainability issues are considered in the project.

SUSTAINABILITY

Sustainability means different things to different people. It is an ambiguous term that is currently in vogue. However, it is a 'positive vogue' term. Sustainability places emphasis on the efficient balance between nature and the built environment, while taking into account the impact of man's activities on the environment in meeting the needs of the present generation without inflicting harm on the future generation. Sustainability is the "ability to provide healthy human-influenced existence or process symbiotic while allowing, encouraging or capturing stability with natural variance over generations" (Christensen, 2005).

The fundamental goals of sustainability drives include the ability to reduce carbon dioxide emissions by at least 60% from its current level by 2050 (Killip, 2006), reduction of waste, and efficient energy utilization. Exceptionally large amounts of carbon dioxide can be reduced through systemic building management. Building construction and operation are also claimed to account for close to half of the water used globally. The building sector makes use of one-third of the world's resources, and is responsible for about 40% of GHGs emissions and makes use of about 15% of the world's water. Furthermore, about 40% of the world's solid waste is generated through building construction and operation.

A building's envelope is also argued to contain about 5 times more pollutants than the air outdoors. A substantial part of a building is composed of concrete. However, cement is the most active component of concrete, thus, in order to reduce carbon dioxide-emissions, there is a need for radical change in cement production techniques and application. Buildings are responsible for about one-third of the energy use and one-half of the electricity use in the majority of industrialised countries (Kaluarachchi, *et. al.* 8).

Sustainable is a principle, philosophy, and mind-set. The term means different things to different people, however the word is often used interchangeably with words including green, and eco-friendly. In another respect, the word sustainable has been prefixed with numerous words like, economy, tourism, building, banking, education, technology, and information. It is common today to hear or see expressions like sustainable economy, sustainable tourism, sustainable construction, sustainable construction contract, sustainable education, and sustainable technology. However, irrespective of the words or terms used, the fundamental intent is the same. Sustainability is a blend of energy optimisation, durability, waste minimisation, social impacts, good indoor environment, pollution control, life cycle-cost, user-friendliness, user comfort, and satisfaction. Strictly speaking, the sustainable concept is about tackling change in the world's climate. Climate change is caused as a result of changes in temperature. Meaning to say, the temperatures close or around the Earth's surface are warmer of cooler than normal. On the other hand, the major force behind the change in temperature is due to human activities. With specific reference to buildings, building construction and operation involves resources such as energy, water, and raw materials. It also generates wastes and emits potentially harmful atmospheric emissions. All these are contributing to the climatic changes directly and indirectly. From the conceptualisation phase of a building to its disposal phase, it impacts greatly on the environment. For instance, cement, which is a major building material, contributes significantly to carbon dioxide emissions.

SUSTAINABLE CONSTRUCTION PROCUREMENT CRITERIA

From the definitions, prefixing sustainable to the "construction procurement" therefore changes the scope of the theory and practice of construction procurement. This redefinition means construction procurement can no longer be taken as a standalone term because of the expansion in the requirements that the construction projects must fulfil to earn value for the clients, users, communities and the environment. In other words, sustainable construction procurement is the process, practices, and procedures of acquiring projects that deliver projects that are beneficial to the clients, users, communities, and the environment over a long time.

This definition means that the scope of construction procurement must not only focus on maximising user satisfaction and productivity but should also consider the environmental, social, and economic value system of other stakeholders. This is necessary in order to supply and operate the requirements of the sustainable building and infrastructure, which is the building and infrastructure that strives to preserve the economic, ecological, spiritual, social, and cultural requirements for societal well-being, and at the same time preserves the natural environment for future use.

Traditionally, construction procurement focuses on what is generally termed "golden triangle" or "iron triangle" expressed in terms of cost, time, and quality. However, because much of the processes and procedures involved in the procurement of projects have great impact on social and environmental spectrum / issues, it is only logical and imperative to include the social and environmental spectra into the procurement practices, process and procedures.

Therefore, construction stakeholders should be cognizant of the social and environmental consequences of their actions and reactions. There are sufficient literatures to conclude that the current construction procurement theory and practices did not link procurement with the sustainability criteria. The requirements that projects must meet remain traditional. Although, some procurement strategies like PFI have opportunities to include sustainability, yet because that is not the major purpose of these strategies, the practical considerations of the sustainability criteria are often constrained. In this paper, "sustainable construction procurement" is introduced and defined in terms of how it is measured. Measurable elements that enable stakeholders to determine whether their project's procurement process is sustainable or not are presented to respondents. These are used to measure practitioner understanding on the application of the sustainable development criteria in projects. Although a definitive list of sustainability criteria in construction procurement is lacking, however, good practice is to be observed. The members of the design and construction teams should be experts that are sustainability conscious.

Indicators of Sustainable Construction

Terms including eco-construction, liveability construction, green construction, natural construction, sustainable construction, and energy efficient building are synonymous with sustainable construction and they are sometimes used interchangeably. Paraphrasing the definition for sustainable development, sustainable construction is generally defined as "a construction that meets the needs of the present without compromising the ability of future generations to meet their needs". The flaw with the above definition is that it is philosophical as opposed to being scientific. It is an elusive definition because it is difficult to measure. For that purpose, sustainable construction is defined as construction that strives to improve the capital outlay, the operational performance and cost and not harmful to the environment and communities. In general, this definition allows opportunity for measurement of the elements in sustainable construction.

Therefore, procurement strategies that contribute to attain these objectives should have some measurable indicators. Building construction and operation involves resources such as energy, water, and raw materials. It also generates wastes and emits potentially harmful atmospheric emissions. All these are contributing to the climatic changes directly and indirectly. From the conceptualisation phase of a building to its disposal phase, it impacts greatly on the environment and stakeholders (including users, neighbours, members of the design and construction teams and passersby). This section describes the indicators of sustainable construction procurement, namely the elements that need to be included in the procurement of a construction before it is termed as sustainable construction procurement?

The criteria for sustainable construction are not a simple wish list. While there are no conclusive lists on what are the basic elements that form sustainable construction, the following elements are often cited (Cartledge, 2006): economic issue, social/community, environmental issue, energy cost, maintenance cost, and reducing main water consumption. An issue like waste management is not included because appropriate feedback would not be obtained. Measuring the indicators is beneficial to organizations to understand its process and identifies opportunities for improvements or to review the performance of their process. Certainly, if you do not know how you are doing, there is no way you can know whether you are doing well or not. Therefore, there is the need to measure how well you are doing. To know how you are doing, you need to have indicators to help compare targets with achievements, which will serve as the basis for benchmarking.

In making decisions on the selection of the indicators to include, thoughts were given to:

1. Why sustain?
2. What to sustain?
3. Where to sustain?
4. How to sustain?

The issues of why construct, what to construct, where to construct, and how to construct are well established. However, why sustain the construction, what to sustain, where to sustain, and how to sustain remain questions of ingoing debate. Understanding why, what, where, and how to sustain accentuate and trigger the elements of sustainable procurement of construction.

OVERVIEW OF EFFORTS OF NIGERIAN GOVERNMENT ON SUSTAINABILITY OF ITS BUILT ENVIRONMENT

Nigeria, with its sizeable population that is also increasing, will have an enormous impact on global (and regional) resources. Agenda 21 recognises the construction industry as an essential means for attaining advancement towards sustainable development which will promote the implementation of all parts and stages of the agenda. The impact of the construction industry is multifaceted, from the time the project is conceptualised to when it is demolished it continuously affects (negatively) the environment. With the many challenges involved in realising sustainable development in Nigeria today, well-articulated construction procurement requires the inclusion of sustainable issues into policies, strategies, processes and implementation on procurement of constructed facilities. There is a clear understanding that sustainable development extends to more than environmental issues. Therefore, what is required is for clear links to be made between construction procurement processes and procedures that facilitate the attainment of sustainable development.

Nigeria is making concerted efforts toward inculcating sustainability into all spheres of activities. The draft objectives and strategies for Nigeria's Agenda 21 has highlighted how this could be achieved (http://www.nesrea.org/images/NIGERIA'S%20AGENDA%2021 .pdf). According to the draft, the cardinal objectives of \ Nigeria's Agenda 21 comprise of four programmes, namely:

1. To integrate environment into development planning at all levels of government and the private sector;
2. To commence a transition to sustainable development;
3. To address sectoral priorities, plans, policies and strategies for the major sectors of the economy; and
4. To simultaneously foster regional and global partnership

In addition, the National Policy on Environment on the Nesrea (Nigeria National Environmental Standards and Regulation) will ensure that (http://www.nesrea.org/environmentalpolicies.php):

1. Environmental concerns are integrated into major economic decision- making process;
2. Environmental remediation costs are built into major development projects; and
3. Economic instruments are employed in the management of natural resources; environmentally friendly technologies are applied.

This policy also requires that environmental impact assessment must be administered prior to the commencement of any major projects. However, the definition of major projects remains unclear.

While there is much literature on how Nigeria could attain sustainable development status, particularly in the areas of housing development and education (Jiboye, 2011), there remains a general paucity of literature focusing on the construction industry. Furthermore, information and knowledge on experience of practitioners or their understanding of sustainable construction is grossly inadequate. Therefore, the current paper investigates the procurement of sustainable construction in the Nigerian built environment. However, the practical implication and implementation of environment policies and strategies are rather elusive. The government in particular is not doing enough and quite a number of shortcomings exist in the various environmental policies that are in need of serious investigation.

OUTLINE OF THE RESEARCH METHOD

The methodology of the study combines a literature review and survey questionnaire. In order to achieve the aim of this study, six indicators were used to measure the extent to which construction projects in Nigeria are procured to meet the sustainability issues. The respondents were selected based on convenient sampling. Convenient sampling is applicable if the appropriate response/feedbacks can only be administered on available respondents (Sekaran 2004). A total of 120 questionnaires were distributed to the construction practitioners. The administration and collation of data commenced in December 2011 and ended in January 2012 (for a period of six weeks). While most of the questionnaires were administered by hand, others were administered through e-mail. Respondents were asked based on their current experience, to tick the extent of considering the six factors on five continuum scale; where 5 denotes extremely often, 3 denotes often and 1 denotes not often at all. 2 and 4 are located in between. We hypothesised that all these factors could predict / explain sustainable procurement. The extent of consideration is determined by the Average Relative Index (ARI) (Equation 1). The average relative is based on the cumulative weighting of the initial frequency score of each construct (i.e. factors, criteria, items, *et al*.)

$$ARI = \frac{\sum_{i=0}^{5} a_i x_i}{5\sum_{i=0}^{5} x_i}, (0 \le ARI \le 1) \quad \text{(Equation 1)}$$

Where a_i is the index of a group; constant expressing the weight given to the group; x_i is the frequency of response; i = 1, 2,3,4,5 are the frequencies of the response corresponding to $a_1 = 1, a_2 = 2, a_3 = 3, a_4 = 4, a_5 = 5$ respectively. For interpretation, the lowest possible score is 0 (zero) while highest possible score is 1 (one). Therefore, the indicator with the score closest to 1 (one) is the highest mean score and the most considered indicator.

DATA ANALYSIS, RESULT AND DISCUSSION

Tables 1 and 2 and Figure 1 present the respondents' profiles. What is evident from the profiles is that the respondents are capable of providing valid and unbiased information and knowledge on the Nigerian built environment.

Table 1. Distribution of respondents' professional background

Background	Frequency	Percentage
Quantity surveying	34	41.0
Engineering	8	9.6
Architecture	21	25.3
Estate management	11	13.3
Town planning	4	4.8
Other	5	6.0
Total	83	100.0

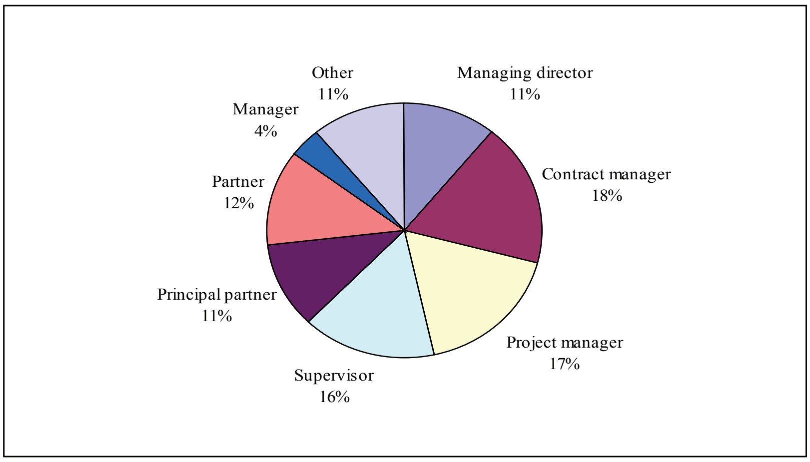

Figure 1. Distribution of respondents' position

Table 2. Distribution of respondents' industrial experience

Experience (year)	Frequency	Percentage
Not more than five years	22	26.5
Five years to less than ten years	23	27.7
Ten years to less than fifteen years	25	30.1
Fifteen years to less than 20 years	6	7.2
20 years and above	7	8.4
Total	83	100.0

Prior to presenting respondents with the procurement factors, they were asked certain control questions. Tables 3 through to 7 and Figures 2 to 5 contain and display the information.

Table 3. Distribution of respondent's empirical knowledge on sustainable construction

Knowledge on sustainable construction	Percentage
Very low extent	3.7
Low extent	9.8
Moderate extent	50.0
High extent	28.0
Very high extent	8.5
Total	100.0

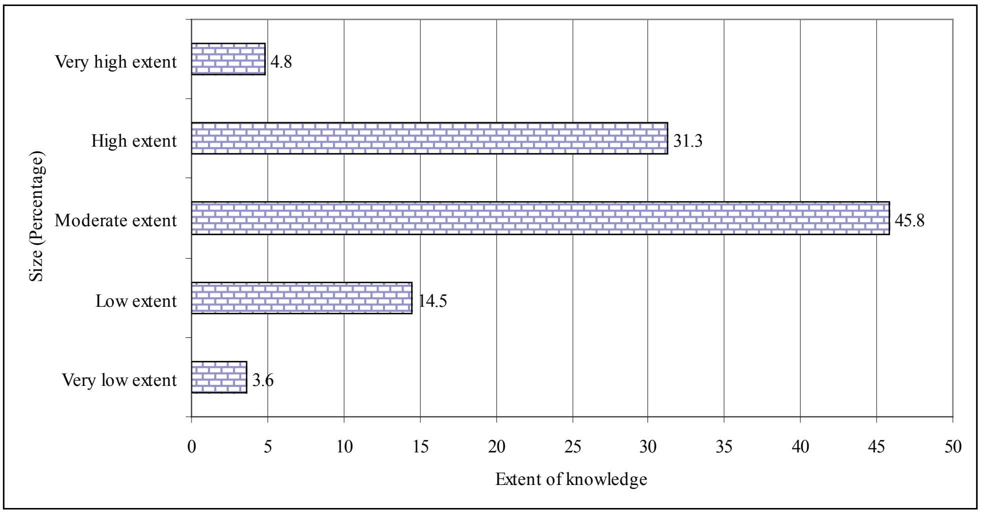

Figure 2. Distribution on w whether respondent has empirical knowledge on sustainable procurement

Table 4. Distribution on to know if respondent is aware of any completed sustainable projects in Nigeria

Sustainable building	Percentage
Yes	36.7
No	32.9
Not certain	30.4
Total	100.0

Table 5. Distribution to know if government provides incentives of clients of sustainable buildings

Clients of sustainable buildings	Percentage
Yes, to a larger extent	4.9
Yes, to a small extent	45.1
No	25.6
Not sure	24.4
Total	100.0

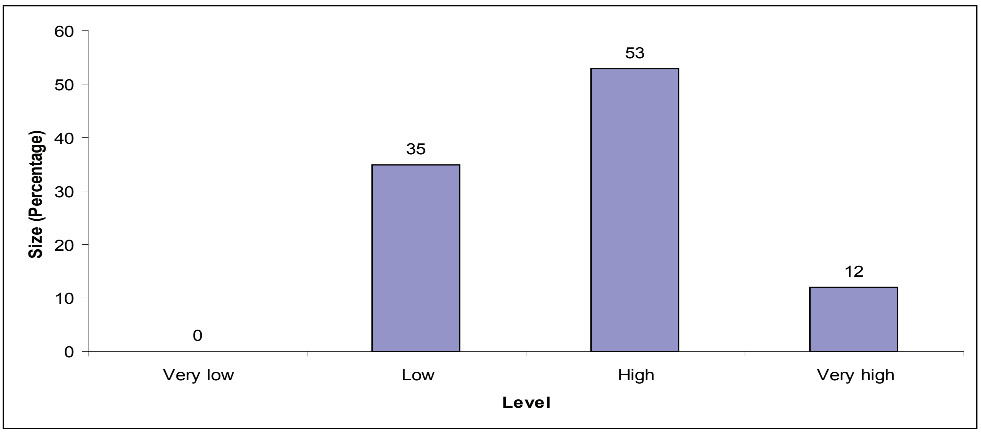

Figure 2. Distribution to know how active are the design teams in promoting sustainable design

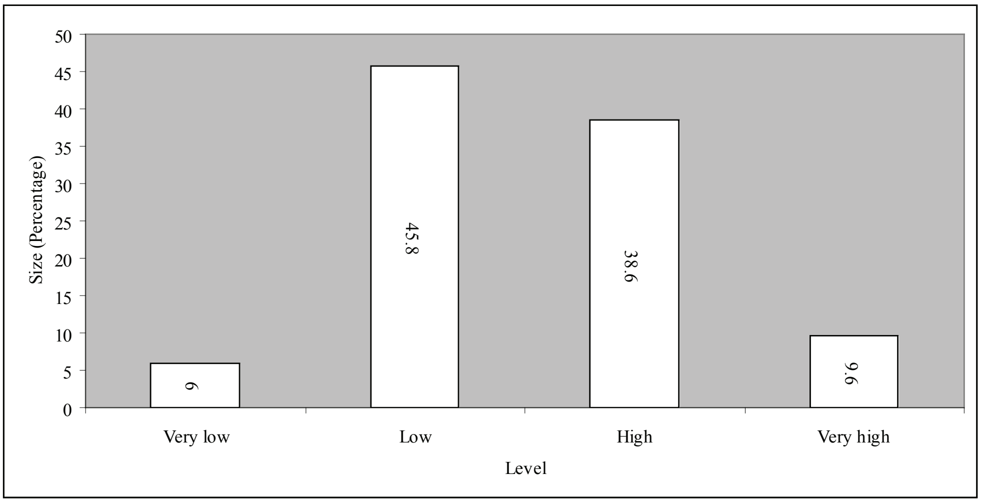

Figure 3. Distribution to know how active are the construction teams in promoting construction projects

Table 6. Distribution to know clients' demand for sustainable projects

Level	Percentage
Yes, to a larger extent	16.3
Yes, to a small extent	52.5
No	12.5
Not sure	18.8
Total	100.0

DISCUSSION OF SUSTAINABLE CONSTRUCTION PROCUREMENT INDICATORS

In this section, the measurements of the indicators that render the procurement of construction project sustainable are examined. Six factors were addressed to respondents to tick the rate at which they have considered the indicators in the projects they were involved in the last ten years. The results of the analysis are contained in Table 7. As can be observed in the Table, the consideration of each of the indicators ranges from 60% to 70% except for water consumption, which is below 60% (actual measure was 59%). The consideration of maintenance indicator has the highest ranking while the least is taking water consumption when operating the building. Specifically, most of the respondents measured the consideration of social / community (38), environmental (34) and water consumption (39). In terms of considering energy cost and maintenance cost, most of the respondents measured them as very often.

Table 7. Sustainable construction procurement indicators

No.	Indicator	1	2	3	4	5	Index
1	Social /community	1	6	38	32	5	0.6829
2	Environmental	0	11	34	32	6	0.6795
3	Economic	1	6	40	31	5	0.6795
4	Energy cost / efficiency	1	15	24	37	6	0.6771
5	Maintenance	0	16	20	40	7	0.6916
6	Water consumption	5	20	39	14	5	0.5855

It is interesting to find that the maintenance is given proper attention by the construction experts in Nigeria. This is not surprising though, because buildings are subjected to strenuous climatic and environmental factors. Different building materials and components react differently to weather. Therefore, to minimize the maintenance expenditure, there must be a proper selection of materials and components, as well as alternative designs for different atmospheric conditions and geographical locations (Somerville and McCosh, 2006).

While increase in temperature and humidity is increasing the rate of decay and deterioration, flooding is also making the buildings unreliable. Building materials and components are exposed to different weather conditions for long periods of time. For this reason it is important to determine the effects of sunlight, heat, humidity and climatic changes in the properties of the materials, colour, and gloss. There is a need to understand these properties in the evaluation of the building performance. For instance, determining the colour of materials is important not only for aesthetic reasons, but also because any change in outlook or appearance may be a sign of pre-decay alterations (Costa *et al.,* 2010).

Projects are often conceived, designed, constructed, and operated with little to no consideration of the consequences they have on local communities. Projects do not exist in isolation of its environment; they are situated among people. It thereby becomes imperative that the needs of those living in the community must be taken into consideration when the need to construct exists.

The outcome of the results in terms of considering water consumption is relatively low. Interestingly, it is the least considered indicator among the design and construction teams. This is not encouraging considering the cost of water consumption. Building construction and operation make use of a substantial part of the world's water. There is a continued realisation that buildings should be equipped with rainwater harvesting systems. In addition grey water (wastewater generated from domestic activities) can be used for gardening.

Energy efficiency is an indicator considered by the respondents. There is a cogent need to consider energy efficiency in Nigeria. Energy cost is very high in Nigeria. The combined energy generation in Nigeria is very low particularly when weighed against its population. The construction design should, among other things, take into account the sun's movement in order to take advantage of natural lighting. Metal roofs that reflect heat from the direct sunlight should be used. Energy efficient equipment and plant should be installed. Solar photovoltaic should be installed in the buildings. Clients of existing buildings should be encouraged to install such equipment.

From the survey, the government is not doing much to promote the consideration of sustainability issues in buildings. The government needs to provide tax incentives to building owners / users. It could also provide sales tax exemption to clients for purchasing energy, efficient equipment, and plants. Government needs to have in place a green rating agency for the construction industry. New publicly owned buildings should be designed to meet green standards. These are veritable boosts by the government to promote green construction.

Designers in Nigeria should observe a green building rating system for sustainable buildings. There is a need for the introduction of a green building index (GBI), that will be used to measure greenhouse gaseous emissions from the building (especially the corporate and governments buildings). This is necessary as it helps in making decisions on what to do in order to make the buildings sustainably compliant. It will also help in awarding incentives to green-minded clients / users.

Existing buildings should be retrofitted to reduce their GHG emissions. Examples of how this can be achieved are using energy efficient appliances like bulbs, fridges, fans, and air conditioners. Fluorescent bulbs are durable, energy efficient, environmentally friendly and generate less heat. The need to retrofit existing buildings to meet with the sustainability standard is \ critical because approximately 5% of buildings are added annually. In other words, existing buildings constitute more than 90% of total building. Therefore, materials and components should be re-use

CONCLUSION AND RECOMMENDATIONS

The content of this paper constitutes an initial attempt to define the indicators of sustainable construction procurement in the construction industry in Nigeria. The term "passive" means performing an action without concerted thought or without system, in which case, the outputs of the actions are not well known in advance. As such, the performance of the outcome cannot be measured. By extension, a situation where the design / construction team are not consciously considering sustainability in the projects will not produce the expected results. Also, where the considerations of the sustainability criteria are not well integrated into the procurement process they will not produce the desired outcomes. Several 'green' or indicators of sustainability were identified and reviewed in an attempt to promote sustainable construction procurements. The survey included six sustainable drivers. The original research question for this study revolved around whether construction procurement in Nigeria complies with the sustainability agenda. While sustainable indicators are many, six major indicators were used for this paper. As observed through the review section, sustainability drivers are now beginning to standardise into a definite spectrum. While sustainable construction is desirable, all members of the construction team need to be proactive and innovative and work together for a common interest.

Sustainable procurement standards of practice are also required to make certain that the sustainability issues are well considered and to measure the performance process and procedure. As a strategic recommendation, it is recommended that a research project should be conducted into how quantity-surveyors in Nigeria can be *sustainable construction experts* because of the significant roles they play in construction, which may promote sustainable projects. Clients will definitely want to listen to someone that can "*talk money.*" The 'drivers' used for measuring the degrees of 'sustainability' were adapted. While making decisions on sustainable procurement strategy, a mechanism is required to actively consider issues including waste, eco-system, the local community, aesthetic degradation, embodied energy, health risks, transport, pollution, and labour. The limitation of the research was that only a relatively small sample was taken. This thereby limits the generalisation of the findings onto the Nigerian construction industry.

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REFERENCES

Ashworth, A. and Hogg, K. (2002) Willis's Practice and Procedure for the Quantity Surveyors. 11th edition. Blackwell Science Limited, Oxford

Cartlidge, D. (2004) Procurement for built assets, Elsevier Butterworth – Heinemann, Oxford

Cheung, S. I., Lam, T. I. and Leung, M.Y. (2001) An analytical hierarchy process based procurement selection method*, Journal Construction Management and Economics*, 19:4, pp.427 – 437

Christensen, A J. (2005) Dictionary of landscape architecture and construction, USA: McGraw Hill Companies, Inc.

Costa, R., Paiva, A., Rodriguez, O., De Rojas, M. I. S. and Frias, M. (2010) The Influence of the Colour Behaviour of External Envelope Materials in the Quality of the Buildings. *CIB 2010 World Congress Proceedings.* Edited by Peter Barrett, Dilanthi Amaratunga, Richard Haigh, Kaushal Keraminiyage and Chaminda Pathirage. The Lowry, Salford Quays - United Kingdom 10 -13 May 2010

Jiboye, A. D (2011), Achieving Sustainable Housing Development in Nigeria: A Critical Challenge to Governance. International Journal of Humanities and Social Science Vol. 1 No. 9 121-127

Kaluarachchi, Y., Jones, K., James, P., Jentsch, M., Bahaj, A., Clements, D. and Gann D. (2005) Building facades: sustainability, maintenance and refurbishment. I*n Proceedings of the Institution of Civil Engineers* 158, June 2005 Issue E53 pp. 89 – 95

Khairuddin, A.R. (2002) Construction procurement in Malaysia: Processes and Systems, Constraints and Strategies. International Islamic University Malaysia, Malaysia

Killip, G. (2006) The housing maintenance and sustainability debate, *In Proceedings of the Annual Research Conference of The Royal Institution of Chartered Surveyors*, London

Love, P. E. D., Skitmore, M. and Earl, G. (1998) Selecting a suitable procurement methods for a building project, *Journal of construction management and economics*, 16:2, pp221-233, Routledge , UK

Marsh, C. (2003). Building services procurement, 1st edition. London: Spon Press

Olanrewaju, A. A., and Khairuddin, A. (2006). Value Management: New Direction for the Nigerian Quantity Surveyors. P102 – 109, *Proceedings of Quantity Surveying National Convention*, Organized in conjunction with the International Construction Week. 4 – 5 September 2006. ISBN: 983 – 41749 -2 -6, Held at University Science Malaysia (USM)

Olanrewaju, A. A., and Khairuddin, A. (2007). Determining whether Value Management is practiced in the Nigerian Construction Industry, In: *Proceeding of Quantity Surveying International Convention* (QSIC). Jointly organized by Visit Malaysia 2—7; International Islamic University Malaysia; Board of Quantity Surveyors Malaysia; Institution of Surveyors Malaysia; JKR and CIDB. Held on 4-5th September 2007, Kuala Lumpur.

Perry, J. G. (1985) The development of contract strategies for construction projects. PhD. thesis, University of Manchester, cited in Cheung, S. I., Lam, T. I. and Leung, M.Y. (2001) An analytical hierarchy process based procurement selection method, *Journal Construction Management and Economics,* 19:4, pp427 - 437

Sekaran, U. (2004) Research methods for business: A skill building approach John Wiley & Sons, Inc. 4th Edition.

Sommerville, J. and MoCosh, J. (2006), "Defects in homes: an analysis of data on 1,696 new UK houses" *Journal of Structural Survey*, Vol. 24 No. 1 pp.6-21

Taylor, M (2000) Avoiding claims in building design: risk management in practice, 1st Edition, Oxford: Blackwell Science Limited The Europa World Year Book (2009) Nigeria: Introductory Survey. 50th Edition. Volume 2. Countries: Kazakhstan-Zimbabwe. pp 3446-3471

THE RELATIONSHIP BETWEEN COMPETITIVE PRIORITIES AND PERFORMANCE: A STUDY ON THE TACTICAL APPROACH USED BY THE REAL ESTATE FIRMS IN DUBAI TO ACHIEVE COMPETITIVE ADVANTAGE

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Abstract
An essential element for firms to achieve superiority over their competitors is the ability to make good use of its operations. In fact the literature on manufacturing strategy suggests the importance of operational strategy which is considered as the missing link in the formulation of corporate strategy. A review of the manufacturing strategy literature also indicates that much of the works on competitive priorities is focused on the manufacturing sector. Despite the central role of the real estate sector in a given economy, there is a distinct lack of research that is focused in the area. In Dubai there is not only a marked lack of study, there is also a need for studies which are focused on the competitive priorities, competitive advantage and performance of the real estate firms. This study attempts to address this research issue by examining competitive priorities, competitive advantage and performance of real estate firms in Dubai. The data for the study was collected by using structured questionnaire from 30 managers who worked in six real estate firms in Dubai. The results of the analyses of the data collected in study indicated that the firms in the study emphasized competitive priorities that include flexibility, cost, quality and delivery. In addition, the results of the study showed that quality, cost and delivery are positively related to competitive advantage. Finally this study adds support to the idea that there exist relationships between competitive priorities, competitive advantage, and performance of real estate firms in Dubai.

Keywords: *Competitive Priorities; Competitive Advantage, Performance; Real Estate Firms*

INTRODUCTION

An essential element for firms to achieve superiority over their competitors is the ability to make good use of its operations function. Effective operational function will be valuable in providing support for a firm to formulate its business strategy. More specifically a firm with effective operations will be able to achieve competitive superiority over its competitors. With effective operational capability a firm will not only be in a better position to achieve competitive superiority over its competitors but also improved its performance as well. To achieve this end a firm needs to improve on its operational effectiveness.

A firm's operational effectiveness does not take place in a vacuum. A firm needs to deliberate and focus on achieving its operational effectiveness. The literature on manufacturing indicates that effective operations can be achieved with the use of proper operation strategy. Much of the works on the formulation of operational strategy can be found in the manufacturing strategy literature.

In fact Skinner (1969; 1974) noted the paramount importance of operational strategy, as it is the missing link in the formulation of corporate strategy. The literature suggests that operational effectiveness can be achieved with a thoroughly planned operational strategy. The ability of a firm to devise a proper operational strategy is by focusing on the right alignment of its manufacturing capabilities or what is now known as competitive priorities with its competitive requirement, (Tarigan, 2005; Mady, 2008; Chi, Kilduff and Gargeya, 2009).

A review of the manufacturing strategy literature indicates that much of the works on competitive priorities is focused on the manufacturing sector particularly in the developed economies. Even though the study on competitive priorities is focused on the manufacturing sector in developed economies, there are a number of scholars who suggest that the study on competitive priorities should not be limited only to the manufacturing sector. Studies on competitive priorities should be extended to other areas as well. For instance, Phusavat and Kanchana (2007) suggest that the approach used in the manufacturing industry be applied in the service sectors which encompass transportation, retailing, wholesale, finance, tourism and also real estate.

As far as the real estate sector is concern it has always been an important sector of a nation's economy. In general, strategy scholars and practitioners note that in a growing economy with its increase in individual disposable income, there will be a corresponding demand for real estate investment. More so the demand for real estate is likely to swell for an economy that is experiencing transition say from manufacturing to a more service oriented economy. Despite the central role of the real estate sector in a given economy, there is a distinct lack of research that is focused in the area. Though there is a marked increase in the research in real estate, studies which are focused on competitiveness, business strategy, the evolution of real estate market, and performance of real estate firms are much needed, (Parsa, et. al., 2002; McLaurin and Chinta, 2005; et. al., 2007).

While there are numerous studies that are carried out in the real estate sector in developed countries there is a marked lack of research among companies engaging in the real estate in the less developed countries, particularly in those countries in the Middle East. Particularly lacking in focus is the study on real estate companies in Dubai. The literature indicates that in Dubai there is not only a marked lack of study, there is also a need for a study which is focused on the competitive priorities, competitive advantage and performance of the real estate firms in the Emirate. This paper is an attempt to fill part of the research gap in the study of competitive priorities, competitive advantage and performance of firms that are involved in the real estate sector in Dubai.

LITERATURE REVIEW

In general firms particularly those which are involved in the real estate business faced a lot of challenges in the present business environment. The challenges may stemmed from global competition, product and service innovation and also restructuring of economies. These challenges pose real and apparent threat to their business operations, and in most extreme case tend to wipe out a firm's operations. In the face of these challenges real estate firms need to focus on the operational elements in order to achieve competitive advantage. The studies by Singer, et. al. (2007) and Park and Glascock, (2010) indicate that with a superior planning of real estate elements firms will be able to achieve competitive advantage.

Gaining competitive advantage in the real estate sector means that a firm needs to build capability to come up with product or service offerings to its customers. However as authors (Roulac, 2001; Roulac et al., 2005; Park & Glasscock, 2010) pointed out mere capability to develop products and services is not enough. The above authors suggest that the extent of service or product offerings would also depend on the operational capability.

The need for greater operational capability hence competitive advantage is even greater among real estate firms in Dubai. In the case of the real estate sector in the emirate of Dubai, it had just experienced a real estate bubble in 2008. In Dubai, the extent of the crisis is reflected in the prices of its real estate. Prices dipped to somewhat less than 50 percent for lesser quality real estates while the prices showed some resilience particularly high quality real estate in attractive location. Renaud (2010) considered the real estate crisis of 2008 as one of the worst global economic crises in 70 years that ever to hit the Middle East area.

In spite of the crisis, a number of scholars such as Renaud (2010) and Balasubramanian (2010) indicate that Dubai can still maintain its positions as one of the economic centers of the Middle East. As for its real estate sector, strategy scholars and practitioners concur that it would never come close to the kind of exuberant growth it enjoyed in the prior years to 2008, nevertheless as a growth center it would be able to maintain and even generate further businesses. This is so as Dubai is still considered as the gateway to the Middle East. Additionally it is also regarded as the trade and transport hub for the Middle East.

As the level of economic activity improved in Dubai so too would the demand for real estate. However, the Dubai real estate sector needs to avoid future economic onslaught. One of the ways to survive future crisis is through proper planning. The studies by Roulac et al. (2005), Singer et al. (2007), and Park and Glascock (2010) and indicate that with superior planning of real estate elements, firms will be able to achieve competitive advantage.

Competitive Priorities

The early manufacturing strategy literature indicates that most scholars such as Hayes and Wheelwright (1984), Buffa (1984), and Skinner (1985) tended to view competitive priorities as means for a firm to compete and determine the type of market to focus on. In relation to this, competitive priorities are yet another avenue for a firm to enhance its operational functional capability.

Competitive priorities are also viewed as manufacturing capacities. Along this line, authors such as Fine and Hax (1985) regard competitive priorities as manufacturing capacities which is made up of a combination of various operational functions used to support business strategy. In similar tone, Swamidass and Newell (1987), refer to competitive priorities as the dimensionality or content of manufacturing strategy. Likewise, Adam and Swamidass (1989), Vickery, et. al. (1993), and Ward, et. al.,(1996), refer to competitive priorities as elements of the production function.

In a somewhat greater focus given to the market needs, Krajewski and Ritzman (1993) define competitive priorities as the dimensions which are required of a firm's production system in order to support the demands of the markets that a firm wishes to compete in. Leong, et. al., (1990) and Takala (2002) and Phusavat and Kanchana (2008) refer to competitive priorities not only subject to the requirement of the market but also as the basis for a firm to focus on its future competitiveness. Thus competitive priorities form the basis in which operational strategy is focused on and also the future direction of a firm.

Although there are several different views and definitions of competitive priorities, most of the conceptual and empirical studies concur that competitive priorities comprise four basic dimensions: cost, quality, delivery and flexibility, (Swink and Way, 1995; Ward et al., 1995; Boyer, 1998; Danagyach and Deshmukh, 2001; Boyer and Lewis, 2002). The literature suggest that the above four dimensions form the content of a firm's operational strategy. Over the years scholars have added other dimensions to the four existing ones including dependability, service and innovativeness.

In addition, findings of previous also suggest that competitive priorities are associated with competitive advantage. According to these studies, competitive priorities such as cost, quality, delivery dependability, flexibility, service and innovativeness have close and strong relationships with business environment as well as the competitive advantage of firms (Chi et al., 2009; Sarmiento et al., 2008; Askar and Mortagy, 2007; Zhang, et. al.,2002; Dangayach and Deshmukh, 2001; Bolden, et. al., 1997; Cox, 1989; and Zelenovich, 1982).

Competitive Advantage

Competitive advantage is an important concept in strategic management, (Lin, 2003; Porter and Kramer, 2006; Liao and Hu, 2007; Barney, 2007). The literature suggests that the importance and focus on competitive advantage can be attributed especially with the work of Porter (1980). Porter (1985 and 1988) suggests that competitive advantage is a way in which a firm can measure its success against competitors. Competitive advantage can be realized through the use of low cost competitive strategy or differentiation competitive strategy. The use of low cost competitive strategy allows a firm to achieve competitive advantage when it is able to provide product or service offerings at an acceptable quality and competitive prices, and in the process enjoying higher return. On the other hand the use of differentiation competitive strategy allows a firm to achieve competitive advantage when it is able to provide superior value product or service offerings at premium prices.

According to Barney (1986), (1991) and (2001) and Peteraf and Bergen (2003), the ability of a firm to achieve competitive advantage depends on the attributes of the resources and capabilities that a firm possesses. The attributes of the resources and capabilities that enhance competitive advantage among others are difficult to duplicate and durability which is the rate in which a particular resource become obsolete. Strategy which hinges on resource and capabilities with the above attributes when properly applied would lead to competitive advantage, (Porter and Kramer, 2006; Powell, 2003; Arend 2003).

A firm would be able to achieve competitive advantage if it possesses the various competitive priorities. This depends on the ability of the firm to identify and choose competitive priorities. The competitive priorities identified would depend on a number of factors including business environment, customer needs, competitor actions, as well as internal resources. The correct choice of competitive priorities can enhance the firm position in the market place. (Connell, 2010; Mady, 2008; Murray, Gao,et. al., 2011).

Competitive Advantage and Performance

The literature seems to suggest that competitive advantage and performance are two different constructs, though both are used interchangbly. A number of authors such as Newbert (2008), Powell (2003), and Ma (2000) suggest that the two constructs are conceptually different. In addition a number of empirical studies too seem to support the notion that competitive advantage and performance are two different constructs including those by Newbert (2008); Ray, et. al., (2004); Schroeder, et. al.,(2002).

Not only that the two constructs are conceptually and empirically different, studies suggest that there are significant relationships between the competitive advantage and performance, (Barney, 1986; Conner, 1991; Mills, et. al., 2003; Peteraf & Bergen, 2003). Accordingly, the presence of competitive advantage in a firm can lead to the improvement in performance. Further according to Newbert (2008), capabilities and resources would only indirectly affect performance, thus for a firm would require to generate a position of advantage prior to improvement in performance.

For the present analysis, a firm which is able to identify and exploit its competitive priorities would be able to generate competitive advantage. The competitive advantage can be in the form of competitiveness in several forms such as competitiveness in terms of market share, profitability, financial return, technological provision, and financial management. Performance in the present study would include average sales and sales growth. A number of studies noted that significant relationship between competitive advantage and sales based performance, (Wang & Lo, 2003; Neely, 2005; Falshaw, et. al., 2006).

RESEARCH METHODOLOGY

Sampling and Data Collection

The real estate companies registered with the Dubai Financial Market's web site were selected as the sampling frame of the study. The web site is located at http://www.dfm.ae/. A total number of 66 real estate companies registered with the web site. The companies were selected as they are involved in the constructions and development of real estates in Dubai. Originally, out of the 66 real estate companies contacted, nine companies agreed to participate in the study. However, six out of the nine companies actually participated in the study, representing a response rate of 67 percent. This response can be considered encouraging as more than fifty percent of the companies that agreed to participate provided their inputs for the study. On the other hand however the six companies represented only about nine percent of the total sampling frame. Nevertheless the views from the management personnel of the six companies that participated in the study provided some insights into the competitive approach of their respective companies. The six companies were represented by 30 management personnel who provided the responses. The management personnel include; director, vice-president of operations, production manager, marketing manager, and financial manager.

Survey Instrument

The study used structured questionnaire to obtain data from the respondents. The questionnaire consisted of three parts. The first part of the questionnaire comprised seven questions on the background of the real estate companies and two questions on the background of the respondents. The background information sought from the companies include: headquarter, area of operation, legal form, age, construction activities, paid up capital, and number of employees. The background information of the respondents included questions on years of experience in the real estate sector and job title.

The second part of the questionnaire covered items on competitive priority, which consisted of four dimensions; quality, cost, flexibility and delivery. There are 34 items covered in the second part. The third part of the questionnaire comprised 14 items on competitive advantage. The competitive advantage items; level of competitiveness in terms of market share, profitability, financial return, technological provision, financial management, quality of products and services, after sales services, managers' educational background, customer loyalty, supplier loyalty, location of establishment, employees' commitment and loyalty, location of real estate, and competitive pricing. The fourth part of the questionnaire consisted of two items on the performance of the firms which were sales and assets for the past three years.

Both the competitive priority items and the competitive advantage items were measured on a scale from strongly disagree (1) to strongly agree (5). The respondents are expected to give their responses based on the scale ranging from strongly disagree (1) to strongly agree (5). The questionnaire was tested for its reliability. The coefficient alpha scores of the measures of competitive priorities and competitive advantage ranged from 0.717 to 0.867. The Cronbach's alpha scores recorded which were greater than 0.7 can be considered acceptable for social research, (Hair, et. al., 2003). The scores which were greater than 0.7 represented good reliability which suggested that the survey instruments were internally consistent in measuring the variables, competitive priorities and competitive advantage.

THE RESULTS

Background of the Real Estate Companies

Table 1 presents the information on the location of the companies, area of operations, their age and legal entity of the six firms that participated in this study. As shown in Table 2, the headquarters of the six real estate companies are located in Dubai. These companies also had operations in countries inside as well as outside the Middle East. As for the age of the company, one firm had been operating for less than ten years, three companies between 11 to 20 years, and the remaining two companies had been operating for more than 30 years. The companies are incorporated as public firms (5 companies) while one company is government owned.

Table 1. Location of companies, Area of operation, Firm age, and Legal entity

Characteristics of the Sample Firms	Frequency
Headquarter in Dubai	6
Area of operations of firm:	
Dubai	6
Other Middle East countries	6
Other countries outside Middle East	4
Age of firm (years):	
Less than 10 years	1
11-20 years	3
21-30 years	0
More than 30 years	2
Legal entity of the firm:	
Public limited	5
Government Owned	1

The information on the business activities of the real estate companies, their number of employees, and their paid-up capital are presented in Table 2. Among the business activities of the companies include; development of residential houses, shopping complex and hotels. All six companies are involved in the development of residential properties and hotels, while two of the companies are involved only in the development of shopping complex. In terms of the number of employees, two companies employed less than 1000 employees, another two companies employed between 1000 to 2000 employees and remaining two employed 4000-5000 employees, and more than 5000 employees. Two companies had paid-up capital of less than USD 500 million. Another two companies reported having paid-up of between USD 500 million and USD 1000 million. One company had paid-up capital of between USD 1,000 million and USD 1,500 million, and the remaining company had paid-up capital of more than USD 1,500 million.

Table 2. Business activities, number of employees, and paid-up capital

Business Activities:	Frequency
Residential houses	6
Shopping complex	2
Hotels	6
Others	6
Number of employees of the firm	
Less than 1000	2
1001-2000	2
2001-3000	-
3001-4000	-
4001-5000	1
More than 5000	1
Paid-up Capital	
Less than 500 Million	2
501 M-1000 Million	2
1001 M -1500 Million	1
More than 1500 Million	1

In terms of the number of employees, two companies employed less than 1000 employees, while another two companies employed 1000 -2000 employees. Two other companies each employed from 4001 to 5000 employees, and more than 5000 employees.

The paid-up capitals of the companies are recorded in the US Dollar. Two companies recorded paid-up capital less than USD 500 million and another two companies recorded paid-up capital between USD 500 million and USD 1000 million. One company with paid-up capital between USD 1000 million and USD 1500 million, while another company with paid-up capital of more than USD 1500 million.

The 30 respondents in the study include, company directors, vice- president, marketing manager, operation manager, and financial manager. The work experience of the respondents ranged from less than 10 years to more 20 years in the real estate business.

Mean and Standard Deviation Scores of Competitive Priorities

The competitive priorities consist of quality, cost, delivery, and flexibility. The mean and standard deviation (SD) scores of these four competitive priorities are presented in the following Tables 3 and 4. Table 3 indicates the mean and standard deviation scores of quality, cost and delivery. Following this, Table 4 presents the mean and standard deviation scores of flexibility. The mean score ranged from a low of 2.3333 for two of the quality dimension items, namely low defect rates and durability, to a high of high of 2.7000 for cost dimension item, reduce material cost. As for the flexibility dimension, the highest mean score recorded of 2.8333 for the item increase capacity and capability easily when needed and the lowest mean score of 2.4000 for item, varying total production volume economically.

Table 3. Mean and Standard Deviation (SD) Scores of Quality, Cost and Delivery

Quality	Mean	SD
1. Meeting customer requirement	2.5667	.72793
2. Conformance to specifications	2.5333	.50742
3. Reliability	2.3667	.66868
4. High performance	2.3667	.61495
5. Effective after-sales service	2.3667	.71840
6. Low defect rates	2.3333	.66089
7. Durability	2.3333	.54667
Cost		
1. Reduce materials cost	2.7000	.46609
2. Apply economy of scale	2.6667	.71116
3. Reduce the per unit real estate cost	2.5667	.62606
4. Reduce construction time	2.5000	.68229
5. Reduce stock costs	2.4667	.62881
6. Decrease labor cost	2.4667	.73030
Delivery		
1. Increase reliability of delivery	2.6333	.71840
2. Provide fast delivery	2.6333	.76489
3. Deliver customers' orders on time	2.5667	.62606
4. Introduce new product quickly	2.5667	.56832
5. Increase rate of delivery	2.5000	.90019
6. Shorten delivery time	2.4333	.56832

Table 4. Mean and Standard Deviation (SD) Scores of Flexibility

Flexibility	Mean	Std. Deviation
1. Increasing capacity and capability easily when needed	2.8333	.53067
2. Maintaining performance standards when producing a wide variety of products	2.8000	.76112
3. Detecting the changes in marketplace, customer demands, needs and competitors' activities and position	2.7667	.72793
4. The workforce can perform a broad range of Firm tasks economically and effectively	2.7333	.78492
5. Operating profitability at different production volumes	2.7333	.69149
6. Producing different combinations of products economically and effectively given certain capacity	2.7000	.59596
7. Changing the number of units easily	2.5667	.62606
8. Changing the quantities of products quickly	2.5667	.56832
9. Introducing new products ate quickly in a short time	2.5333	.62881
10. Facing unpredictable changes in real estate life cycle imposed by the market and competitors	2.5333	.68145
11. Building proactive strategies to deal with changes in the market	2.5000	.62972
12. Reacting quickly to competitor's actions	2.5000	.50855
13. Doing construction time quickly	2.4667	.62881
14. Different real estate products without major changeover	2.4333	.62606
15. Varying total production volume economically	2.4000	.49827

Mean and Standard Deviation Scores of Competitive Advantage

The competitive advantage variable consists of 14 indicators for the level of competitiveness. The mean and standard deviation scores of competitive advantage are presented in the following Table 5. The first three items with the highest mean score are employees' commitment and loyalty, competitive pricing and market share. The three items with the lowest mean score are employees' professional know how, quality of products-services, and location of real estate.

Table 5. Mean and Standard Deviation (SD) Scores of Competitive Advantage

Competitive Advantage	Mean	Std. Deviation
1. Employees' commitment and loyalty	2.8667	.68145
2. Competitive pricing	2.8333	.74664
3. Market share	2.8000	.84690
4. After sales services	2.8000	.71438
5. Customer loyalty	2.8000	.61026
6. Supplier loyalty	2.8000	.55086
7. Technological provision	2.7667	.67891
8. Financial management	2.7667	.56832
9. Location of establishment	2.7667	.56832

10. Profitability	2.7333	.69149
11. Firm's reputation	2.7333	.58329
12. Employees' professional know-how	2.6667	.60648
13. Quality of products -services	2.6333	.55605
14. Location of real estate	2.4667	.57135

The average mean, minimum, and maximum score for each of the competitive priorities dimension and competitive advantage are shown in the following Table 6. In descending order, starting with the dimension with the highest mean score to the lowest mean score, the ranking of the dimensions are; competitive advantage, flexibility, cost, delivery, and quality.

Table 6. Average Mean, Minimum, and Maximum Scores of Competitive Priorities and Competitive Advantage

Item	Minimum	Maximum	Mean
Competitive Advantage	2.29	3.43	2.7452
Flexibility	2.27	3.73	2.6044
Cost	1.83	3.67	2.5611
Delivery	1.67	3.67	2.5556
Quality	1.29	3.29	2.4095

Correlations between Competitive Priorities and Competitive Advantage

The competitive priority variable comprise four dimensions; quality, cost, delivery, and flexibility while the competitive advantage variable consists of 14 items. Statistically significant relationships are noted for the correlation between quality, cost, and delivery dimensions and competitive advantage. The statistically significant correlations between the three dimensions of competitive priorities (quality, cost, and delivery) and competitive advantage variable are presented in Tables 7, 8 and 9.

Table 7 shows the correlation between the quality dimension and competitive advantage items. The quality item High performance recorded significant correlation with the competitive advantage item, Technological provision at the .05 level

Table 7. Correlation between Competitive Priority (Quality) and Competitive Advantage

Quality	Competitive Advantage	R	Sig. level
High performance	Technological provision	.377(*)	.05

The correlations between the cost dimension and competitive advantage are shown in Table 8. As shown there are ten significant correlations between the cost dimension and the competitive advantage items. The ten correlations are significant at the 0.05 and .01 levels.

Table 8. Correlations between Competitive Priorities (Cost) and Competitive Advantage

Cost	Competitive advantage	R	Sig. level
Reduce stock costs	Employees professional know how	.422(*)	0.05
Reduce the per unit real estate cost	Profitability	.361(*)	0.05
Reduce materials cost	After sales services	.435(*)	0.05
Reduce materials cost	Supplier loyalty	.430(*)	0.05
Decrease labour cost	Employees' commitment and loyalty	.476(**)	0.01
Decrease labour cost	Customer loyalty	.371(*)	0.05
Apply economy of scale	Profitability	.514(**)	0.01
Apply economy of scale	Financial management	.483(**)	0.01
Apply economy of scale	Employees' commitment and loyalty	.474(**)	0.01
Apply economy of scale	Competitive pricing	.411(*)	0.05

Table 9 shows the correlation between the delivery dimension and the competitive advantage variable. The correlation analysis between the delivery dimension and competitive advantage resulted in six significant relationships at the .001 and .005 levels.

Table 9. Correlation between Competitive Priority (Delivery) and Competitive Advantage

Delivery	Competitive advantage	R	Sig. level
Increase rate of delivery	Employees' commitment and loyalty	.506(**)	0.01
Increase rate of delivery	Firm's reputation	.394(*)	0.05
Provide fast delivery	Location of real estate	.484(**)	0.01
Introduce new product quickly	Competitive pricing	.474(**)	0.01
Introduce new product quickly	Profitability	.398(*)	0.05
Introduce new product quickly	Market share	.387(*)	0.05

In addition to the above results, it is noted that the correlation analysis that was carried out between the flexibility dimension and competitive advantage did not yield any significant result. Nevertheless the result is in the expected direction.

Correlations between Competitive Advantage and Performance

The correlations between competitive advantage and performance are shown in Table 10 and Table 11. Table 10 showed the correlation between three competitive advantage items; employees' professional know-how, firm's reputation and location of real estate, and the performance measure, sales growth. The correlation analysis between the three competitive advantage items and sales growth recorded significant relationships at the .02 and .08 level.

Table 10. Competitive Advantage and Performance (Sales Growth)

Competitive Advantage:	Performance	R	Sig. level
Employees' professional know-how.	Sales Growth	.422*	.020
Firm's reputation	Sales Growth	.413*	.023
Location of real estate	Sales Growth	.320	.084

The results of the correlation analysis between competitive advantage and the performance measure, assets growth and average assets are shown in Table 11. The results of the correlation analysis indicate significant relationships between the competitive advantage items, employees' professional know-how and firm's reputation, and assets growth at .01 and .02 level. The results of the correlation analysis also indicate significant relationships between the competitive advantage items; employees' commitment and loyalty, firm's reputation and location of real estate, and average assets at .04, .002, and .01 levels respectively.

Table 11. Competitive Advantage and Performance (Growth and Average Assets)

Competitive Advantage:	Performance	R	Sig. level
Firm's reputation	Average Assets	.551**	.002
Location of real estate	Average Assets	.461*	.010
Employees' professional know-how.	Assets Growth	.459*	.011
Firm's reputation	Assets Growth	.411*	.024
Employees' commitment and loyalty.	Average Assets	.381*	.038

DISCUSSION AND CONCLUSION

This study is an attempt to examine the relationships between competitive priorities, competitive advantage and performance among real estate firms in Dubai. First, the results of the study suggest that real estate firms in Dubai employed the competitive priorities in their operational strategy or sometimes known as tactical strategy. The competitive dimensions employed by the firms are quality, cost, delivery and flexibility. However, there are variations among the competitive priorities. More specifically, the results indicate that the management personnel of the real estate firms stressed more on the flexibility and this is followed by the emphasis on cost, delivery, and quality. The findings also add support to the earlier studies that cost, delivery, quality and flexibility are the basic dimensions of competitive priorities, (Krajewski and Ritzman, 1993; Reeves and Bednar, 1994; Upton, 1994; Li, 2002; Kumar and Kumar, 2004; Phusavat and Kanchana, 2007; Lee and Zhou, 2008).

Second, in line with the proposition advocated by strategic management authors such as (Wheelright, 1984; Helms, 1996; Conner, 2003; Kim and Oh, 2004; Ma, 2004; Kazan, et. al, 2006; Phusavat and Kanchana, 2007), the results of the study show that there is a relationship between competitive priorities and competitive advantage. In this study quality, cost, and delivery are associated with competitive advantage among the real estate firms. The statistically significant relationships between competitive priorities; quality, cost, and delivery, and competitive advantage further add support to the notion that there is a link between competitive priorities and competitive advantage.

Third, it had been widely discussed in the strategic management literature on the relationship between competitive advantage and performance, a firm with a stronger competitive advantage would enjoy greater performance. The results of this study indicate that a number of significant correlations between competitive advantage items and performance of the real estate firms. More specifically, competitive advantage items such as employees' professional know-how, firm's reputation and location of real estate are related to the performance measure growth sales. Further, competitive advantage items, employees' professional know-how, firm's reputation and employees' commitment and loyalty, firm's reputation and location of real estate are related to the performance measures assets growth and average assets respectively. The results of the correlation analysis suggest that there exist significant relationships between competitive advantage and performance. These findings are in line with conceptual and empirical studies, (Barney, 1986; Conner, 1991; Peteraf & Bergen, 2003; Mills et al., 2003; Wang & Lo, 2003; Neely, 2005; Falshaw et al., 2006; Newbert, 2008).

At the general level, the applications of competitive priorities are not limited to firms in the manufacturing sector only. Competitive priorities that emphasize flexibility, cost, delivery and quality are also practiced by real estate firms in Dubai. In addition, competitive priorities are closely related to competitive advantage. A firm that is able to properly orientate its competitive priorities can enhance its competitive position. Finally there is a link between competitive advantage and performance. Real estate firms that command strong competitive position may also enjoy greater performance.

REFERENCES

Adam, E.E. Jr and Swamidass, P.M. (1989) Assessing operations management from a strategic Perspective. Journal of Management, 15 (2):181-203.

Anderson, J.C., Cleveland, G. and Schroeder, R.G. (1989) Operations strategy: a literature review. *Journal of Operations Management*, 8 (2): 133-58.

Arend, R. J. (2003) Revisiting the logical and research considerations of competitive advantage. *Strategic Management Journal,* 24: 279–284.

Askar, M. and Mortagy, A.K. (2007) Assessing the relative importance of competitive priorities in Egyptian companies. *Advanced Management Journal,* 72 (3): 35-46.

Balasubramanian, A. (2010) Rebuilding Dubai: Post-bubble economic strategy. *Harvard International Review*, Winter: 10-11.

Barney, J.B. 1986 Strategic factor markets: expectations, luck, and business strategy. *Management Science* 32 (10): 1231-1241.

Barney, J.B. (1991) Firm resources and sustained competitive advantage. *Journal of Management* 17(1): 99-120.

Barney, J.B. (2001) Is the resource-based "view" a useful perspective for strategic management research? yes. *Academy of Management Review* 21(1): 41-56.

Barney, J. B. (2007). Gaining and sustaining competitive advantage. (3rd ed.). NJ: Pearson Education.

Bolden, R., Waterson, P, Warr, P., Clegg, C., and Wall, T. (1997) A new taxonomy of modern manufacturing practices. *International Journal of Operations & Production Management.* 17 (11): 112-1130.

Boyer, K.K. (1998) Longitudinal linkages between intended and realized operations strategies. *International Journal of Operations & Production Management*, (18) 4: 356-73.

Boyer, K.K. and Lewis, M.W. (2002) Competitive priorities: investigating the need for trade-offs in operations strategy. *Production and Operations Management*, 11(1): 9-12.

Buffa, E.S. (1984) Meeting the Competitive Challenge, Irwin, Homewood, IL.

Chi, T., Kilduff, P.P.D. & Gargeya, V.B. (2009) Alignment between business environment characteristics, competitive priorities, supply chain structures, and firm business performance. *International Journal of Productivity and Performance Management*, 58 (7): 645-669.

Connell, R.B. (2010) The attractiveness-competitiveness matrix: a methodology used to assist policy makers select priorities for industrial development initiatives. *International Journal of Business and Management*, 5 (7): 3-13.

Conner, K. R. (1991) A historical comparison of resource-based theory and five schools of thought within industrial organization economics: Do we have a new theory of the firm? *Journal of Management, 17*(1), 121–154.

Cox, T., Jr. (1989). Towards the measurement of manufacturing flexibility. *Production and Inventory Management.* 30 (1): 68-72. Danagyach, G.S. and Deshmukh, S.G. (2001) Manufacturing strategy: literature review and some issues. *International Journal of Production and Operations Management*, 21 (7):884-932.

Falshaw, J. R., Glaister, K. W., & Ekrem, T. (2006) Evidence on formal strategic planning and company performance. *Management Decision, 44*(1), 9–30.

Fine, C.H. and Hax, A.C. (1985) Manufacturing strategy: a methodology and an illustration. *Interfaces*, 15 (6): 28-46.

Hair, Jr., J.F., Babib, B., Money, A.H., & Samouel, P. (2003) Essentials of business research methods. United States: John Wiley & Sons, Inc.

Hayes, R.H. and Wheelwright, S.C. (1984) Restoring Our Competitive Edge, Wiley, New York, NY.

Helms, M. (1996) Perspectives on quality and productivity for competitive advantage, *The TQM Magazine*, 8 (3): 5-10

Kazan, H., Ozer, G., and Cetin, A. (2006) Insight from research: the effect of manufacturing strategies on financial performance. *Measuring Business Excellence*, 10: 14-26.

Kim, B.Y. and Oh, H. (2004) How do hotel firms obtain a competitive advantage? *International Journal of Contemporary Hospitality Management*, 16 (1): 65-71.

Krajewski, L.J. and Ritzman, L.P. (1993) Operations Management: Strategy and Analysis, 3rd ed., Addison-Wesley, Wokingham.

Kumar, K. and Kumar, U. (2004), A conceptual framework for the development of a service delivery strategy for industrial systems and products. *Journal of Business & Industrial Marketing*, 19 (5): 310-319.

Leong, G., Snyder, D. and Ward, P. (1990) Research in the process and content of manufacturing strategy. *Omega*, 18 (2): 109-22.

Laposa, S, (2007). Bridging Gaps, Building Portfolios. *Journal of Real Estate Portfolio Management*, 13 (2): 173-178.

Lee,C.Y. and Zhou, X. (2000) Quality management and manufacturing strategies in China. *International Journal of Quality and Reliability Management*, 17 (8): 876-898.

Liao, S. H., & Hu, T. C. (2007) Knowledge transfer and competitive advantage on environmental uncertainty: An empirical study of the Taiwan semiconductor industry. *Technovation*, 27: 402–411.

Lin, B. W. (2003) Technology transfer as technological learning: A source of competitive advantage for firms with limited R&D resources. *R&D Management, 33*(3): 327–341.

Lindholm, A. and Leväinen, K.I. (2006) A framework for identifying and measuring value added by corporate real estate. *Journal of Corporate Real Estate,* 8 (1): 38-46.

Ma, H. (1999) Anatomy of competitive advantage: A SELECT framework. *Management Decision, 37*(9): 709–718.

Mady, M.T. (2008) The impact of plant size and type of industry on manufacturing competitive priorities: an empirical investigation. *Competitiveness Review*, 18 (4): 351-66.

McLaurin, J.R. and Chinta, R. (2005) Congruence analysis for strategy options development: Dubai municipality experience. *Proceedings of the Academy of Strategic Management.* Las Vegas 4 (2): 19-23.

Mills, J., Platts, K., & Bourne, M. (2003) Competence and resource architectures. *International Journal of Operations & Production Management, 23*(9): 977– 994.

Murray, J.Y., Gao, G.Y. and Kotabe, M. (2011) Market orientation and performance of export ventures: the process through marketing capabilities and competitive advantages. *Academy of Marketing Science Journal*, 39 (2): 252-69.

Neely, A. (2005) The evolution of performance measurement research: Developments in the last decade and a research agenda for the next. *International Journal of Operations & Production Management, 25*(12): 1264–1277.

Newbert, S. L. (2008) Value, rareness, competitive advantage, and performance: A conceptual-level empirical investigation of the resource-based view of the firm. *Strategic Management Journal,* 29 (7): 745–768.

Noble, M.A. (1995) Manufacturing strategy: testing the cumulative model in a multiple country Context. *Decisions Sciences*, 26 (5): 693-721.

Park, A. and Glascock, J.L., (2010) Corporate real estate and sustainable competitive advantage. *Journal of Real Estate Literature*, 18 (1): 3 - 20.

Parsa, A., Keivani, R., Sim, L.L., Ong, S.E., and Younis, B. (2002) Emerging global cities: Comparison of Singapore and the cities of the United Arab Emirates. *Journal of Real Estate Portfolio Management,* 8, (4): 95-101.

Peteraf, M. A., & Bergen, M. E. (2003). Scanning dynamic competitive landscapes: A market-based and resource-based framework. *Strategic Management Journal, 24*: 1027-1041.

Powell, T. C. (2003 Strategy without ontology. *Strategic Management Journal, 24*: 285 291.

Phusavat, K. and Kanchana, R. (2008) Competitive priorities for service providers: perspectives from Thailand. *Industrial Management & Data S*ystems, 108 (1): 5-21.

Porter, M.E. (1980). Competitive Strategy. The Free Press: New York.

Porter, M. E. (1985). Competitive advantage. NY: Free Press.

Porter, M.E. 1998. The Competitive Advantage of Nation. Palgrave: New York.

Porter, M. E., & Kramer, M. R. (2006) Strategy and society: The link between competitive advantage and corporate social responsibility. *Harvard Business Review,* 79 - 92.

Prajogo, D.I. and McDermott, P. (2011) Examining competitive priorities and competitive advantage in service organisations using Importance-Performance Analysis matrix. *Managing Service Quality*, 21 (5): 465-483

Ray, G., Barney, J. B., & Muhanna, W. A. (2004) Capabilities, business processes, and competitive advantage: Choosing the dependent variable in empirical tests of the resource-based view. *Strategic Management Journal, 25*(1): 23-37.

Reeves, C. A. and Bednar, D. A. (1994) Defining quality: alternatives and implications. *Academy of Management Review*, 19 (3): 419-445.

Renaud, B. (2010) Dubai's real estate boom and bust of 2002 – 2008: Dynamics and policy responses. *Housing Finance International*, Summer: 6-17.

Roulac, S.E. (2001) Corporate Property Strategy is Integral to Corporate Business Strategy. *The Journal of Real Estate Research*, 22 (1/2): 130-152.

Roulac, S., Adair, A., McGreal, S., Berry, J., Brown, L. and Heaney, J., (2005) Corporate strategic decision making: A comparative analysis of companies in the industrial and non-industrial sectors. *Journal of Property Investment & Finance,* 23 (4): 364-378.

Sarmiento, R., Rowles, G. and Byrne, M. (2008) Strategic consensus on manufacturing competitive priorities: a new methodology and proposal for research. *Journal of Manufacturing Technology Management,* 19 (7): 830-843.

Schroeder, R. G., Bates, K. A., & Junttila, M. A. (2002) A resource-based view of manufacturing strategy and the relationship to manufacturing performance. *Strategic Management Journal, 23*(2): 105-117.

Singer, B.P., Bossink, B.A.G.,and Putte, H.J.M.V., (2007) Corporate real estate and competitive Strategy. *Journal of Corporate Real Estate*, 9 (1): 25 -39.

Skinner, W. (1969) Manufacturing - missing link in corporate strategy. *Harvard Business Review*, 47 (3): 136-45.

Skinner, W. (1974) The focused factory. *Harvard Business Review* 52 (3): 113-121.

Skinner, W. (1985) Manufacturing: The Formidable Competitive Weapon, Wiley, New York, NY.

Swamidass, P.M. and Newell, W.T. (1987) Manufacturing strategy, environmental uncertainty and performance: a path analytical model. *Management Science*, 33 (4): 509-24.

Swink, M. and Way, M.H. (1995) Manufacturing strategy: prepositions current research,renewed direction. *International Journal of Operations & Production Management*, 15 (7): 4-26.

Takala, J. (2002) Analyzing and synthesizing multi-focused manufacturing strategies by analytical hierarchy process. *Journal of Manufacturing Technology and Management*, 4 (5): 345-50.

Tarigan, R. (2005) An evaluation of the relationship between alignment of strategic priorities and manufacturing performance. *International Journal of Management*, 22 (4): 586-97.

Upton, D.M. (1994) The management of manufacturing flexibility. *California Management Review*, 36 (2): 72-89.

Vickery, S.K., Droge, C. and Markland, R.R. (1993) Production competence and business strategy: do they affect business performance. *Decision Sciences*, 24 (2): 435-56.

Wang, Y., & Lo, H. (2003) Customer-focused performance and the dynamic model for competence building and leveraging: A resource-based view. *Journal of Management Development, 22*(6) 483-526.

Ward, P.T., Duray, R., Leong, G.K. and Sum, C.C. (1995) Business environment, operations strategy, and performance: an empirical study of Singapore manufactures. *Journal of Operations Management*, 13: 99-115.

Ward, P.T., Deborah, J.B. and Leong, G.K. (1996) Configurations of manufacturing strategy, business strategy, environment and structure. *Journal of Management*, 22 (4): 597-626.

Ward, P.T., McCreery, J.K., Ritzman, L.P. and Sharma, D. (1998) Competitive priorities in operations management. *Decision Sciences*, 29 (4): 1035-46.

Zelenovich, D.M. (1982) Flexibility: A condition for effective production systems. *International Journal of Production Research*, 20 (3): 319-337.

Zhang, Q., Vonderembse, M., and Lim, J. (2002) Manufacturing flexibility: Defining and analyzing relationships among competence, capability, and customer satisfaction. *Journal of Operations Management*, 327:1-19.

Zhao, X., Hoi, J., Yeung, Y. and Zhou, Q. (2002) Competitive priorities of enterprises in Mainland China. *Total Quality Management*, 13 (3): 285-300.

ROOFING SHEETS SYSTEMS FOR INDUSTRIAL SHEDS IN CYCLONE PRONE AREAS BASED ON DYNAMIC TESTING

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Abstract
Roofing sheets of industrial sheds have been observed to fail in uplift under extreme wind conditions as in a cyclone. The ultimate loads from full scale static uplift load tests on asbestos cement and galvanized iron corrugated roofing sheet systems with different connections for span/purlin spacing of 1.4 m used in India using gravity load method were used to arrive at suitable connections for different wind zones. Since suitable roofing systems are not available for AC single span (case 1) and for Asbestos Cement (AC) and Corrugated Galvanized Iron (CGI) single and double span (case 2), static tests were done reduced spans and suitable spans were identified. Fatigue is a major factor contributing to failure of roofing systems in the cyclone prone Eastern coastal zone. The roofing systems selected based on static tests were subjected to simulated dynamic tests which simulate low-high-low load cycles during a cyclone, ensuring that the frequency of load application does not coincide with natural frequency of roofing sheet system. If failure occurs, smaller spans are tested. For testing single and two span roofing sheets the two-point load systems and midspan load systems respectively were used. Based on the tests, suitable reduced spans are recommended for these zones. General guidelines to be followed while fixing AC and CGI roofing sheet systems are also given.

Keywords: *AC; CGI; Roofing Sheet; Cyclone Prone Areas; Dynamic Testing; Fatigue Loading Spectrum*

INTRODUCTION

Wind damage studies have shown that in addition to other factors fatigue is a major factor contributing to failure of roofing sheets and its connections. It has been established that connections of metal roofing could undergo fatigue failure during cyclone (Morgan and Beck, 1977). Morgan and Beck (1977) also showed experimentally that failure can occur at 15% of the ultimate static load over a significant number of load cycles.

LITERATURE REVIEW

Cyclones cause severe damage to low-rise buildings: namely houses, schools, industrial, commercial and farm buildings. Roof claddings suffer most, leading to accelerated damage to the whole buildings and its contents. The Andhra cyclone (May 1990) caused extensive damage to industrial buildings in and around Vijayawada in India. Somayaji and Kalyanaraman (1990) have noted that AC roofing sheets were pulled off from the purlins, since they were connected to the purlins using simple J-bolts. They noted that while the structural system has withstood the cyclonic wind very well, the cladding has not performed well. They felt that proper evaluation of wind pressures at the eaves and ridges, and the development of proper design and detailing rules at these locations are necessary. Lakshmanan (1995) has noted that during the Kavali cyclone (1989), the J-bolts failed by opening out due to the fluctuating nature of wind pressures on the roof.

The different types of roofing materials used in industrial sheds and their connections are discussed by Narayanan and Mathews (2003). Detailed information on static uplift tests, ultimate loads, deflections, analysis of failure patterns, Effect of Reduced Number of Centre Support Bolts, Effect of Using Different Types of Purlins are reported by Narayanan and Mathews (1996; 2003) and Narayanan (1999). Figure 1 and Figure 2 show the standard way of stacking Asbestos Cement roofing sheet and CGI sheet respectively on the floor.

Figure 1. AC Roofing sheet stacked

Figure 2. CGI roofing sheet

IS 875 Part 3 1987 recommends the basic wind speed for the six wind zones in India. For cyclone prone Eastern coastal zone, a modified basic windspeed of 65 m/s has been recommended (Lakshmanan and Shanmughasundaram, 1996). The former constitutes the case 1 and later constitutes the case 2 (Table 1).

Areas on the roof of the industrial shed named as critical areas are locations of high suction like the edges, ridges and along the eaves whereas general/interior area are locations of low suction. Higher local pressure coefficients are prescribed for critical areas.

CGI and AC roofing sheet system with suitable connections for cyclone prone areas were determined on the basis of static design load condition using the results of static uplift tests. Roofing sheet systems for CGI roofing sheet and AC roofing sheet found suitable for different wind zones in case 1 is summarized in Table 2. The roofing systems found suitable for different wind zones in case 2 are summarized in Table 3. In Tables 2 and 3, the roofing sheet system is indicated by the thickness of the sheet used with the number of bolts per purlin within brackets.

For CGI sheets considering IS 875 Part 3 1987 suitable connections are available for a span of 1.4 m for wind zone 1 (for both single and double spans) and wind zone 2 (both single and double spans). However, if the modified basic wind speed (65 m/s) is used for wind zone 2, for a span of 1.4 m, no suitable CGI roofing sheet system is available for wind zone 2 (both single and double spans). Thus it is necessary to adopt a shorter span when these roofing sheets are to be used in wind zone 2.

Table 1. Basic wind speeds and Design wind speeds (m/s)

b	Basic wind speed (IS 875)	Modified basic wind speed (Lakshmanan and Shanmughasundaram, 1996	Design wind speed Case 1	Design wind speed Case 2
6	33	33	33	33
5	39	39	39	39
4	44	44	44	44
3	47	47	47	47
2	50	65	50	65
1	55	55	55	55

Table 2. Connections for CGI and AC roof sheet of span 1.4m for different wind zones – case 1

Wind zone	CGI roofing sheet		AC roofing sheet	
	Single span	Double span	Single span	Double span
1	0.6 (5,6)	0.6 (4, 5, 6)	-	-
2	0.6(3,4)	0.6 (3)	-	3 type B
3	0.6(3)	0.6 (3,4,5,6)	-	3 type B
4	0.5(3,4,5,6)	0.6 (3,4,5,6)	3 type B	4
5	0.4(6)	0.5(3,4,5,6)	4	4
6	0.4(3,4,5)	0.4(3,4,5,6)	3 type A	3 type A

Table 3. Connections for CGI and AC roof sheet of span 1.4m for different wind zones – case 2

Wind zone	CGI roofing sheet		AC roofing sheet	
	Single span	Double span	Single span	Double span
1	0.6 (3,4,5,6)	0.6(3,4,5,6)	-	-
2	-	-	-	-
3	0.6 (3,4,5,6)	0.6(3,4,5,6)	-	3 type B
4	0.5 (3,4,5,6)	0.6(3,4,5,6)	3 type B	4
5	0.5 (3,4,5,6) 0.4(6)	0.5 (3,4,5,6) 0.4(3,4,5,6)	0.6(3,4,5,6)	4
6	0.4(3,4,5,6)	0.4(3,4,5,6)	3 type A	3 type A

When the design wind speed of 50 m/s is used, for AC sheets spanning over 1.4 m, no suitable connection is available for zone 1 for both single and double span. No suitable single span AC roofing sheet systems are also available for zones 2 and 3. If the modified basic wind speed for wind zone 2 is used, no suitable roofing sheet system are available for both single and double span for zones 1 and 2. And even for zone 3 single span roofing sheet systems with suitable connections are not available for a span of 1.4 m. Thus it is necessary to go in for a reduced span for these cases.

Spans for AC Sheets in Zone 2

Results show the need for the use of reduced span for both AC and CGI sheets in zones 1 and 2. Table 4 shows the test results on AC roofing sheets with 3B connection of different spans (1.4m, 1.2m, 1.0m and 0.8m). The maximum permissible wind speeds corresponding to ultimate loads are shown in row 4. Comparing with IS 875 Part 3 1987 design wind speeds, suitable spans are identified for each wind zone. If IS 875 Part 3 Provisions are followed, a span of 1.2m is required for zone 1 and 2 for single span. If the modified basic wind speed is used for zone 2, a span of 1.0 m may be required for critical areas whereas for zone 1, span of 1.2 m will be sufficient.

Table 4. Ultimate load (N) and maximum permissible wind speeds for different spans for AC sheets with 3 bolts per purlin (type B) and wind zone in which the span length is safe

	Span of the roofing sheet (m)			
	1.4	**1.2**	**1.0**	**0.8**
Ultimate load (N)	6160	8766	10465	11998
Maximum permissible wind speed (m/s)	44.8	57.7	69.09	82.7
IS 875 part 3 1987	4	1	1	1
Modified basic wind speed used in zone 2	4	1	2	2

Reduced Spans for CGI Sheets in Zone 2

Table 5 shows the permissible load per square meter for 0.6mm CGI roofing sheet with span 1.4m, 1.2m and 1.0m and 5 bolts per purlin connection. The maximum permissible wind speed for each case is calculated assuming category 2 terrain and large openings in the building (column 3, Table 5).Comparing with Table 1, the wind zone in which a particular span of roofing sheet can be used is determined (column 4 and 5).

Table 5. Ultimate load (N) per m^2 for 0.6 mm CGI roofing sheet with 5 bolts per purlin connection for different spans and suitable wind zone in which it could be used

Span (m)	Ultimate load (N/m^2)	Maximum permissible wind speed (m/s)	Case 1	Case 2
1.4	921	60.45	1	1
1.2	1254	70.53	1	2
1.0	1806	84.65	1	2

Thus the roofing sheet system with connections suitable for cyclone prone areas were evaluated for general area of the roof as well as critical areas of the roof. The results are summarized in Table 6.

Table 6. Connections suitable for wind zone 2 for AC and CGI roofing sheet

Wind zone	Material	Thickness (mm)	Span	Span (m)	Number of bolts per purlin
General area of roof	CGI	0.6	Single	1.3	5
			Double	1.3	5
	AC	6.0	Single	1.4	3 type B
			Double	1.4	3 type B
Critical areas of the roof	CGI	0.6	Single	1.2	5
			Double	1.2	5
	AC	6.0	Single	1.0	3 type B
			Double	1.0	3 type B

The roofing sheet systems in zone 2 undergo fatigue failure during cyclone and hence have to be tested further under dynamic loads that simulate the low-high-low load cycles during a cyclone. Mahendran (1993, 1997) proposed a simplified fatigue loading sequence, applied as a low-high-low sequence (Table 7), developed at the culmination of more than two decades of research in Australia. Earlier researchers proposed fatigue loading sequences using different approaches which were of the same order like the Darwin Area Building Manual Test (DABM test) sequence, Melbourne loading sequence (Melbourne, 1977), Beck and Steven's sequence (Beck and Steven , 1979), TR 440 and modified TR 440 sequence. Mahendran (1993b) analyzed wind pressure traces on the roof of a model of industrial building for many wind directions obtained from wind tunnel tests using rainfall counting method to obtain fatigue load matrices for each hour of design cyclone. The Random block load test method with 64 blocks of loading was complicated and did not simulate the low high low nature of loading during cyclone. Considering the worst fatigue life curve from different roof cladding materials, the load sequence was simplified into few load ranges. The resulting Simplified Fatigue Loading spectrum is easy to apply and was applicable for any general configuration of the roof slope.

Table 7. Simplified Fatigue Loading Spectrum (Mahendran, 1993;1997)

Load Range	Cycles (c/s)
0 – 0.45Pu	9000
0 – 0.6Pu	1250
0 – 0.75Pu	130
0 – 0.90Pu	20
0 – 1.0 Pu	3

P_u is the ultimate design wind load

In the current research three samples for each category of roofing sheet system have been tested, hence a sample factor of 1.0 as per recommendations of AS/NZS 1170-2:2011 can be used.

Methods of Testing Roofing Sheet Systems

Different Systems and Choice for this Research

The method recommended by IS 5913-1970 is not suitable to test the capacity of roofing sheet in uplift but may be sufficient for quality control purposes. The method recommended in BS 5950 Part 6 1995 is adequate for static uplift tests and has been used in present work. The load can be applied either as a uniform load or as a line load. Uniform load can be applied using Vacuum Chamber method (ASTM E 1592-95), Airbag or gravity load method. Line loads are applied using timber or steel beams (rectangular to the span) with timber packing to simulate distributed loading. For dynamic testing the line load system is chosen due to ease of application. For testing single span roofing sheet, 4 point or 2 point load systems can used. The latter has been chosen. For testing 2-span roofing sheet, the methods available are 8-point load, 4-point load; midspan load and simulated central support methods are available. The midspan method was chosen. The midspan load system has been used by earlier researchers (Mahendran, 1990a; Xu and Reardon, 1992). The equivalent span of the model (Le) is so chosen that the ratio of support moment to the reaction is the same in the model and the prototype. The equivalent span in the model should satisfy the following condition.

$L_e = 0.733L_p$ where Lp is the span of the prototype.

Research Objectives

The objectives of the investigation are:

a) Determine the natural frequency of CGI and AC roofing sheet and compare with theoretical values.

b) Determine the fatigue wind loading spectrum for dynamic testing of roofing sheets used in cyclone prone areas.

c) Identify suitable roofing system for AC roofing and CGI roofing based on dynamic tests for cyclone prone Eastern coastal Zone of India.

METHODOLOGY AND EXPERIMENTAL SET UP

Determination of Natural Frequency of Roofing Sheet Systems

The natural frequency of the roofing sheet system is determined by noting its deflection under uniformly distributed load. The load deflection values have been obtained as reported in [1]. The average central deflection corresponding to a load equal to the self weight of the roofing sheet is determined. The natural frequency of the roofing sheet is determined using equation 1.:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{g}{\Delta}} \tag{1}$$

'g = acceleration due to gravity expressed in mm/s^2; Δ = principal deflection in mm

The experimental values of natural frequencies of the roofing sheet system are compared with theoretical evaluations for end conditions of fixed and simple supports. The natural frequency is determined to ensure that during dynamic testing the natural frequency does not coincide with the frequency of load application.

Dynamic Test Program

Suitability of Line Loads System for Dynamic Tests on Roofing Sheets Systems

The load deflection curves and the failure loads of roofing sheets for the line loading systems are determined and compared with the corresponding values for the uniform load case. The suitability of the line load system for simulating the same load effect as the uniform load case is assessed. Several tests were conducted to arrive at a suitable loading system.

Preliminary Dynamic Tests on AC Roofing Sheets Systems

The failure of metal roofing sheets due to fatigue during cyclones and from cyclic load tests has been established. Though AC sheets fail due to fluctuating during cyclones, the nature and load levels at which these occur has not been established experimentally. These tests were undertaken to verify whether fluctuating loads could cause failure of AC roofing sheet systems at lower load levels than the ultimate loads and to understand the nature of failure. The two-point loading system was adopted for these tests. The load on the roofing sheet was first increased to the design ultimate load and then slowly released. This was repeated until the failure of sheet occurred. The test was repeated with different maximum loads.

Dynamic Testing of Roofing Sheet Systems using Simulated Cyclonic Wind Loads

Starting with the span found suitable under static loading, the span is progressively reduced till the roofing sheet system does not fail under fatigue loading (when a particular roofing sheet system passes three consecutive tests). Tests were done to identify suitable roofing sheet systems for both critical (along the ridges, eaves and gable ends) and the interior areas on the roof. The test program is summarized in Table 8.

Table 8. Test programme for dynamic testing of roofing sheets

Location on the roof	Different roofing systems planned for testing		
	Roofing sheet	Single span (m)	Double span (m)
Critical area of the roof	AC	1.0, 0.8	1.0, 0.8, 0.7
	CGI	1.2, 1.0, 0.8	1.2, 1.0, 0.8, 0.7
General / Interior area of the roof	AC	1.4, 1.2	1.4, 1.2
	CGI	1.3, 1.1	1.3, 1.1

Test Set Up for Dynamic Tests on Roofing Sheets

The test set up for the dynamic test is the same as that for the static test. The roofing sheet is supported on purlins, and loaded simulating uplift loading. Rubber pads cut to the shape of the corrugation is placed correctly at the position. Wooden beams are placed above the pads, to keep them rigid. The wooden beam is centred and leveled accurately. Rigid packing is placed between the wooden beam and the loading jack so that the set up is not disturbed during the test. The dynamic load is applied at a frequency of 2 to 3.5 Hz. This frequency is adopted since roofing has been observed to vibrate at this frequency during cyclones (Morgan and Beck, 1977). The natural frequencies of the roofing sheet systems are much higher than frequency of the load application. The two point load system (shown in Figure 3) is adopted for testing the single span roofing sheet system since it has the same bending moment and shear force at mid span and support as in the uniform load case. The midspan load method (shown in Figure 4) is adopted for testing the two-span roofing sheet system since it has the same BM and SF at the middle support as in the uniform load case.

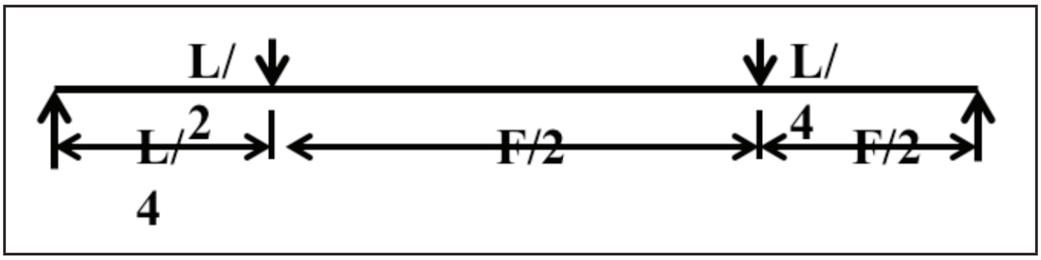

Figure 3. Two point Loading

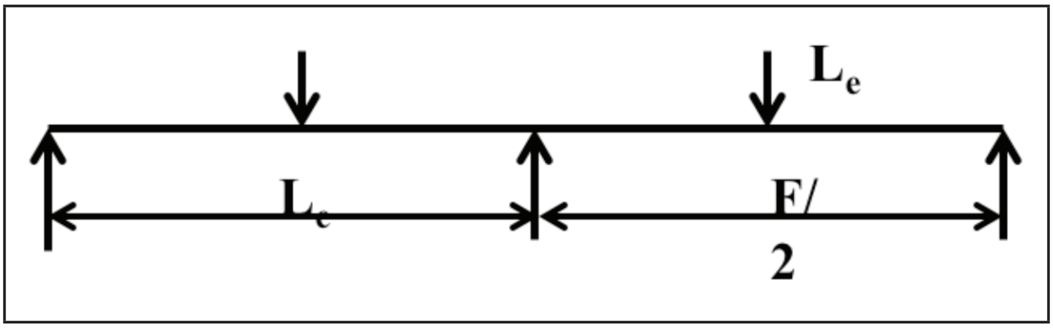

Figure 4. Midspan load method

The ultimate wind speeds used to determine the ultimate design wind load is given in Table 9. Using the ultimate design load, the loading spectrum to be applied on AC roofing sheet of 1m span located in critical area of the roof of the industrial shed is evaluated and shown in Table 10. Although the loading is indicated as low – high loading sequence, it should be applied as low-high-low load sequence as shown in Figure 5. The loading spectrum to be applied on AC roofing sheet of 1m span located in general area of the roof (Table 11), for CGI sheet in critical area (Table 12) and general area (Table 13) was similarly calculated.

Table 9. Ultimate wind speeds for Wind zone 2

	Basic wind speeds (m/s)	Ultimate Wind speeds (m/s)
IS 875 Part 3 1987	50	61.24
Modified basic wind speed	65	79.61

Table 10. Load spectrum to be applied on AC sheet of 1m span located in the critical area of the roof for a building in wind zone 2

Number of cycles	Load Range (N)		
	Range	Single span	Double span
9000	0 – 0.45Pu	0 – 4168.5	0 – 8337.0
1250	0 – 0.6 Pu	0 – 5557.9	0 – 11115.8
130	0 – 0.75 Pu	0 – 6947.5	0 – 13895.0
20	0 – 0.9 Pu	0 – 8336.9	0 – 16673.8
3	0 – 1.0 Pu	0 – 9263.0	0 – 18526.0

Table 11. Load spectrum to be applied on AC sheet of 1m span located in the interior area of the roof for a building in wind zone 2

Number of cycles	Load Range (N)		
	Range	Single span	Double span
9000	0 – 0.45 Pu	0 – 2858.0	0 – 5716.0
1250	0 – 0.6 Pu	0 – 3800.0	0 – 7620.0
130	0 – 0.75 Pu	0 – 4762.5	0 – 9525.0
20	0 – 0.9 Pu	0 – 5715.0	0 – 11430.0
3	0 – 1.0 Pu	0 – 6350.0	0 – 12700.0

Table 12. Load spectrum to be applied on CGI sheet of 1m span located in the critical area of the roof for a building in wind zone 2

Number of cycles	Load Range (N)		
	Range	Single span	Double span
9000	0 – 0.45 Pu	0 – 4313.0	0 – 8626.0
1250	0 – 0.6 Pu	0 – 5750	0 – 11500.0
130	0 – 0.75 Pu	0 – 7188	0 – 14376.0
20	0 – 0.9 Pu	0 – 8625	0 – 17250.0
3	0 – 1.0 Pu	0 – 9584	0 – 19168.0

Table 13. Load spectrum to be applied on CGI sheet of 1m span located in the interior area of the roof for a building in wind zone 2

Number of cycles	Load Range (N)		
	Range	Single span	Double span
9000	0 – 0.45 Pu	0 – 2162.0	0 – 4320.0
1250	0 – 0.6 Pu	0 – 2883.0	0 – 5766.5
130	0 – 0.75 Pu	0 – 3604.0	0 – 7208.1
20	0 – 0.9 Pu	0 – 3844.0	0 – 7688.7
3	0 – 1.0 Pu	0 – 4805.0	0 – 9610.9

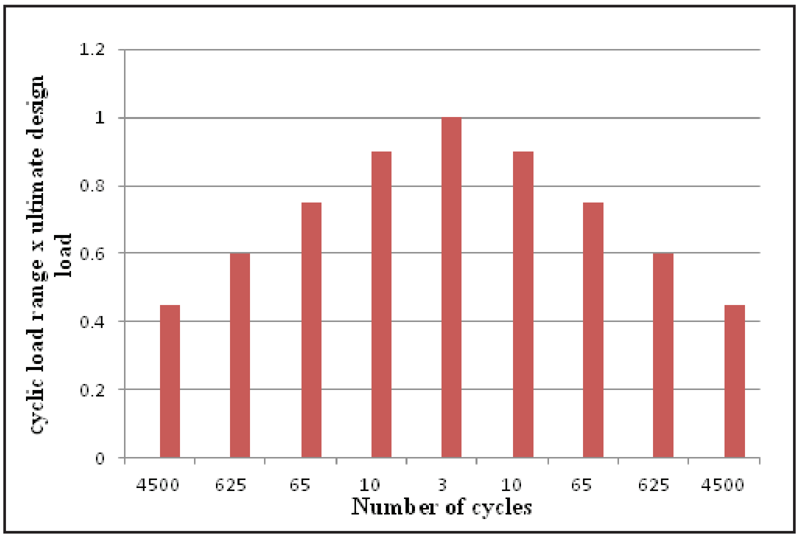

Figure 5. The simplified loading sequence applied as a low-high-low sequence

Calibration of Loading Jack

Before commencement of tests, the loading jack was calibrated. The loading jack was calibrated against a 10kN load cell for tests on single span roofing sheets, due to the lower loads required for causing failure in single span roofing sheet systems. The calibration curve for the 10kN load is shown in figure 6. The loading jack was calibrated against 20kN and 40kN load cells for use in testing two-span roofing sheets systems.

Test Procedure and Load Application

The roofing sheet system is carefully fixed and the load ranges and number of cycles to be applied in each range is determined (Tables 10-13). Using the calibration chart, the divisions' equivalent to the load range is marked in the control panel of the loading machine. The fatigue load sequence is applied as a low high low sequence. The behaviour of the setup is closely monitored so that any unstable condition is prevented.

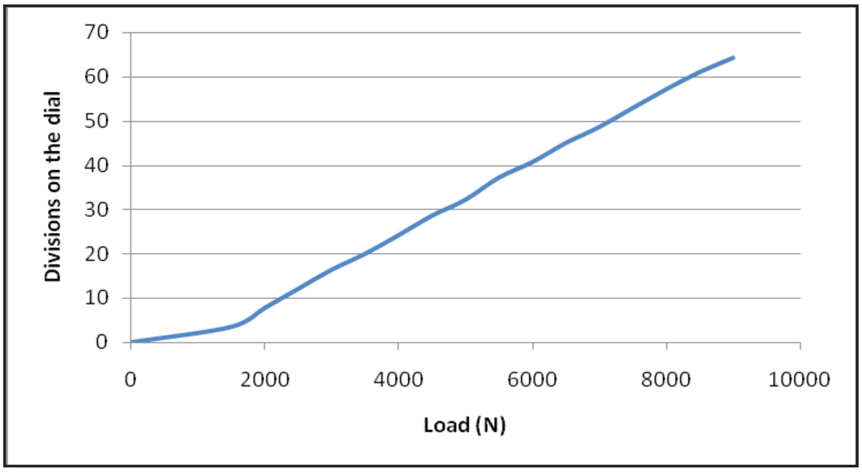

Figure 6. Calibration chart for the loading jack using 10kN load cell

RESULTS AND DISCUSSIONS

Natural Frequency of Vibration of Roofing Sheets

The values of natural frequency are tabulated for AC roofing sheet systems (Table 14) and the CGI roofing sheet systems (Table 15). For AC and CGI roofing sheet systems, the experimentally determined values of the natural frequency are less than the values of natural frequency for theoretical simply supported and fixed end conditions. The roofing sheet tested for wind uplift is supported on only a few numbers of bolts (depending on the type of connection used) and hence end fixity of the sheet is less than for the roofing sheet with the theoretical simply supported end condition. This explains the lower natural frequency of the roofing sheet systems under uplift loads.

Table 14. Comparison of experimentally determined natural frequencies of AC roofing sheet systems with theoretical values

Type of connection used		Natural frequency (c/s)
Number of bolts used for connection	2A	17.83
	2B	26.63
	3A	31.83
	3B	35.49
	4	38.48
Theoretical end condition	Simply supported	39.10
	Fixed	87.44

Table 15. Comparison of experimentally determined natural frequencies of CGI roofing sheet systems with theoretical values

Thickness of CGI sheet (mm)	Natural frequencies of roofing sheet systems determined experimentally (c/s)				Theoretical values (c/s)	
	Number of bolts used per connection				Simply supported ends	Fixed ends
	3	4	5	6		
0.4	11.46	13.87	18.50	21.07	21.9	50.2
0.5	18.85	18.98	21.91	22.19	23.46	52.46
0.6	20.0	21.6	22.37	23.60	24.68	55.21

Dynamic Tests on roofing sheets

Suitability of Line Loads System for Dynamic Tests

Tests were conducted on AC roofing sheets with 3B connection using uniform load and line loads. The failure load for uniform distributed loading using sand and bricks was 6426.8N and for the two-point loading was 6575.8N with a difference of only 6.07% (Table 16). Figure 7 indicates a difference of approximately 13% for deflection at 3920N between the uniform load and two-point load while the theoretical difference in deflection between the two cases is 10%. Thus the difference between the theory and experiment is very small. Thus the two point load system simulates very closely the uniform load system for the single span and can be adopted for the fatigue tests for the single span roofing systems. The two-point load system was also adopted due to the ease of load application in the laboratory.

For testing the double-span roofing system, the midspan load method was chosen due to ease of load application even though the four point load method gave closer failure loads (Table 16). The eight point load was not considered since it is too difficult for load application in dynamic tests.

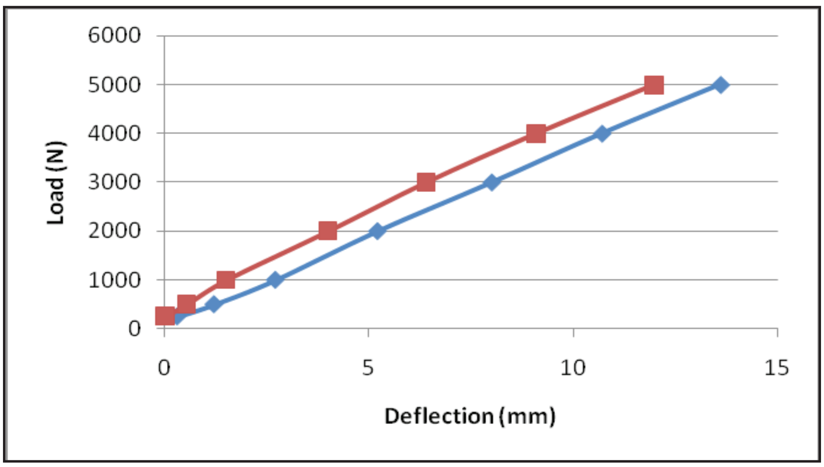

Figure 7. Comparison of Load deflection curves for single span sheet between uniform uplift load (♦) and two point loading (■)

Table 16. Failure loads for AC sheets with 3 bolts per purlin connection (type B) for UDL and line load systems

Span	Method of loading	Failure loads (N)
Single span	UDL	6426.8
	2 point load method	6575.8
	Four point load method	Not done
Double span	UDL	8378.0
	Midspan load method	8700.0
	Four point load method	8619.0
	8 point load system	Not done
	Simulated Central support test	Not done

Preliminary Tests on AC Roofing Sheets

Table 17 indicates the number of cycles to failure for different maximum loads. The results indicate that there is a reduction in the failure loads when repeated cycles of load are applied. It is also noted that cracks originate at points of concentrated loads or bolt connections and these cracks extend under repeated loads.

Table 17. Number of cycles to failure

Maximum load applied	Number of cycles to failure
Static Breaking Load Pu	1
0.95Pu	7
0.90Pu	78

Dynamic Tests Results

Table 18 shows the results of the dynamic tests. The span of the roofing sheet system chosen on the basis of static tests for cyclone prone East coast of India are shown in column 4. Table 18 also shows the span of the roofing sheet system found suitable based on the dynamic tests in column 5.

Table 18. Results of dynamic tests on AC and CGI roofing systems

Material	Location on the roof	Type of span	Span found suitable based on static uplift tests (m)	Span found suitable based on dynamic tests (m)
AC sheet	Critical area	Single	1.0	0.8
		Double	0.8	0.7
	Interior area	Single	1.4	1.2
		Double	1.4	1.2
CGI sheet	Critical area	Single	1.2	0.8
		Double	0.8	0.7
	Interior area	Single	1.3	1.1
		Double	1.3	1.1

AC Roofing Sheet

The AC roofing sheet systems for cyclone prone zone 2 selected based on static tests was found unsuitable when subjected to dynamic tests. They showed larger deflections than in the static load case. The failure started by formation of cracks at the bolt points, which spread along the corrugation leading to failure. The failures occurred with large sound and were brittle in nature. Roofing sheet system with 3B connection and 0.8m span was found suitable for single span. For two-span case, the failure occurred at the central support by cracking along the line of bolts.

CGI Roofing Sheet

In single span CGI sheet, buckling failures are observed at midspan. Yielding of the sheet at bolt points is also observed. In double span CGI roofing sheet failure occurs at middle support. In few cases, the bolts at the centre-support punched through the sheet at failure.

General Guidelines

Based on the observations made during the tests, some general guidelines to be followed while fixing AC and CGI roofing sheet systems are also recommended.

1. Over tightening of bolts while fixing: This produces cracks in AC sheet in the vicinity of the bolt and causes the failure to occur at low dynamic loads
2. Insufficient clearance for the bolt in the bolt hole results in formation of cracks on sheet due to rubbing action caused by cyclic motion during cyclones
3. Use of poor quality washers
4. All purlins should be in one plane
5. The holes for fixing AC sheet should be drilled not punched.

It was observed during the dynamic tests that in roofing sheet systems connected using J-bolts to angle purlins, no bolt failures by opening up of the hook were observed. Hence it is felt that angle purlins and corresponding J- bolts are better suited in cyclone prone areas compared to channel and pipe purlins and corresponding bolts. It is also observed that metal washers conforming to IS 8869-1978 performed well during the dynamic tests.

CONCLUSIONS

The results of dynamic upload tests on roofing sheets systems for cyclone prone Eastern coastal zone of India identified on basis of static upload tests were presented. The wind loading spectrum recommended by Mahendran (1997) were used for the dynamic load tests. The conclusions based on the study are given below.

1. The natural frequencies of AC roofing sheet ranged from 11 – 24 Hz whereas that of CGI roofing sheet ranged from 17 – 39 Hz.

2. The maximum allowable spans in cyclone prone zone for single span and double span AC and CGI sheets for both interior and critical areas of the roof have been determined on the basis of dynamic tests

3. General guidelines regarding choice of purlins, bolts, washers are provided based on the observations made during the dynamic tests.

REFERENCES

AS/NZS 1170.2 (2011) Minimum Design Loads on Structures Part 2 Wind Loads. Standards Australia.

ASTM E 1592 (1995) Standard Test Method for structural performance of sheet metal roof and siding system by uniform static air pressure difference.

Beck, V. R. and Stevens, L. K. (1979) Wind loading failures of corrugated roof cladding. *Civil Engineering Transactions*, Sydney, I.E. Australia, 21 (1), 45-56.

BS 5950 Part 6 (1995) Structural Use of Steelwork in Buildings: COP for the Design of light gauge profiled steel sheeting. British Standards, 44 – 49.

Eurocode 3 (2006) Design of Steel Structures Part 1.3 General Rules – Supplementary rules for Cold formed Members and sheeting.

IS 5913 (1970) Methods of test for AC products. Bureau of Indian Standards.

IS 875 Part 3 (1987) Design Loads on Buildings and Structures: Wind Loads. Bureau of Indian Standards.

Lakshmanan, N. (1995) Materials and methods of construction to resist the effects of cyclones. *Workshop on Engineering of structures for mitigating damage due to cyclones*, January 4-6, SERC CSIR Madras, p10.1- 10.32.

Lakshmanan, N. and Shanmughasundaram, J. (editors), 1996, Guidelines for design and construction of buildings and structures in cyclone prone areas, SERC, CSIR, Madras.

Mahendran, M. (1992a) Static behaviour of corrugated roofing under simulated wind loading, *Civil Engineering Transactions*, Canberra, Australia, 32(4), 212-218.

Mahendran, M. (1992b) Fatigue behaviour of corrugated roofing under cyclic wind loading, *Civil Engineering Transactions*, Canberra, Australia, 32(4), 219-226.

Mahendran, M. (1993) Pull through strength of screwed connections for crest fixed profiled Steel claddings, *Proceedings International Workshop on Cold formed Steel Structures*, Sydney, February.

Mahendran, M. (1997) Personnel Communication.

Melbourne, W. H. (1977) Loading Cycles for simulation of wind loaing, Proc. *Workshop on*

Guidelines for cyclone product testing and evaluation, Experimental Building Station, Australia.

Morgan, J. W. and Beck, V. R. (1977) Failure of Sheet Metal Roofing Under Repeated Wind Loading. *Civil Engineering Transactions.* Canberra. Australia, CE (19), 1-5.

Narayanan, S. and Mathews, M. S. (1996) Behaviour of Roofs of Industrial Structures to Cyclonic Wind Loads. *Proceedings of International Conference on Disasters and Mitigation,* January 19-22, pp B1.68-B1.73.

Narayanan, S. (1999) *Improving Cyclone Resistant Characteristics of Roof Cladding of Industrial Sheds*. PhD Thesis, Department of Civil Engineering, IIT Madras.

Narayanan, S. and Mathews, M.S. (2003) Behaviour of Roofing Sheet Systems under Static Uplift Loads, *IE (India)* – Civil , 84, 216 – 222, November.

Somayaji, S. and Kalyanaraman, V. (1990) Andhra cyclone of May 90: Damage to structures, *CE & CR*, November.

Xu, Y. L. and Reardon, G. F. (1992) Behaviour of different profiled roofing sheet subjected to Wind uplift, *Technical report no: 37*, James Cook Cyclone Structural Testing Station, Australia.

ROOFING SHEETS SYSTEMS FOR INDUSTRIAL SHEDS FOR DIFFERENT WIND ZONES BASED ON STATIC LOAD TESTING

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Abstract
Roofing sheets of industrial sheds have been observed to fail in uplift under extreme wind conditions as in a cyclone. This paper presents the results of static uplift load tests on asbestos cement and galvanized iron corrugated roofing sheet systems used in India using gravity load method. About 250 full-scale tests were carried out on roofing sheet systems with different connections for span/purlin spacing of 1.4 m. The ultimate loads obtained from the tests are used to evaluate the maximum permissible wind speeds. The values are compared with design wind speeds for critical and interior regions of the roof for different wind zones. The suitability of a particular roofing sheet system for a particular wind zone is then assessed. For Asbestos Cement roofing sheet system for both cases (as per IS 875 Part 3 1987 and modified basic wind speed for zone 2) no suitable connections are available for standard span of 1.4 for zone 1 (both single span and double span). For zone 2 and 3 no suitable connections are available for single span case. For Corrugated Galvanised Iron roofing sheet of 0.6 mm thickness and standard span of 1.4 m suitable connections are available for wind zones 1 and 2. No suitable connections are available if modified basic wind speeds are used for zone 2. Suitable shorter spans and connections have been identified for these cases through static load testing.

Keywords: *AC Roofing Sheet; CGI Roofing Sheet; Ultimate Load; Design Wind Speeds; Connections*

INTRODUCTION

The most common roof claddings used in industrial sheds are Asbestos Cement (AC) and Corrugated Galvanized Iron (CGI) roofing sheets. The post-disaster cyclone damage assessment of the Chennai cyclone (November, 1994) highlighted the damages suffered by the industrial sheds like (1) breaking of roofing sheets (limited to a few locations like ridges and eaves); (2) deformation of bolts that hold down the sheets; and (3) bolt shearing through roofing sheets (Narayanan and Mathews, 1996). The roofing sheet systems have performed well under normal conditions of load where dead load and live load are the deciding factors. However, their performance under cyclonic wind loads has been disastrous. The predominant failure mode under such conditions is uplift. Narayanan and Mathews (2003) has reported on the behaviour of roofing sheet systems under uplift loads. It is necessary to have guidelines on the suitability of a particular roofing sheet system for a particular wind zone. This has been undertaken in this research paper.

LITERATURE REVIEW

The different types of roofing materials used in industrial sheds and their connections are discussed here. Different static test methods recommended by codes of practice and reported in literature are also summarized.

Roof Cladding Materials and Roof Cladding Connections

Figure 1 shows a portion of the roof giving details of the connections of AC roofing sheets to the purlins as recommended by IS 3007-1964 , MDSS (1964) and CPWD (1967). At each end of the roofing sheet, two bolts have been used to connect the sheet to the purlin and this is called two bolts per purlin connection (2A). The detail of connection at A shows a half corrugation overlap of AC roofing sheet. The other connections recommended by various agencies are summarized in Figure 2. Roofing sheet with 4 bolts, 3 bolts (type A) and 2 bolts (type A) per purlin connection have only half corrugation overlap. The covered width of the sheet (effective width of sheet after considering the side overlap) is 1.01m. Roofing sheets these connections are suitable only in areas where heavy rains with driving winds do not occur. Roofing sheets with 3 bolts (type B) and 2 bolts (type B) per purlin connections have one and half corrugation overlap. The covered width is 0.876m. They are suitable for areas where heavy rains with driving winds occur.

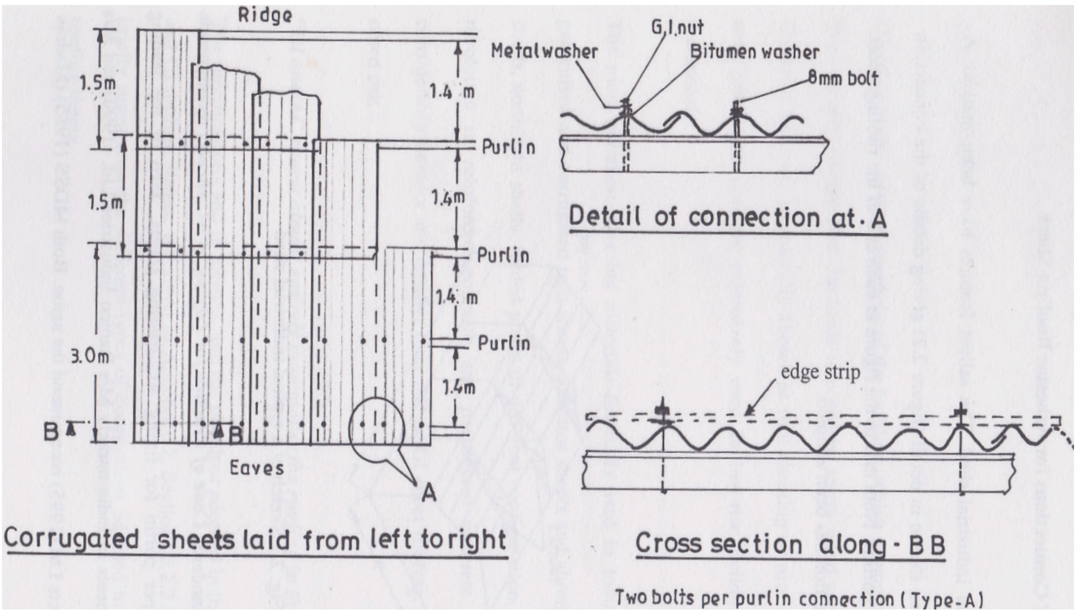


Figure 1. Details of connecting the AC roofing sheets to purlins (Narayanan and Mathews, 2003)

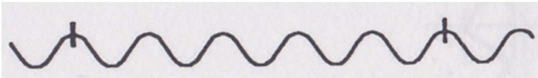
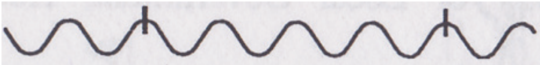
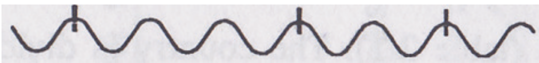
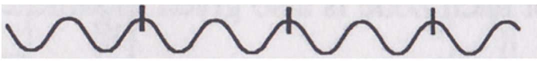
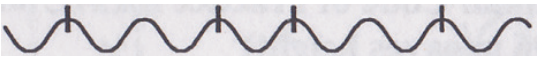
Configurations for fixing roofing sheet systems		No. of bolts per purlin
AC roofing sheet system		2A
		2B
		3A
		3B
		4
GI roofing sheet systems		3
		4
		5
		6

Figure 2. Connections used for fixing AC and CGI roofing sheets (Narayanan and Mathews, 2003)

Figure 3 shows the cross section of AC roofing sheet which has a pitch of 116 mm, overall width of 1.05 m, effective cover width of 1.01m, depth of corrugation of 48 mm and lengths of 1.5, 2.25, 2.5, 2.75 and 3.0m (IS 459, 1992 reaffirmed 1997). Figure 4 shows the cross section of CGI roofing sheet which has a pitch of 76 mm, effective cover width of 914 mm, depth of corrugation of 18 mm and length limited only by transportable size.

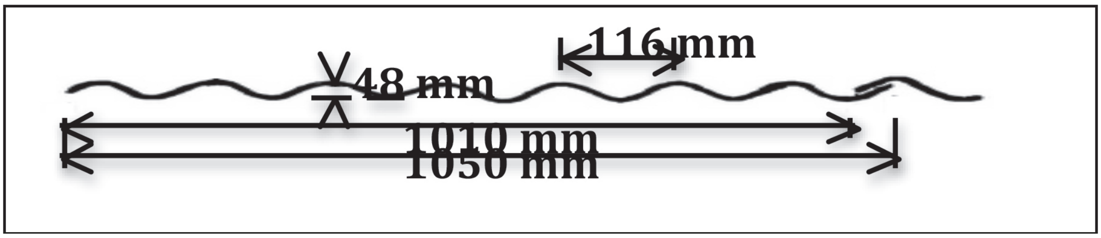


Figure 3. Cross section of AC roofing sheet (IS 459, 1992)

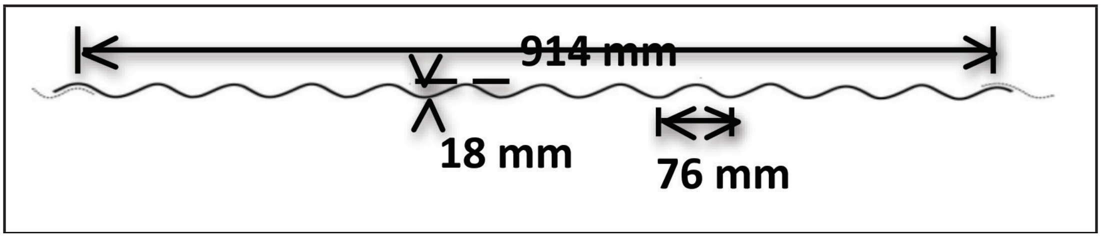


Figure 4.Cross section of CGI roofing sheet (914 mm cover width with single corrugation overlap)

There is no provision in the Indian Standards for connection of CGI roofing sheets. The recommendations for connections by various organizations and the standards of various countries are given in Figure 2 (AISC 325, 2011; MDSS, 1964; CPWD, 1967; British Steel Producers Conference, 2012; AS 1562 – 1992). The standard distance over which the AC and CGI roofing sheet is supported (the purlin to purlin distance) is 1.4 m. The pitch of the roof is normally 18^{o}. The roofing sheets are normally connected using J-bolts, conical metal washers and nuts, made watertight by the use of bituminous felt washers. While the standard thickness of AC sheets is 6 mm, the CGI sheets are available in different gauges, the commonly used thicknesses being 24 gauge, 26 gauge and 28 gauge (0.60 mm, 0.50 mm and 0.40 mm, respectively).

Different sizes of washers are available (Figure 5a and Table 1). While MW-1 to MW-5 are conical washers, MW-6 is a flat washer. Among the washers, MW-1 and MW-2 had thickness less than the minimum specified by IS 8869-1978, which is 0.9 mm while MW-3, MW-4 and MW-5, had thickness greater than the specified minimum. Washer type MW-3 has been used throughout the test programme. The flat washer had an average thickness of 1.5 mm while IS 8869-1978 specifies a thickness of 1.6 mm.

Table 1. Dimensions of metal washers

Type of washer	Notation used	Outer diameter (mm)	Inner diameter (mm)	Height (mm)	Thickness (mm)
Conical washer	MW-1	22.90	8.50	3.60	0.40
	MW-2	24.94	8.32	7.64	0.80
	MW-3	30.40	8.10	8.60	1.00
	MW-4	34.60	8.14	9.20	1.20
	MW-5	38.00	8.24	9.50	0.66
Flat washer	MW-6	26.00	8.38	-	1.50

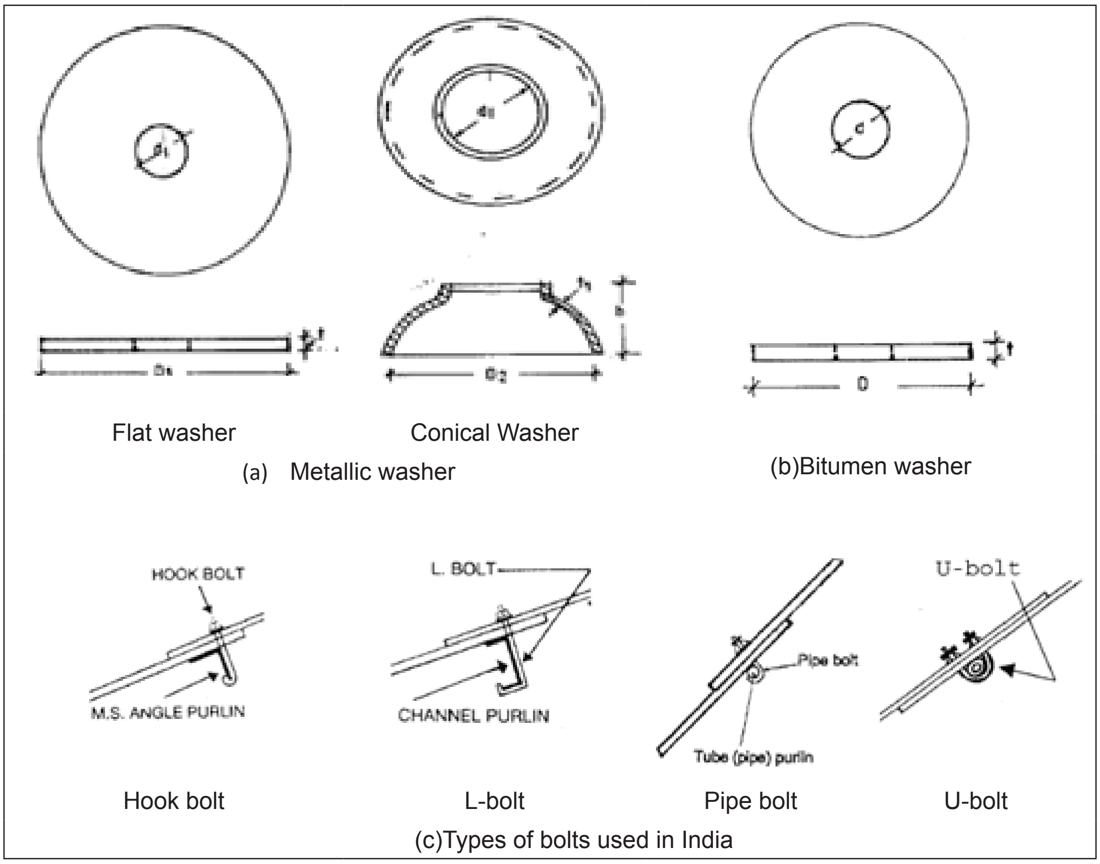


Figure 5. Accessories for Connections (Narayanan and Mathews, 2003)

Though different types of bolts (J or hook-bolts, L and U-bolts) are recommended for use by IS 730-1978, the U-bolt is not generally used (Figure 5c). They have also not been used in this research programme. IS 1367 Part 3 1979 specifies that the bolts shall be manufactured from low or medium carbon steels. The chemical composition of the material of the bolt was determined using vacuum emission spectrometry. The bolts satisfy the specifications. IS 3007-1964 specifies that the fixing bolts for AC sheets shall be 8 mm or more in diameter. The British Steel Producers Conference (2012) also recommends the use of 8 mm bolts for CGI sheet roofing. However, only 6.8 mm diameter bolts are available and these have been used in the tests. Narayanan and Seavhai (2013), Seavhai and Narayanan (2013a;2013b) have reported studies on suitability of metal roofing sheets in Malaysia based on wind code provisions and ultimate strength based on static tests available in producers technical brochures.

Performance of Roof Claddings during Cyclones

The performance of existing buildings when exposed to strong winds is the indicator of success or failure of design and construction practice. Low rise buildings suffered severely during high wind events due to the comparatively less engineering input into their design. The wind forces act on structural weaknesses. If the weakness can be eliminated, the damages will lessen (Connor et al, 1987). Damage to roofing has decreased significantly in Australia mainly due to the research and development work in Australia after cyclone Tracy (Mahendran, 1995). Sheet metal panels of 0.55mm and higher gauges performed well in bending when supported over a span of 1.5m or less. Performance of sheet metal panels thinner than 26 gauges was poor. Generally fasteners (No 14 hex head US sheet metal screws) were adequate. Failures occurred by tearing of sheet metal around the holes. The size of washers and thinner sheet metal can be linked to the primary causes of the tearing at the fasteners (Minor et al, 1972). The annual average cost of damage caused by cyclones in India is estimated at USD 0.05 billion which at times exceed 0.1 billion. Post disaster field surveys (Shanmughasundaram et al, 1996) after Kavali cyclone in 1989 have noted heavy damage of houses with pitched roof covered with AC or CGI sheet roofing. The failure was due to wind uplift, low dead weight of cladding, and due to poor strength of connections.

Research Objectives

The aspects studied during the investigation were:

a) The bending capacity of the roofing sheet system (ultimate capacity).

b) The maximum permissible wind speed corresponding to ultimate loads.

c) The design wind speeds based on basic wind speed for different wind zones.

d) Suitable connections for different wind zones for standard span of 1.4 m.

e) Where suitable connections for different wind zones for standard span of 1.4 m are not available, identification of reduced spans and connections.

METHODOLOGY

Static Uplift Tests on Roofing Sheet Systems

The provisions of IS: 5913-1970 is inadequate for testing roofing sheets in uplift. BS 5950 (Part 6)-1995, EC1993-1-3:1996 and CP 143 Part 10 contain provisions for uplift test on roofing sheets. Gravity loading may be used to simulate uplift load by inverting the sheet. In this method, the roofing assembly is set upside down on a test bed specially prepared for this work, with a provision of supporting three purlins at a spacing of 1.4 m (Figure 6).

Figure 6. Static uplift load tests on roofing sheets

The purlins are rigidly fixed to the supports. The troughs of the corrugated sheets are first filled uniformly with sand of known weight, and then loaded with layers of brick. This simulates uniform uplift loading which can be evaluated without any approximation. The deflections at the centre of the span have been measured with a specially fabricated deflectometer having an accuracy of 0.1 mm. Two types of the deflection measurements were made, namely central deflections and the transverse cross sectional deflections of the sheets at midspan and at supports. The tests have been carried out on AC and CGI roofing sheets for the connections given in Figure 2 and for different thicknesses of roofing sheets.

The failure criteria are taken as any one of the following:

i. Local failure and pull-through of the bolt.

ii. Failure by bending or dimpling of crests.

iii. Tearing of the sheet at the edges.

iv. Failure of bolts and washers.

More details on the deflections, analysis of failure patterns, Effect of Reduced Number of Centre Support Bolts, Effect of Using Different Types of Purlins are reported in Narayanan and Mathews (2003) and Narayanan (1999).

RESULTS, ANALYSIS AND DISCUSSION

Ultimate Loads

The uplift capacities determined from tests on AC and CGI roofing sheets of different thickness and types of connections for standard span of 1.4 m are given in Table 2. Each load value in the table is the average of three test results.

Table 2. Failure loads (N/m^2) for a purlin spacing of 1.4 m

Roof sheet	Thickness of sheet mm	Type of span	Different bolt connections for roofing						
			2A	2B	3A	3B	4	5	6
AC	6	Single	1816.0	2425.0	3462.5	5341.8	4838.0	*	*
		Double	1494.7	2110.0	3492.0	6878.0	5859.7	*	*
CGI	28 gauge (0.4 mm)	Single	*	*	3662.0	*	3931.0	4055.2	4745.0
		Double	*	*	4684.5	*	6119.0	5937.0	5565.0
	26 gauge (0.5mm)	Single	*	*	5480.5	*	5504.0	5588.7	5559.0
		Double	*	*	5633.1	*	5294.8	4509.3	4821.2
	24 gauge (0.63 mm)	Single	*	*	6716.5	*	7235.0	9210.0	ND
		Double	*	*	7165.7	*	8820.5	7696.4	7799.9

*Note * denotes that the test configuration is not applicable and ND denotes test not done*

Maximum Design Windspeeds for Critical Areas and Interior Areas on Roof

The maximum permissible wind speeds are calculated as follows:

Design load = Ultimate load/1.5 (1)

Design wind pressure = Design load /(area of sheet x pressure coefficient) (2)

Maximum permissible wind speed = √(Design wind pressure/0.6) (3)

IS 875 Part 3 1987 has given the external pressure coefficients for local effects to be used in areas of high suction as well as for interior areas of the roof. The maximum value of local coefficients is -2.0 for roof slope less than 10 degrees and h/w ratio (height to width ratio of the building) is ½. The calculations have been done for different permeabilities of the building. The value of internal pressure coefficient to be used for evaluating the wind loads on the roof for different permeabilities of the building are shown in Table 3. Tables 4 and 5 indicate the maximum permissible wind speeds for both AC and CGI roofing sheets of different bolt connections calculated as above.

Table 3. Internal air pressure coefficients

No	Condition	Internal pressure coefficients
1	Where cladding permits the flow of air with openings not more than 5% of the wall area but where there are no large openings	±0.2
2	Medium openings between 5 to 20%	±0.5
3	Large openings, larger than 20% of the wall area	±0.7
4	One side open	±0.8

Design Windspeeds

IS 875 Part 3 1987 provides the basic wind speeds for the six wind zones in India (column 2 of Table 6). Basic wind speed is the wind speed at 10 m height above the mean ground level, and is based on peak gust velocity averaged over a short time interval of about 3 seconds in an open terrain. They have been worked out for a 50 year return period. The design wind speeds is calculated based on equation 4.

$$V_z = k_1 k_2 k_3 V_b \tag{4}$$

Where k_1 is the risk coefficient (assumed as 1.0 for general buildings and structures), k_2 = terrain, height and structure size factor (here a class A structure for terrain category 2 has been assumed), and k_3 is the topography factor (assumed as 1.0).

Using the basic wind speeds in Table 6 and assuming the values of k_1, k_2 and k_3 as 1.0, the design wind speeds are calculated (column 3 and 4 of Table 6). Note that for zone 2, modified basic wind speed of 65 m/s has been recommended (Lakshmanan and Shanmughasundaram, 1996). This gives two cases; case 1 : design wind speeds based on IS 875 part 3 1987 provisions and case 2: design wind speeds based on the newly recommended modified basic wind speed of 65 m/s for wind zone 2.

SUITABLE ROOFING SHEET SYSTEMS FOR DIFFERENT WIND ZONES

The maximum permissible wind speeds calculated from ultimate loads in Tables 4 and 5 is compared with the design wind speeds for critical locations on the roof for different wind zones in Table 6 and the suitability of a particular roofing sheet system for a particular wind zone is decided. This is done for all cells in Tables 4 and 5. Tables 7 and 8 indicate the wind zone for which different roofing sheet system are suitable for different permeabilities of the structure (case 1), where the basic wind speed is taken as 50 m/s.

When the basic wind speed for zone 2 is taken as 65 m/s the corresponding design wind speed is indicated in column 4 of Table 6. The suitability of roofing sheet system with different connections for different wind zones, when design wind speed of 65 m/s is assumed is given in Tables 9 and 10.

Table 4. Maximum design wind speeds for critical areas of the roof based on static testing: Single span roofing sheet

Sheet Thickness (mm)		Permeability of building															
		Low permeability				Medium permeability				High permeability				Large opening			
		AC	CGI			AC	CGI			AC	CGI			AC	CGI		
		6	0.4	0.5	0.6	6	0.4	0.5	0.6	6	0.4	0.5	0.6	6	0.4	0.5	0.6
No of bolts per purlin	2	30.2	-	-	-	28.4	-	-	-	27.3	-	-	-	26.8	-	-	-
	3	41.8	43.0	52.6	58.2	39.2	40.3	49.3	54.6	37.7	38.8	47.5	52.6	37.1	38.1	46.6	51.6
	4	49.4	44.5	52.7	60.4	46.4	41.8	49.4	56.7	44.6	40.2	47.6	54.6	43.8	39.5	46.7	53.6
	5	34.9	45.3	53.0	68.2	32.8	42.4	49.8	63.9	31.6	40.8	47.9	61.6	31.0	40.1	47.1	60.4
	6	51.9	48.9	53.0	-	48.7	45.9	49.7	-	46.9	44.2	47.8	-	46.0	43.4	47.0	-

Table 5. Maximum design wind speeds for critical areas of the roof based on static testing: Double span roofing sheet

Sheet Thickness (mm)		Permeability of building															
		Low permeability				Medium permeability				High permeability				Large opening			
		AC	CGI			AC	CGI			AC	CGI			AC	CGI		
		6	0.4	0.5	0.6	6	0.4	0.5	0.6	6	0.4	0.5	0.6	6	0.4	0.5	0.6
No of bolts per purlin	2	27.4	-	-	-	25.7	-	-	-	24.8	-	-	-	24.3	-	-	-
	3	42.0	48.6	53.3	60.2	39.3	45.6	50.0	56.4	37.9	43.9	48.1	54.3	37.2	43.1	47.2	53.5
	4	54.4	55.6	51.7	66.7	51.0	52.1	48.5	62.6	49.1	50.2	46.7	60.2	48.2	49.3	45.8	59.1
	5	32.6	54.7	47.7	62.3	30.6	51.3	44.7	58.5	29.5	49.4	43.0	56.3	28.9	48.5	42.3	55.2
	6	58.9	53.0	49.3	62.7	55.3	49.7	46.3	58.9	53.2	47.9	44.5	56.6	52.2	47.0	43.7	55.6

Table 6. Basic wind speeds and Design wind speeds

Zone	Basic wind speed	Design wind speed - Case 1	Design wind speed - Case 2
6	33	33	33
5	39	39	39
4	44	44	44
3	47	47	47
2	50 & 65	50	65
1	55	55	55

Table 7. Wind zones in which each roofing system can be used – case 1 - Single span

		Permeability of the building																			
Roofing	**Thick (mm)**	**low**					**medium**					**high**					**large**				
		No of bolts					**No of bolts**					**No of bolts**					**No of bolts**				
AC		2A	2B	3A	3B	4	2A	2B	3A	3B	4	2A	2B	3A	3B	4	2A	2B	3A	3B	4
	6		6	5	2	3			5	3	4			6	4	4			6	4	5
		No of bolts					**No of bolts**					**No of bolts**					**No of bolts**				
		3	4	5	6		3	4	5	6		3	4	5	6		3	4	5	6	
G I	0.4	5	4	4	3		5	5	5	4		6	5	5	4		6	5	5	5	
	0.5	2	2	2	2		3	3	3	3		3	3	3	3		4	4	3	3	
	0.6	1	1	1	1		2	1	1	1		2	2	1	1		2	2	1	1	

Blank cell indicates that the connection is not suitable for any wind zone

Table 8. Wind zones in which each roofing system can be used – case 1 - Double span

		Permeability of the building																			
Roof sheet	**Thick (mm)**	**low**					**medium**					**high**					**large**				
AC		**No of bolts**					**No of bolts**					**No of bolts**					**No of bolts**				
		2A	2B	3A	3B	4	2A	2B	3A	3B	4	2A	2B	3A	3B	4	2A	2B	3A	3B	4
	6			5	1	2			5	1	2			6	2	3			6	2	3
G I		**No of bolts**					**No of bolts**					**No of bolts**					**No of bolts**				
		3	4	5	6		3	4	5	6		3	4	5	6		3	4	5	6	
	0.4	3	1	2	2		4	2	2	3		5	2	3	3		5	3	3	3	
	0.5	2	2	3	3		2	3	4	4		3	4	5	4		3	4	5	4	
	0.6	1	1	1	1		1	1	1	1		2	1	1	1		2	1	1	1	

Blank cell indicates that the connection is not suitable for any wind zone

Table 9. Wind zones in which each roofing system can be used – case 2 - Single span

		Permeability of the building																			
Roof sheet	**Thick(mm)**	**low**					**medium**					**high**					**large**				
AC		**No of bolts**					**No of bolts**					**No of bolts**					**No of bolts**				
		2A	2B	3A	3B	4	2A	2B	3A	3B	4	2A	2B	3A	3B	4	2A	2B	3A	3B	4
		6	6	5	3	3			5	3	4			6	4	4			6	4	5
G I		**No of bolts**					**No of bolts**					**No of bolts**					**No of bolts**				
		3	4	5	6		3	4	5	6		3	4	5	6		3	4	5	6	
	0.4	5	4	4	3		5	5	5	4		6	5	5	4		6	5	5	5	
	0.5	3	3	3	3		3	3	3	3		3	3	3	3		4	4	3	3	
	0.6	1	1	2	2		3	1	1	1		3	3	1	1		3	3	1	1	

Blank cell indicates that the connection is not suitable for any wind zone

Table 10. Wind zones in which each roofing system can be used – case 2 - Double span

		Permeability of the building																			
Roof sheet	**Thick(mm)**	**low**					**medium**					**high**					**large**				
		No of bolts					**No of bolts**					**No of bolts**					**No of bolts**				
AC		2A	2B	3A	3B	4	2A	2B	3A	3B	4	2A	2B	3A	3B	4	2A	2B	3A	3B	4
	6			5	1	3			5	1	3			6	3	3			6	3	3
		No of bolts					**No of bolts**					**No of bolts**					**No of bolts**				
		3	4	5	6		3	4	5	6		3	4	5	6		3	4	5	6	
G I	0.4	3	1	3	3		4	3	3	3		5	3	3	3		5	3	3	3	
	0.5	3	3	3	3		3	3	4	4		3	4	3	4		3	4	5	5	
	0.6	1	2	1	1		1	1	1	1		3	1	1	1		1	1	1	1	

Blank cell indicates that the connection is not suitable for any wind zone

Roofing sheet systems suitable for CGI roofing sheet and AC roofing sheet for different wind zones in case 1 is summarized in Table 11. The roofing systems suitable for different wind zones in case 2 are summarized in Table 12. In Tables 11 and 12, the roofing sheet system is indicated by the thickness of the sheet used with the number of bolts per purlin within brackets.

Table 11. Connections for CGI and AC roof sheet of span 1.4m for different wind zones – case 1

Wind zone	GI roofing sheet		AC roofing sheet	
	Single span	Double span	Single span	Double span
1	0.6 (5,6)	0.6 (4, 5, 6)	-	-
2	0.6(3,4)	0.6 (3)	-	3 type B
3	0.6(3)	0.6 (3,4,5,6)	-	3 type B
4	0.5(3,4,5,6)	0.6 (3,4,5,6)	3 type B	4
5	0.4(6)	0.5(3,4,5,6)	4	4
6	0.4(3,4,5)	0.4(3,4,5,6)	3 type A	3 type A

Table 12. Connections for CGI and AC roof sheet of span 1.4m for different wind zones – case 2

Wind zone	CGI roofing sheet		AC roofing sheet	
	Single span	Double span	Single span	Double span
1	0.6 (3,4,5,6)	0.6(3,4,5,6)	-	-
2	-	-	-	-
3	0.6 (3,4,5,6)	0.6(3,4,5,6)	-	3 type B
4	0.5 (3,4,5,6)	0.6(3,4,5,6)	3 type B	4
5	0.5 (3,4,5,6) 0.4(6)	0.5 (3,4,5,6) 0.4(3,4,5,6)	0.6(3,4,5,6)	4
6	0.4(3,4,5,6)	0.4(3,4,5,6)	3 type A	3 type A

CGI roofing sheet

From Table 11, it is seen that for wind zone 1 (55 m/s wind speed), single span 0.6 mm thick CGI roofing sheet spanning over 1.4 m with 5 bolts per purlin and 6 bolts per purlin connection are both suitable. For zone 2, roofing sheet systems with 3 or 4 bolts per purlin connection is found to be suitable. For two – span case 0.6 mm thick roofing sheet system with 4, 5 and 6 bolts per purlin connection is found suitable for zone 1 and roofing sheet with 3 bolts per purlin connection is suitable for zone 2.

Table 12 gives roofing sheet system with suitable connections if the modified basic wind speed is used for zone 2 (65m/s). It is seen that for both single and two span roofing systems for span of 1.4 m, no connection is suitable for zone 2. For zone 1, for both single and two span roofing 0.6 mm thick sheet with 3, 4, 5 or 6 bolts per purlin connection is suitable.

AC roofing sheet

Table 11 indicates the roofing sheet system with suitable connections for AC roofing sheet for a span of 1.4 m c/c for single and double span for the basic wind speeds indicated in IS 875 part 3 1987 for different wind zones. For zone 1 no roofing sheet system is found to be suitable for both single span and two span cases. For zone 2 and 3, for single span, no roofing sheet system is found to be suitable. For all other cases, roofing sheet systems with suitable connections are indicated in the table. Table 12 gives suitable connections for AC roofing systems if the modified basic wind speed is used for zone 2. It is seen that for zone 1 and 2 for both single and double span, no AC roofing sheet system is found suitable. For zone 3, single span case also, no connection is found to be suitable. For all other wind zones, the suitable connections are indicated in the table.

Thus for CGI sheets considering IS 875 Part 3 1987 suitable connections are available for a span of 1.4 m for wind zone 1 (for both single and double spans) and wind zone 2 (both single and double spans). However, if the modified basic wind speed (65 m/s) is used for wind zone 2, for a span of 1.4 m, no suitable GI roofing sheet system is available for wind zone 2 (both single and double spans). Thus it is necessary to adopt a shorter span when these roofing sheets are to be used in wind zone 2.

When the design wind speed of 50 m/s is used, for AC sheets spanning over 1.4 m, no suitable connection is available for zone 1 for both single and double span. No suitable single span AC roofing sheet system is also available for zones 2 and 3. If the modified basic wind speed for wind zone 2 is used, no suitable roofing sheet system are available for both single and double span for zones 1 and 2. And even for zone 3 single span roofing sheet systems with suitable connections are not available for a span of 1.4 m. Thus it is necessary to go in for a reduced span of roofing sheet for these cases.

SUITABILITY OF REDUCED SPANS FOR WIND ZONES 1 AND 2

Reduced spans for AC sheets in zone 2

Results show the need for the use of reduced span for both AC and CGI sheets in zones 1 and 2. Table 13 shows the test results on AC roofing sheets with 3B connection of different spans (1.4m, 1.2m, 1.0m and 0.8m). The maximum permissible wind speeds corresponding to ultimate loads are shown in row 4. Comparing with IS 875 Part 3 1987 design wind speeds, suitable spans are identified for each wind zone. If IS 875 Part 3 provisions are followed, a span of 1.2m maybe required for zone 1 and 2 for single span. If the modified basic wind speed is used for zone 2, a span of 1.0 m may be required for critical areas whereas for zone 1, span of 1.2 m will be sufficient.

Table 13. Ultimate load (N) and maximum permissible wind speeds for different spans for AC sheets with 3 bolts per purlin (type B) and wind zone in which the span length is safe

	Span of the roofing sheet (m)			
	1.4	**1.2**	**1.0**	**0.8**
Ultimate load (N)	6160	8766	10465	11998
Maximum permissible wind speed (m/s)	44.8	57.7	69.09	82.7
IS 875 Part 3 1987	4	1	1	1
Modified basic wind speed used in zone 2	4	1	2	2

Reduced spans for CGI sheets in zone 2

Table 14 shows the permissible load per square meter of 921 N/m^2 for 0.6mm CGI roofing sheet with span 1.4m and 5 bolts per purlin connection. The permissible load per square meter for 1.2m and 1.0 m span are calculated using

$$W_2 = W_1 \left(\frac{l_1}{l_2} \right)^2$$

Where W_1 is the known load per square m for span l_1 and W_2 is the calculated maximum permissible load per m^2 for span l_2.

The maximum permissible wind speed for each case is calculated assuming category2 terrain and large openings in the building (column 3, Table 14).Comparing with Table 6, the wind zone in which a particular span of roofing sheet can be used is determined (column 4 and 5).

Table 14. Ultimate load (N) per m^2 for 0.6 mm CGI roofing sheet with 5 bolts per purlin connection for different spans and suitable wind zone in which it could be used

Span (m)	Ultimate load (N/m^2)	Maximum permissible wind speed (m/s)	Case 1	Case 2
1.4	921	60.45	1	1
1.2	1254	70.53	1	2
1.0	1806	84.65	1	2

Further the roofing sheet system with connections suitable for cyclone prone areas (zone 2) were evaluated for general or interior area of the roof as well as critical areas of the roof (Table 15). It is seen that for general area, CGI sheets of 0.6mm with 5 bolts per purlin and 1.3 m span is required. For critical areas, a span of 1.2m is required. It is seen that for general area, AC sheets of 6mm with 3 type B connections, a span of 1.4 m span is sufficient. For critical areas, a span of 1.0m is required.

Table 15. Connections suitable for wind zone 2 for AC and CGI roofing sheet

<table>
<tr><th>Area on roof</th><th>Material</th><th>Thickness Mm</th><th>Span</th><th>Span</th><th>Number of bolts per purlin</th></tr>
<tr><td rowspan="4">General area of roof</td><td rowspan="2">CGI</td><td rowspan="2">0.6</td><td>Single</td><td>1.3</td><td>5</td></tr>
<tr><td>Double</td><td>1.3</td><td>5</td></tr>
<tr><td rowspan="2">AC</td><td rowspan="2">6.0</td><td>Single</td><td>1.4</td><td>3 type B</td></tr>
<tr><td>Double</td><td>1.4</td><td>3 type B</td></tr>
<tr><td rowspan="4">Critical areas of the roof</td><td rowspan="2">CGI</td><td rowspan="2">0.6</td><td>Single</td><td>1.2</td><td>5</td></tr>
<tr><td>Double</td><td>1.2</td><td>5</td></tr>
<tr><td rowspan="2">AC</td><td rowspan="2">6.0</td><td>Single</td><td>1.0</td><td>3 type B</td></tr>
<tr><td>Double</td><td>1.0</td><td>3 type B</td></tr>
</table>

CONCLUSIONS

The results of static upload tests on roofing sheets systems were presented and analysis of the same was used to identify suitable roofing sheets systems for different wind zones in India. The conclusions based on the study are given below.

1. Connections have been recommended for different wind zones considering that a reduction in the number of the connections per roofing sheet would mean a reduction in cost.
2. For AC roofing sheets, for both cases (as per IS 875 Part 3 1987 and for modified basic wind speed for zone 2), no suitable connections are available for zone 1(single span and double span). For zone 2 and 3 no suitable connections are available for single span case. For case -1 (wind speed as per IS 875 Part 3 1987), a span of 1.2 m is sufficient for zone 1 (single span and double span) and zone 2 (single span). Using modified provisions (case 2), A span of 1.0 m is needed for zone 2. For zone 1, a span of 1.2m is required.
3. Roofing sheet systems with suitable connections are available for CGI roofing sheet of 0.6mm thickness for span of 1.4m for wind zones 1 and 2. However if the modified basic wind speed of 65m/s is used for zone 2, it is necessary adopt a shorter span of 1.2m (for both single span and double span).
4. Roofing sheet systems are recommended for different wind zones based on analysis of results of static load tests. However, during a cyclone the roofing sheet systems are subjected to dynamic loads. Thus, dynamic properties of the roofing sheet systems and its performance under simulated cyclonic wind loads have to be studied.

REFERENCES

AISC 325 (2011) Manual of Steel Construction, American Institute of Steel Construction. 14th edition.

AS 1562 (1992) Design and Installation of Sheet Roof and Wall Claddings, Part 1: Metal. SAA Standards Australia, Sydney, Australia.

British Steel Producers Conference (2012) Steel Designers Manual. ELBS and Crosby Lockwood and Sons Ltd, London. 7th edition.

BS 5950 Part 6 (1995) Structural use of Steelwork in Buildings: COP for Design of Light Gauge Steel Sheeting, British Standards Institution.

Connor, H.W., Gromala D.S., Burgess D.W. (1987) Roof Connections in Houses: Key to Wind Resistance. *ASCE Journal of Structural Engineering*, 113,12, 2459-2473.

CP 143 Part 10 (1973) Code of Practice for Sheet Roofing and Wall Coverings: Galvanized Steel. British Standards Institution.

CPWD (1967) Central Public Works Department Specification. India.

Eurocode 3 (2006): Design of steel structures – Part 1-3: General – Cold formed thin gauge members and sheeting.

IS 459 (1992) Corrugated and Semi Corrugated Asbestos Cement Sheets – Specification,

Third Revision November 1998. Bureau of Indian Standards, New Delhi.
IS 1367 Part 3 (1979) Mechanical Properties and Test Methods for Bolts, Screws and Studs with Full Weldability. Bureau of Indian Standards, New Delhi.
IS 3007 (1964) Code of Practice for Laying of AC Sheets. Bureau of Indian Standards, New Delhi.
IS 5913 (1970) Methods of Test for AC Products. Bureau of Indian Standards, New Delhi.
IS 730 (1978) Specifications for Hook Bolts for Corrugated Sheet Roofing Bureau of Indian Standards, New Delhi.
IS 875 part 3 (1987) Code of Practice for Design Loads for Buildings and Structures: Wind Loads. Bureau of Indian Standards. New Delhi.
IS 8869 (1978) Specifications for Washers for Corrugated Sheet Roofing. Bureau of Indian Standards, New Delhi.
Lakshmanan, N. and Shanmughasundaram, J. (editors) (1996), *Guidelines for design and construction of buildings and structures in cyclone prone areas*, SERC, CSIR, Madras.
Mahendran, M. (1995) Wind Resistant Low Rise Buildings in the Tropics, *ASCE Journal of Performance of Constructed facilities*, November, 330-346.
MDSS (1985) Madras Detailed Standard Specification. India.
Minor, J. E., Mehta, K. C. and McDonald, J. R. (1972) Failures of Structures due to Extreme Winds, *Journal of Structural Division, ASCE*, November, 98, 11, 2455-2471.
Narayanan, S. and Mathews, M. S. (2003) Behaviour of Roofing Sheet Systems under Static Uplift Loads, Journal of *Institution of Engineers (IE) (India) – Civil*, 84, 216 – 222, November.
Narayanan, S. P., Seavhai, K. and Wee, T. (2013) Building Roofing Sheets Systems For Different Wind Zones In Malaysia. *2nd International Conference on Modeling & Simulation in Civil Engineering (ICMSC 2013),*TKM College of Engineering, Kollam, Kerala, India.
Narayanan, S. (1999) *Improving Cyclone Resistant Characteristics of Roof Cladding of Industrial Sheds*. PhD Thesis, Department of Civil Engineering, IIT Madras.
Narayanan, S. and Mathews, M. S. (1996) Behaviour of Roofs of Industrial Structures to Cyclonic Wind Loads. *Proceedings of International Conference on Disasters and Mitigation*, January 19-22, pp B1.68-B1.73.
Seavhai, K. and Narayanan, S. P. (2013a) Roof wind pressures for rectangular low rise buildings using MS1553, EC1-1-4, BS6399-2 and IS875-3. *CUSAT National Conference on Recent Advances in Structural Engineering RASE 2013*, December 13-15, 2013, Kochi, Kerala, India, Paper ID: 12.
Seavhai, K. and Narayanan, S. P. (2013b) Roof wind pressures for rectangular low rise buildings using MS1553, EC1-1-4, BS6399-2 and IS875-3. *American Journal of Engineering Research (AJER), Special issue, Recent Advances in Structural Engineering, RASE2013*, Volume 1, pp-32-42.
Shanmughasundaram, J. S., Arunachalam, S. and Apparao, T. V. S. R. (1996) Post Disaster Cyclone Damage Surveys and their impact on design of structures, *Proc. International Symposium on Experimental Determination of Wind Loads on Civil Engineering Structures*, Oxford and IBH Publishing Co.Pvt Ltd, Dec 5-7, New Delhi, 261-270.

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The Malaysian Construction Research Journal (MCRJ) is the journal dedicated to the documentation of R&D achievements and technological development relevant to the construction industry within Malaysia and elsewhere in the world. It is a collation of research papers and other academic publications produced by researchers, practitioners, industrialists, academicians, and all those involved in the construction industry. The papers cover a wide spectrum encompassing building technology, materials science, information technology, environment, quality, economics and many relevant disciplines that can contribute to the enhancement of knowledge in the construction field. The MCRJ aspire to become the premier communication media amongst knowledge professionals in the construction industry and shall hopefully, breach the knowledge gap currently prevalent between and amongst the knowledge producers and the construction practitioners.

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CODIFICATION AND APPLICATION OF SEMI-LOOF ELEMENTS FOR COMPLEX STRUCTURES

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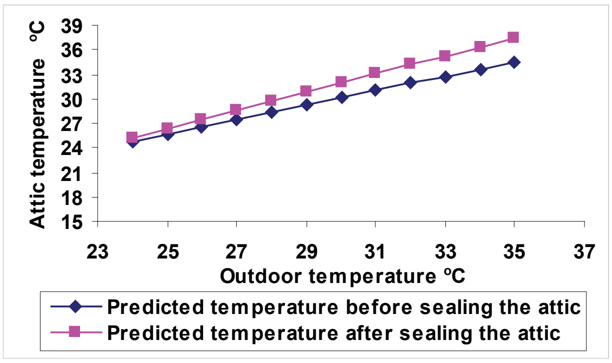

Figure 8. Computed attic temperature with sealed and ventilated attic

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Table 1. Recommended/Acceptable Physical water quality criteria

Parameter	Raw Water Quality	Drinking Water Quality
Total coliform (MPN/100ml)	500	0
Turbidity (NTU)	1000	5
Color (Hazen)	300	15
pH	5.5-9.0	6.5-9.0

(Source: Twort et al. 1985;MWA,1994)

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Journal

Sze, K. Y. (1994) Simple Semi-Loof Element for Analysing Folded-Plate Structures. *Journal of Engineering Mechanics*, 120(1):120-134.

Books

Skumatz, L. A. (1993) Variable Rate for Municipal Solid Waste: Implementation, Experience, Economics and Legislation. Los Angeles: Reason Foundation, 157 pp.

Thesis

Wong, A. H. H. (1993) *Susceptibility To Soft Rot Decay In Copper-Chrome-Arsenic Treated and Untreated Malaysian Hardwoods*. Ph.D. Thesis, University of Oxford. 341 pp.

Chapter in book

Johan, R. (1999) Fire Management Plan For The Peat Swamp Forest Reserve Of North Selangor and Pahang. In Chin T.Y. and Havmoller, P. (eds) *Sustainable Management of Peat Swamp Forests in Peninsular Malaysia* Vol II: Impacts. Kuala Lumpur: Forestry Department Malaysia, 81-147.

Proceedings

Siti Hawa, H., Yong, C. B. and Wan Hamidon W. B. (2004) Butt Joint In Dry Board As Crack Arrester. *Proceeding of 22nd Conference of ASEAN Federation of Engineering Organisation* (CAFEO 22). Myanmar, 55-64.

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