A Sustainable-Eco-Building Assessment Method

This research aims at investigating the present situation of residential buildings in Greater Khartoum, and to evaluate them using a sustainable assessment method. The problems of residential buildings that are to be investigated are environmental problems in the indoor and outdoor environment and services in Greater Khartoum. The methodology of the research starts by reviewing the principles of ecological design; the suitable passive solutions for hot-dry climates; the conditions of the case studies; the environmental assessment methods; previous methods adopted to evaluate the case studies; and the quantitative, the qualitative and sustainable assessment methods. The previous methods are not applicable to the case study conditions; hence, reflecting the identified eco building principles to the case study conditions, and then rationalizing a new method of assessment that evaluates the residential areas in the hot-dry climate of Greater Khartoum. The proposed assessment method contains eight categories, which are sustainable site, indoor environmental quality, outdoor thermal control, building form, materials and resources, water supply, drainage system and Env. design process

Assistant Professor Hind Abdel Moneim Khogali Osman, Ph.D., in Architecture Philosophy, Faculty of Architecture, UOFK, 2019 MSc. Environmental Studies, University of Khartoum /2006, BSc. Architectural Engineering/ Ain Shams University /1994. Work place: Dar Al Uloom University/Riyadh City/KSA.

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Abdel Moneim Khogali Osman

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DEDICATION

In His Holy Book, the Almighty Allah mentioned: **"And says (unto Act! Allah will behold your actions, and (so will) His messenger and the believers, and you will be brought back to the Knower of the Invisible and the Visible, and He will tell you what you used to do"** (Surat Al-Tawbah. 105); and He mentioned: "**And We have enjoined Upon man concerning his parents - His mother beareth him in weakness Upon weakness, and his weaning is in two years - give thanks unto Me and unto thy parents. Unto Me is the journeying**" (Surat Luqman, 14). This dissertation is dedicated to my beloved mother Mrs. Al-Sareerah Mohammad Ata-Almanan. I cannot find more eloquent words than Prophet Mohmmad's words Peace Be Upon him as he mentioned: "**Who is the most worthy of your company? He mentioned: Your mother. Then, he added: Your mother and added: Your mother, then, your father**". My dear father, Engineer Dr. Abdel Moneim Khogali, who worked and struggled until his name flew up in the sky of Sudan. His plant has produced delicious fruits literally speaking. I pray Almighty Allah to watch over him, protect him, and bestow upon him His blessings and bounties. It is a great honour and source of ultimate happiness to me to dedicate this effort and dissertation to my beloved parents, in recognition of their love and care. I also dedicate this effort and dissertation to my respectable beloved husband, Dr. Al-Fatih Mohi Al Dein. I cannot forget, and I appreciate your endless and relentless support and love. I also dedicate this work and dissertation to my beloved children: Muhammad, Momen, Mazin and Noon. This work should be a guiding light for you to follow on the path of knowledge and learning.

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Abstract

This research aims at investigating the present situation of residential buildings in Greater Khartoum, and to evaluate them using a sustainable assessment method. The problems of residential buildings that are to be investigated are environmental problems in the indoor and outdoor environment and services in Greater Khartoum. The methodology of the research starts by reviewing the principles of ecological design; the suitable passive solutions for hot-dry climates; the conditions of the case studies; the environmental assessment methods; previous methods adopted to evaluate the case studies; and the quantitative, the qualitative and sustainable assessment methods. The previous methods are not applicable to the case study conditions; hence, reflecting the identified eco building principles to the case study conditions, and then rationalizing a new method of assessment that evaluates the residential areas in the hot-dry climate of Greater Khartoum was the way forward. The proposed assessment method contains eight main categories, which are sustainable site, indoor environmental quality, outdoor thermal control, building form, materials and resources, water supply and drainage systems, power supply system and environmental design process.

The system has a scale -2,-1, 0, +1, +2 and a total points of 125 points, the research studied forty-eight cases in the residential areas in Greater Khartoum that were selected according to the certain criteria. The method has a scale of points for evaluation; main categories and sub issues contribute towards achieving points to get the result of evaluation for the building. The evaluation is range from excellent, very good, good and weak. The field work includes the criteria of selecting of the samples, method of documentation, method of analysis, and presenting the data in tables and figures, then the discussion conclusion and recommendations. The research outlines that zero of the case studies were excellent, 20.8% of the cases studies were good, 25% of the case studies were pass and 54% were weak. The analysis of buildings showed good results in sustainable site, outdoor thermal control and indoor environmental control; and weak results in building forms, materials and resources, drainage and water supply systems, power supply systems, and environmental process for first group. However, it showed weak results in all categories in the areas of the third group. The research proposed a sustainable evaluation method in order to evaluate the sustainable- eco-buildings in residential buildings in Greater Khartoum; and general conclusions for the areas of the study in the main categories are set in the conclusions and recommendations in urban, house, construction, services and community levels and global challenges for future research are set up to be applied in sustainable ecological buildings in Greater Khartoum.

المستخلص

يهدف هذا البحث إلى التحقيق في الوضع الراهن للمناطق السكنية في الخرطوم الكبرى ومن ثم تقييم هذه الحالة بمنهجية البحث المستدامة. مشاكل المباني السكنية التي سيتم التحقيق فيها هي مشاكل بيئية في البيئة الداخلية والخارجية والخدمات. في الخرطوم الكبرى.

بدأ البحث بمراجعة مبادئ التصميم البيئي والحلول غير المكلفة والمناسبة للمناخ الحار الجاف وشروط دارسه الحالة وطرق التقييم البيئي واستعراض ونقد الطرق ألسابقة لتقييم البيئة منها الكمية والوصفية والمستدامة، لا تنطبق الطرق السابقة على ظروف دراسة الحالة. ثم عكس مبادئ التصميم البيئي المستدام على طبيعة الحالات الدراسية ومن ثم تقديم طريقة جديدة لتقييم المناطق السكنية في الخرطوم الكبرى.

تم اعداد منهجيه لتقييم كفاءة المباني في المناخ الحار الجاف مثل مدينه الخرطوم الكبرى، وتتضمن المنهجية ثمانية محاور رئيسية هي: الموقع المستدام، جودة البيئة الداخلية، التحكم الحراري في البيئة الخارجية، وشكل البناء، ومواد البناء والموارد، وإمدادات المياه ونظام الصرف الصحي، ونظام إمدادات الطاقة، خطة التصميم البيئي. ويحتوي النظام على مقياس للتقييم يتراوح من 2-،1,0- ،1+ ،2+ مجموع النقاط الذي ينبغي أن تتحقق هو 125 نقطه في منهجية التقييم. درس البحث ثمان وأربعين حالة في المناطق السكنية في الخرطوم الكبرى وتم اختيارها تقييمها بناء على أسس محددة وهذا النظام يعطي أربع معايير للتقييم على النحو التالي: ممتاز وجيد جدا وجيد وضعيف. وتشمل المنهجية مقياس لتحديد مدى أهمية النقاط. شملت عمليه البحث الميداني تحديد معايير اختيار دراسة الحالة وأدوات التحقيق وتوثيقها وتحليل البيانات باستخدام طريقة تقييم البحث وتلخيص النتائج في الجداول ومنحنيات بيانيه. ثم المناقشة والتحليل، والملخص النتائج والتوصيات.

وكانت النتيجة في مجال المباني البيئية: لا يوجد حالة ممتاز، 20.8 ٪ من الحالات التي تمت دراستها سجلت جيدة، 25٪ من الحالات التي تمت دراستها سجلت مرور، 54 % من الحالات التي تم دراستها سجلت ضعيفة. أظهر تحليل المباني نتائج جيدة في الموقع المستدام، والتحكم الحراري في البيئة الخارجية والتحكم البيئي الداخلي؛ والنتائج الضعيفة في شكل المبنى ومواد البناء الموارد، وإمدادات المياه ونظام الصرف الصحي، ونظام إمدادات الطاقة وخطة التصميم البيئي للمجموعة الأولى. ومع ذلك، فقد أظهرت نتائج ضعيف في جميع الفئات في مناطق المجموعة الثالثة كما قدم مؤشرات عامه للمباني السكنية في مناطق الحالات الدراسية وفي الخرطوم الكبرى. كذلك أصدر البحث بعض الاستنتاجات والتوصيات المقترحة من أجل تطبيقها على مستوى المباني البيئية المستدامة والتصميم الحضري البيئي وتقنية البناء والتنفيذ والخدمات، والمجتمع في مدينة الخرطوم الكبرى ومثيلاتها ومقترحات للبحث العلمي. المستقبلي وايجاد تحديات عالمية للمباني البيئية في الخرطوم الكبرى.

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CHAPTER ONE
GENERAL INTRODUCTION

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GENERAL INTRODUCTION

1.1 INTRODUCTION

An increasing concern is evident amongst the scientists, professionals, and decision-makers as regards the integrated ecological buildings for sustainable construction. Particularly, the Brundtland report in 1987, defined the term *sustainable development* for the first time and correspondingly, strongly influenced the Earth Summit declaration (Agenda 21) in Rio de Janeiro in 1992 (Eliott, 1999). Specifically speaking sustainable development refers to an economic activity, which fulfils and addresses the needs of the present generation and additionally accounts for the possible needs of the future generations. Correspondingly, it is essential that the key stakeholders like decision makers, designers and builders consider the adverse environmental impact due to the use of various types of building materials such as cement, steel, and burned bricks. It has also been observed that the modern construction techniques contribute significantly towards deforestation, global warming, water overuse, and other environmental problems. Consequently, major attention is now being directed towards research on the adverse environmental impacts of using different building materials in construction. This also includes seeking ways of reducing such impacts. This is corroborated by previous research, as stated in the following paragraph from the "Sustainable Building Manual*"* (U.S.G.B.C., 1996).

> *"Since the Industrial Revolution, the world has witnessed incalculable technological achievements, population growth and corresponding increases in resource use as we enter a new century, we are recognizing the "side effects" of our activities: pollution, landfills at capacity, toxic waste, global warming, resource and ozone depletion, and deforestation. The built environment is one clear example of the impact of human activity on*

resources. Buildings have a significant impact on the environment, accounting for one-sixth of the world's freshwater withdrawals, one-quarter of its wood harvest, and two-fifths of its material and energy flows. Structures also impact areas beyond their immediate location, affecting the watersheds, air quality, and transportation patterns of communities." (U.S.G.B.C., 1996).

Thus, it is imperative that the building design achieves a balance in energy, water, construction material, and technology with context to the surrounding environment. Correspondingly, these concepts form an essential component in the eco-building construction to contribute towards solving the problem of global warming.

1.2 RESEARCH PROBLEM

With the progression of environmental awareness, research and practices on different areas of sustainability have spread globally, in all regions and locales. Moreover, the residential sectors have started to recognize the impact of their activities on the environment since the nineties. This presented the significant changes required to mitigate the environmental impacts of the building sector, which warranted a singular focus on the design, built and operation of buildings. One of the emerging challenges was public policy, and another was the growing market demand for environment-pro products and services, with the underpinning aim to reduce environmental impacts. Hence, this brings forward the need of yardstick to measure environmental performance.

Sustainable design has three main aspects: (i) environmental aspects, (ii) social aspects, and (iii) economic aspects. The residential buildings, particularly, in this regards demonstrate several challenges like;

- management of the indoor environment in lighting, ventilation, building orientation, as well as managing the outdoor environment in providing terraces, water features, and landscaping and services like water, energy

- Sidiq (1996), Ali (2010) and Elhaj (2012) stated that a perceived urgency to use modern construction techniques are estimated to have increased by eight times over a period of five years, and the imports of heavy construction equipment increased by 7% over the same period. Moreover, the local construction product sector has expanded, with more cement, concrete and steel/metal fabrication businesses established over the last 10 years. All this can have a considerable effect on the environmental impacts associated with the Sudanese construction sector. UN-HABITAT (2009) and Al Goni (2007) discussed the experiment of using interlocking stabilized soil block in Sudan, which are prepared through the United Nation's settlement programme. In Greater Khartoum, people use ecological building materials; they use concrete, burnt bricks, cement hollow blocks and thermal hollow blocks, through this research will going to search the percentage of using all these local material, the quality and problems facing.

- Lack of Services: Modern urban planners should follow certain procedures in planning and providing services, when allotting housing plots to the public.

Hamid (2010) presented a seminar about the incremental housing in Khartoum. A paradigm shift showed that the site and services started in post-colonial period (1956-1960) with the development of 98.7% of the 11,807 distributed plots, and ended in 2007 with the development of 34.3% of the 197,375 distributed plots. These figures clearly prove the poor availability or rather lack of services. Consequently. (UN-HABITAT, 2009) Highlighted basic urban services problems like high price for water and energy, increasing gap between rich and poor areas and lower quality service, in this research will search this issue in different urban classes in Greater Khartoum.

In order to gain a better insight into these issues in the study region, the current research will focus on:

1. Suitability or otherwise of global standards to local conditions,
2. Need for the development of a local assessment method,
3. Rationale/process of development of the new assessment method

1.3 RESEARCH OBJECTIVES

1.3.1 To study the literature review in Eco building principles and Environmental comfort principles.

1.3.2 To study the conditions of residential areas in Greater Khartoum

1.3.3 To assess the suitability of existing standards

1.3.4 To develop a local assessment method

1.3.5 To test the new assessment method

1.3.6 To document the situation of residential buildings in Greater Khartoum in indoor environment, outdoor environment and in services.

1.4 RESEARCH HYPOTHESIS

The region of Khartoum has been expanding by almost two folds every ten years. This expansion has, in fact, caused several problems in services, open spaces, and transportation. This has been particularly evident in the construction of medium-rise buildings. Though medium rise construction results in saving land for open spaces, greenery, landscaping, recreations and services, and decreases density it also increases land use. However, this construction has served to aggravate the problems of Greater Khartoum and caused further shortages of services, education, health, transportation, and security; and increased housing demand.

These problems can be solved by the adoption of ecological building solutions, which would meet the local environmental conditions of Greater Khartoum, and also the variety of necessities of the local population.

The corresponding hypothesis of the research is listed as follows:

1. Residential buildings in Greater Khartoum present serious environmental problems in indoor as well as outdoor environments in relation to thermal comfort.
   1.1 Services such as energy, water, and material demonstrate serious environmental problems.
2. Sustainable –eco- building principles and methods are not implemented in the construction of residential buildings in the Greater Khartoum region.

1.5 RESEARCH METHODOLOGY

An intensive study of the available assessment methods leads to the rationalization of a new evaluation method for evaluating the case study of the residential buildings in Greater Khartoum. The study methodology adopted in the current research consisted of several steps including the following:

1. The methodology started by reviewing previous literature in Environmental Sustainable Development (ESD) and the ecological design principles. Specifically, a review of the passive solutions suitable to the hot-dry climate of the case study was conducted. Architectural, spatial and infrastructural details were reviewed in the context of the historical background of the residential areas in Greater Khartoum and the challenges encountered by them. The methodology also entailed a general review of the environmental assessment methods; the physical quantitative assessment methods, the qualitative assessment methods and sustainable assessment methods. A rationalization of the assessment method has been adopted by this research to evaluate the residential buildings in Greater Khartoum, and reflect on the passive solutions ideal to the hot-dry climate in terms of the sustainable eco buildings' principles.
2. Conducting a comparative analysis of the five global standards in order to identify the main principles of sustainable design.
3. Developing the Sustainable-Eco-Building Assessment Method (SEBAM).

4. Application and testing of the proposed method, which was performed through an extensive fieldwork. Particularly, the fieldwork included the study sample survey and evaluation. The sample consisted of 48 residential units in different residential areas of Greater Khartoum. The data were collected, presented and demonstrated in tables and figures, and subsequently analysed by computer programmes.
5. Comparison between the developed method (SEBAM) and existing ones for validation purposes.

1.6 RESEARCH PLAN

The research plan is presented in the Figure (1.1), the research framework is composed of the following structural format

Chapter one: Introduction to the research problem, hypotheses, objectives, methodology and the research plan.

Chapter two: Literature review in sustainable eco building principles and introduction to Environmental Sustainable Development (ESD). Discussion on a general review of thermal comfort design reflecting the hot-dry climate and the passive solutions to control the design in tropical hot- dry climate. These solutions are divided into two main components: The urban element and the architecture element, physical components, outdoor environment and technological components. Further, the chapter presents a reflection on the passive solutions discussed in this chapter aligned with the identified principles of sustainable eco-buildings.

Chapter three: a Literature review of the conditions in Greater Khartoum in respect to the environmental, residential and technological aspects.

Chapter four: Literature review of the previous environmental assessment methods, qualitative, quantitative and sustainable assessment methods. Additionally, the chapter rationalizes and introduces a new method of assessment.

Chapter five: Identification of the research methodology by detailing the study method of assessment in the main categories and sub-issues. The chapter also provides a detailed discussion on the evaluation scale for the assessment method. Further, the chapter identifies the method of case study selection in different areas of Greater Khartoum. The chapter also contains an outline of the fieldwork methodology in data collection from each case study. In addition, it summarizes the method of documentation and presentation of data.

Chapter six: The chapter presents the results of the fieldwork in tables and figures. It documents the case study contents, plot numbers, block numbers, the name of the architects, name of the clients, name of the areas and locations

Chapter seven: The chapter analyses and discusses the results from the fieldwork for the eight areas of the study in Greater Khartoum, Khartoum, Khartoum North and Omdurman using the study method of assessment in eight main categories. The chapter subsequently discusses the average results for the all categories; and analyses the components of each category in order to infer general conclusions for Greater Khartoum for ecological designs.

Chapter eight: This chapter presents the summary of conclusions and recommendations, corresponding to the mentioned study conclusions and issues. A bibliography is provided at the end of the dissertation, and data forms are included in the appendices. Figure 1.1 shows the research plan.

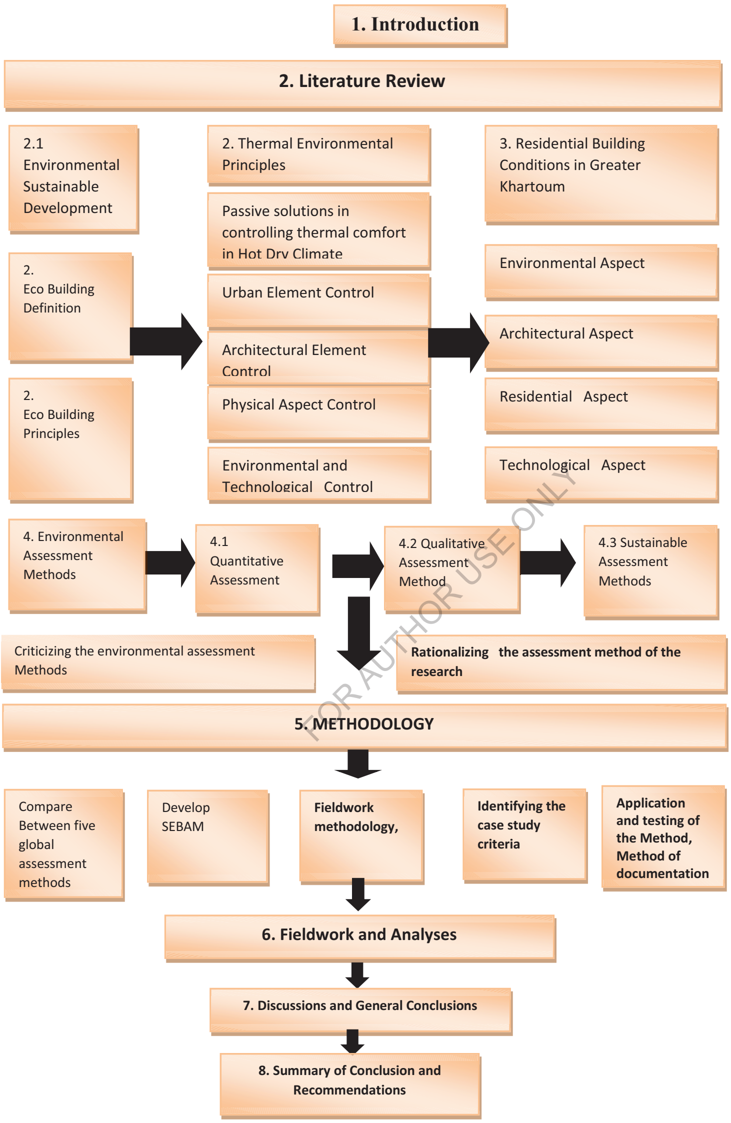

Figure 1.1: Diagram showing the research plan (Adapted by the researcher)

CHAPTER TWO

SUSTAINABLE- ECO- BUILDING AND ENVIRONMENTAL COMFORT PRINCIPLES

CHAPTER TWO
SUSTAINABLE- ECO- BUILDING AND ENVIRONMENTAL COMFORT PRINCIPLES

2.1 INTRODUCTION

The aim of this chapter is to define the sustainable-eco-building principles in the context of the environment and subsequently, identify and discuss the primary ecological design principles. The second part of the chapter discusses the passive solutions in controlling the urban architectural and environmental elements. Finally, the chapter offers a discussion of the suitable solutions for the hot-dry climate in the study area, to be applied to sustainable-eco-buildings and subsequently achieving environmental comfort.

Hassan Fathy conducted several works on the subject of sustainable design in the thirties and forties, and these efforts were later acknowledged in 1992. Since then an inclined trend was observed in the global community towards studying the relationship between building design and the surrounding environment. Specifically, a building should present a balance and congruency with the surrounding environment in terms of social, economic and environmental aspects to achieve the sustainability goals and comfort for a human being. (Ibrahim, 1987).

The main principles of sustainable design, as presented in Table 2.1, are considered as the minimum standard to be followed for sustainable design.

Table 2.1. The principles of eco-design from some books, these are "for example

The Leader in Energy and Environment (LEED)	Announced six main categories of sustainable design, which are the sustainable site, indoor environmental quality, energy, water, material,

	and innovation. Detailed (Appendix-11)
Royal Institute of British Architects' (RIBA, 2010).	Recommended land and ecology, community, health, materials, energy, and water as essential to sustainable design.
Kubba (2010) and Fower (2006)	*Discussed these issues in "The Leader in Energy and Environment "LEED Practices.*
Bromberek, (2009) discussed the principles of designing eco-resorts.	The principles of eco-resort meet with the principles of the eco neighborhood in site selection, landscaping, construction, energy management, water management, waste management and climatic performance.
Barrows, (2009) presented the complete idiots' guides to green building.	The guidelines for green buildings include constructions, planning phase, building materials, water, energy, lighting, roofs, floors, walls, windows, indoor air quality, outdoor, shades, green fencing, green lighting, green decking and green pool.
Sassi, (2006) and Van, (2009) published a book in 1996, the title of its second part is "The Ecological Design Process".	They discussed the principles of ecological design, which are: solutions grow from the place, ecological accounting informs design, design with nature, everyone is a designer, and make nature visible.
(Su, 2016) published a paper in IECC , International conference in Environmental and Climatic Change	Comparison of field measurement CFD simulation is implemented to recreate thermal conditions of two buildings in both seasons. To evaluate the field measurement results in natural ventilation effect at atrium, with the air velocity
(Alwetaishi, 2018) published a paper in IECC International conference in Environmental and Climatic Change.	The paper concentrated in the passive solutions and stated that its one way to ensure low building energy, the researcher applied Thermal Analysis Simulation (TAS) will be utilized which is powered by Environmental Design process.

(UN-HABITAT, 2016) report presented at the 3rd International Conference for housing and sustainable planning	The report covered most of the points of UN sustainable development goals about Sudan .
(Zuhal, November, 2018) published paper in International conference and the built environment in London	Zuhal discussed the low coast housing in Greater Khartoum, in New Deims, El Shabyia, Al Iskan Project, Elthora hara 72 and compare in size, area, design type , and house type
Khalil (2014) published PhD research in sustainable tools in Khartoum Projects.	Detailed in page 73

In this chapter, the research classifies these principles into three groups in order to reflect on sustainability in three dimensions. The first is the environmental dimension, which includes: sustainable site, energy, water, and materials. The second is the economic dimension, which appears in solutions such as energy efficiency, water efficiency, ecological building materials, grey water recycling, and construction materials recycling. The third is the social dimension, which appears in community participation and the outdoor environment management. The chapter introduces each principle and provides sustainable and technical solutions for each principle from a global perspective. It specifically restricts to the solutions applied in eco-building construction by Hassan Fathy since 1930-1940 as well as reflects on the Sudanese context.

2.2 SUSTAINABILITY AND THE DEFINITION OF ECO- BUILDING

An ecosystem is an enclosed system presenting the characteristics of sustainability, stability, and self-dependence. Drawing from this definition, we define the term of the ecological building as a new technology for building houses that can heat and cool themselves. The design, the orientation, and the materials of the buildings would achieve the heating or cooling, rather than a furnace, heat pump, or air-conditioner. The underlying principle of ecological construction is to be friendly with the environment by using local environmental building materials applied in conjunction with new technologies by using renewable natural resources such as solar energy, wind energy, eco-sanitation and re-use of water supply (Entria, 2014).

Specifically, eco-building concentrates on the passive solutions, which uses natural solutions in design without mechanical means, such as ventilation, building orientation, natural light, improve air movement, use of local building material and the use of natural resources in energy, water, and material. All of these issues will be discussed in this chapter. The meaning of eco-homes can be derived from the term 'eco', which finds its origin in the Greek root 'Oikos', meaning 'household'. The Greek root has two meanings: the sense of 'ecological' relationships between organisms in nature, and 'economics' relationships with the use of 'resources'. Additionally, the idea also pertains to the use of new knowledge, materials and renewable technologies in order to create buildings and refers to the new vernacular aimed at minimizing the adverse environmental impacts of the buildings (Hyde, 2008). Diverse environmental impacts can be measured through the use of new methodologies for counting the environmental costs of buildings, as shown in figure 2.1, and Figure 2.2 which present the main principles of eco-building.

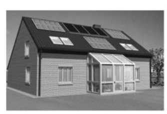

Figure 2.1: Computer image of the new Hungarian eco house development **(**Roaf, 2001)**.**

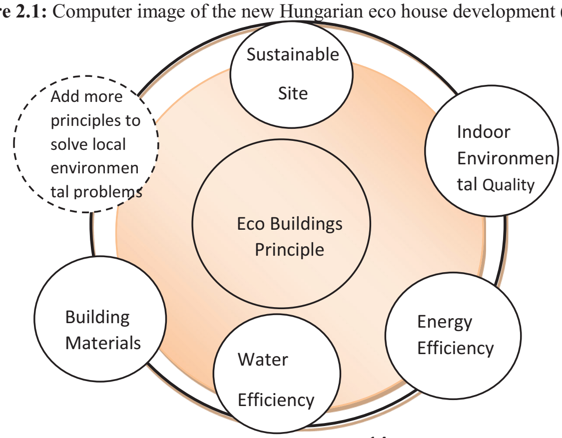

Figure 2.2: Diagrammatic presentation of the main principles of eco buildings, Adapted by researcher

2.3 ENVIRONMENTAL SUSTAINABLE DEVELOPMENT (ESD)

The first approach of environmentally sustainable development was introduced to the global community in the year 1992 at the United Nations conference on environment and development, the "Earth Summit", which took place in Rio de Janeiro, Brazil. The central aim of the conference was to identify the principle actions required towards "sustainable development" in the future. Also, subsequently Elliot (1999) and Abdel Ati (2001) discussed section seven of Agenda 21 on "promoting sustainable Human settlement development" which structures the following eight "Programme Areas":

1. *Providing adequate shelter for all*
2. *Improving human settlement management*
3. *Promoting sustainable land use, planning, and management*
4. *Promoting the integrated provision of environmental infrastructure: water, sanitation, drainage and solid –waste management*
5. *Promoting sustainable energy and transport system in human settlement.*
6. *Promoting human settlement planning and management in disaster-prone areas*
7. *Promoting sustainable construction industry activities and*
8. *Promoting human resources' development*

Therefore, the Environmental Sustainable Design (ESD) is defined as improving human settlement and promoting sustainable land and sustainable design.

2.3.1 Definition of Sustainable Development

According to Fox (2000) and Kubba (2010) the concept of sustainable development is underpinned with the principle to meet the needs of the present without compromising the ability of future generations to meet their own needs. In addition. Setting sustainable principles and methodology in buildings has emerged crucially in recent times. Leaders in Energy and Environment (LEED) and the Royal Institute of British Architects (RIBA), identify principles and categories such as; energy, materials, and resources, sustainable site, indoor environmental quality, water, innovation, and emissions.

2.3.2 The three dimensions of environmental sustainable design.

The three dimensions of environmental design including environmental, economic and social aspects are explained in Figure 2.3, which illustrates the relationship between the three dimensions of environmentally sustainable design.

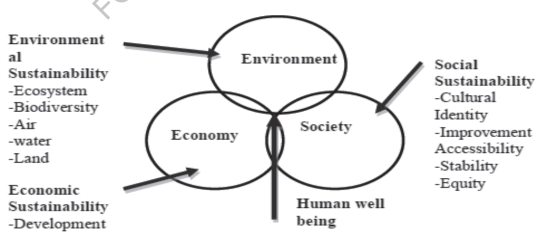

Figure 2.3: Depicts the relation between the three dimensions of environmentally sustainable design, source (Hongkong, 2016)

(i) Environmental dimensions of sustainability

- Reduced generation and emissions of waste and effluent to the environment.

- Reduced impact on human health.
- Use of renewable raw materials and the elimination of toxic substances.
- Reduced environmental impacts by buildings.

(ii) Social dimensions of sustainability

- Worker health and safety impacts on local communities, quality of life-benefits to disadvantaged groups e.g. disabled the beauty of the environment. (Hongkong, 2016).

(iii) Economic dimensions of sustainability

- Creation of new markets, opportunities for sales growth, cost reduction through efficiency improvement.
- Reduced energy, raw material inputs and the creation of additional benefits.

2.3.2.1 Benefits of green buildings

(i) Environmental benefits: Enhance and protect ecosystems and biodiversity, improve air and water quality, reduce solid waste and conserve natural resources.

(ii) Economic benefits: reduce operating costs, enhance asset value and profits, improve employee productivity and satisfaction, and optimize life-cycle economic performance.

(iii) Health and community benefits: improve air, thermal and acoustic environments; enhance occupant comfort and health; minimize strain on local infrastructure and contribute to the overall quality of life.

Figure 2.4 demonstrates the three main dimensions of sustainable design, i.e., the economic, the social and environmental dimensions. The following illustration presents the meaning of eco buildings and the main principles of sustainable design.

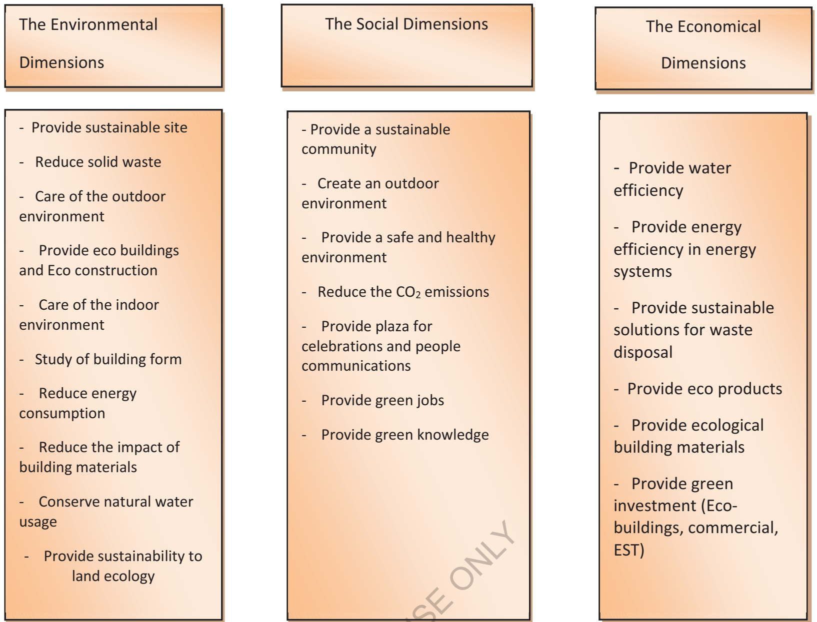

Figure 2.4: Diagrammatic presentation of sustainable design based on three main dimensions. **Source:** Adapted by the researcher.

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2.4 ECO BUILDING PRINCIPLES

LEED in 2011 announced the new construction U.S.G.B.C. (2009), which is also named as LEED V3 and contains six main categories, which are (i) sustainable site, (ii) indoor environmental quality, (iii) the energy, (iv) the water, (v) the material and (vi) innovation. See Appendix -1. Additionally, (U.S.G.B.C., 2019) published LEED V4, they added location and transportation, sustainable site, water efficiency, energy and atmosphere, materials and resources, indoor environment and innovations. Fox, 2000 mentioned that: '*Planners and designers should start by studying the ecology of the natural system. Outputs will also need to be inputed into the production system, with routine recycling of paper, metals,* *plastic, glass, and conversion of organic materials'*. In addition, the Royal Institute of British Architects (RIBA) (2010) considered a minimum set of issues as the key indicators for sustainable design and grouped them according to structural issues of land and ecology, community, health, materials, energy, and water. Presently, the new concepts of architectural design allow us to greatly improve the energy performance and additionally reduce the environmental impact of materials used in buildings.

2.4.1 Sustainable site

(i) Introduction

The sustainable site is one of the most important categories of eco-building, which includes smart location, enhanced controlling system for cars, improved outdoor environment, heat island effect, features controlling natural water, controlled noise from construction sites, alternative transportation axis, and ecological land-use complementation for buildings (Footprint).

(ii) The sustainable site belongs to the environmental aspect and provides sustainable solutions such as the use of isolated parking for cars, maximize outdoor areas for economic, ecological and health aspect to a human being, noise control, natural water features, control construction activities , and land ecology control. The main issue of the sustainable site is to have a positive impact on the environment.

(iii) The relation between the sustainable site and thermal comfort is through on-site landscape management and the provision of trees that can provide shade to buildings and can cool down the air temperature. In addition, water features can change the hot-dry temperature into the humid air.

2.4.2 The environmental impact of building materials

(i) Introduction

Sustainable design includes the informed selection of materials and products in order to reduce product cycle environmental impacts, improve performance, and optimize occupant health and comfort. Correspondingly, Roaf (2001) stated that the processing might be minimal, as in the case of a traditional cottage constructed from the materials locally available. However, in the case of prefabricated construction, the processing of materials inevitably require the use of energy and thus results in a waste generation.

(ii) The ecology of building materials

The second point we should consider is the use of the ecology of building materials available in the local environment. For example, the basic materials such as water, air, minerals, and stones; soil materials such as sand and brick; fossil fuel; plastic and recycling; plants and timbers; industrials by-products such as gypsum, fly ash and fibres; surface building materials such as bricks, earth blocks, mud bricks, gravel stones, earth covered roof, earth vaults, earth dooms, earth walls, earth resistance buildings and structural building materials. Additionally, similar issues were discussed by Berge (2001), Smith (2006) and Mink (2006).

(iii) The embodied energy

The fourth point that we should take into account is the accurate computation of the embodied energy of the building material.

(iv) Life Cycle Analysis (LCA)

This is an essential assessment in terms of the building construction and is defined as the *"Life cycle analysis is a way of assessing the total impact of any building and shows the importance of the building's lifespan. A simple way to think about this is to consider the initial embodied energy of an entire building and divide this figure over its lifetime, making an allowance for maintenance*" (Roaf, 2001).

(vi) Green products

Several ecological building materials and by-products are delivered to the markets every year. Correspondingly, it is essential that the architects study the materials' life cycle environmental impact or environmental building assessment method, that is quantified and the impacts have been weighted. This would contribute towards an easy assessment and identification of the specific, environmentally suited construction material for a site by the designer.

2.4.3 Water efficiency system

Water efficient systems belong to the environmental and economic aspects of ensuring a sustainable design. The followings list defines the sustainable solutions in this category:

(i) Applying standards such as the World Health Organization (WHO).

(ii) Availability of rainwater containers.

(iii) Reducing water usage in toilets, bathrooms and kitchens, high-performance dual flush toilets and low flow showerheads

(iv) Water-conserving in landscape and building design strategies.

(v) Using grey water in landscaping and other water features that cool down the air temperature around the house.

(vi) Using water in traditional solutions such as passive cooling towers and desert coolers suitable to the hot-dry climate such as Greater Khartoum.

2.4.4 Natural resources of the energy system

Sustainable design conserves energy, resources, and reduces the carbon footprint while improving the building performance. In addition, comfort. The element of sustainable design anticipates future energy sources, and needs with the aim to consider the following:

(i) Reduced energy loads for heating, cooling, lighting, and water heating.

(ii) Integration of building systems towards energy conservation, reduction of fossil fuels usage, reduction in greenhouse gas emissions and other sources of pollution, and improvement in building performance and comfort.

(iii) Techniques for systems integration, use of controls and technologies and efficient lighting strategies.

(iv) UNEP (2009) suggests the use of on-site renewable and alternative energy systems in anticipation of future and carbon-neutral fuel sources.

(v) Gvorkian (2008) highlighted the importance of feasibility studies for establishing the actual project design; the feasibility studies include an estimated study in power generation and the cost of installation for the lifespan of the project. Abeer (2010) discussed the means of rationalizing energy consumption in the buildings sector.

(vi) Energy is related to the environmental and economic aspects of sustainable design and affects the environment according to the energy source. The effect can be minimized with the use of natural resources and applications of energy efficient systems. Roaf (2007) discussed that solar PV systems are increasingly emerging as a chosen economic option with feasibility in terms of viability in many parts of the world. These systems can, in fact, be an investment for ordinary householders keen on protecting themselves against future energy and climate changes**.**

(vii) Natural energy is related to the focus of human thermal comfort. Solar or wind energy can improve air-cooling quality, air movement, air humidity and air temperature by mechanical means such as the use of fans or HVAC. To achieve human thermal comfort, systems can support traditional solutions like wind towers or desert coolers that work as natural ventilation.

2.4.5 Holism system: Environmental Design Process

Hide (2008) discussed that holism is the relation between the whole system and its sub-issues and that the whole system needs to be integrated with its smaller sub-parts. Correspondingly, he identified that the whole design process through the following three phases:

(i) Pre-building phase:

Pre-building phase is the designing phase of the building and further is segregated into the primary, developed and final design stages. It is essential that sustainable eco building categories are adopted as the main goals throughout these stages.

(ii) Building phase:

Building phase pertains to the construction and operations phase.

(iii) Post building phase:

After the construction of a building is complete, it involves the users. In this phase, it is essential that the building is maintained regularly, in order to ensure building longevity and durability.

2.4.6 The eco-building form

Roaf (2005), in her book '*Design Guideline for Eco House*", mentioned that the building form is one of the main categories in designing an eco-house. In addition, Alwakil (1989) studied building shades in different building forms (see Figure 2.8). Likewise, MED-ENEC (2010) published a report, which stated that passive solutions are the best solutions for eco-buildings in the Middle East including the components of building form, building materials, orientation, ventilation, and windows design. These three studies, in addition to several other highlight the importance of studying building form.

Studying building forms in alignment with relevant issues will ensure that in the planning phase, the buildings are provided with more shade, which will cool down the air surrounding the buildings. In addition, this will eliminate the need for 24x7 air conditioning with the optimal manage and integration of the buildings' passive design and solutions. Roaf (2001) and Alwakil (1989) discussed different building forms, i.e., cubic form, linear form, L-shaped form, U-shaped form, and circular subject to their use in different climates. Several impacting factors dictate the use of a particular form over others in specific demographics. The following points highlights the importance of studying the building form:

(i) Building location: depending upon the building location (i.e., on top of a mountain or a flat land), each location requires a specific form.

(ii) Building orientation: ideally, the building should be oriented perpendicular to the direction of the wind. In Greater Khartoum, the wind in summer comes from the South and South East; and in winter, it comes from North and North-West. Correspondingly, these two directions should always be taken into consideration when orienting the buildings (Hassan, 2000).

(iii) The climate: It is also important to consider whether the building is located in a hot or cold climate zone. In cold areas, it is better to use cubic forms but in hot climates, it is better to use L-shaped, U-shaped or leaner forms as they provide good ventilation (Water, 2012), as shown in Figure 2.8.

(iv) The sun movement: it is very important to study the sun movement in a specific location while choosing the building form and shape since we need to secure more shade to the buildings and minimize solar radiation.

(v) The greater the volume of the building the more surface area it has to lose or gain heat (Roaf, 2001).

(vi) The surface/volume ratio is very important in conserving heat transfer in and out of a building. To conserve heat or cold the building must be designed with a compact form in order to reduce the efficiency of the building as a heat exchanger. Specifically, buildings can have very different perimeters and area ratios depending on their plan form. For example, an important ration in eco-building is the Surface Volume Ratio (SVR), which refers to the ratio of the exterior surface to the enclosed volume of the building and it should necessarily be controlled. The main objective in calculating the SVR is to minimize the area of exposed surfaces in order to reduce heat gain. This can be achieved through multi-story buildings and by raising the roof height (Fajal, 2002). Thus, it is imperative to compute certain ratios, like,

SVR= Surface Area / Total Volume

SFAR=Surface Area / Floor Area (Fajal, 2002).

Consequently, experiments have shown that this ratio (SVR) ranges from 1: 0.16 to 1: 0.12 in hot-dry climate zones.

(vii) By using computer programmes like Building Information Modelling (BIM) and energy simulation software, the design engineers can also obtain an in-depth understanding and predict the effect of building forms on energy use for various design concepts in the early stages of design (Nicoletti, 2015). In turn, this knowledge base can optimally contribute to studying the building shades.

The consideration of all the above-mentioned criteria in the design of an eco-building, can, in fact, render support to the sustainability and durability of the buildings and provide more shade, thus, cooling the air surrounding buildings. Figure 2.5 shown below presents the different types of building forms with their respective SVR.

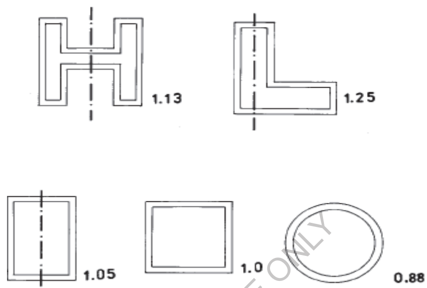


Figure 2.5: SVR of some samples (Roaf, 2005).

In addition, Figure 2.6 shows the relationship between building form and building shades and Surface Volume Ratio (SVR).

2.4.7 Design building envelop in the indoor and outdoor environment

The building form has been in continuous development through history and human beings have always chosen the form that is best suited to their local environment and climate. Similarly, the nomadic tent is one of the best examples of an adaptable building form, which takes into consideration the built environment, local building material, and human needs.

2.5 ENVIRONMENTAL COMFORT PRINCIPLES

Definition of thermal comfort:

Thermal environmental comfort is defined in British Standard BS EN ISO 7730, and in ASHRAE standard 55-2013 as, *'That condition of mind, which expresses satisfaction with the thermal environment'* (Szokolay, 2004; ASHRAE, 2013).

In fact, people in a hot-dry climate such as Greater Khartoum usually spend most of their time away from their workplaces as they are not comfortable in their work environment. This consequently makes it imperative and essential to improving the work environment and thereby encourage people to stay longer at their workplaces and do their work properly.

Cold climate

Moderate climate

Wet hot climate

Hot dry climate

Hot dry climate

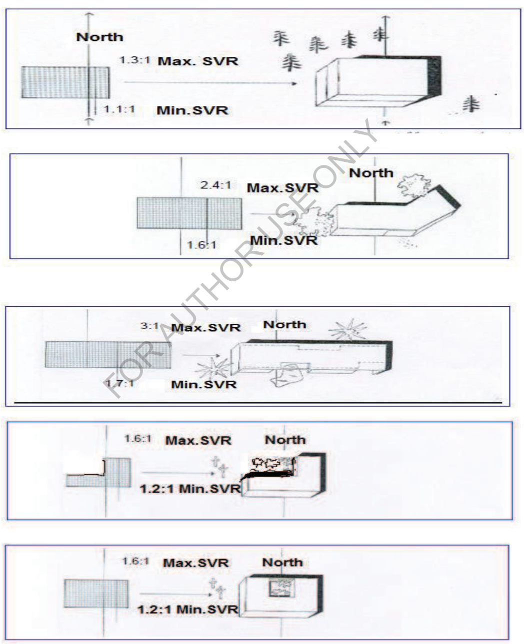


Figure 2.6. The relationship between building forms, surface volume ratios (SVR) and building orientations (Water, 2012).

2.5.1 The six basic factors of thermal comfort

In order to assess and ensure the thermal comfort offered by an eco-building, what all parameters should be measured? Essentially, thermal comfort is identified by six basic factors, which are air temperature, radiant temperature, air velocity, humidity, metabolic heat, and clothing. These six physical variables of the thermal environment must be combined and taken into account in the eco-building design as they affect the human body.

2.6 Passive solutions for designs in tropical hot-dry climates

Human thermal comfort aims at reducing the radiations reflected from surrounding surfaces. The concept of passive design is an energy conservation concept. In this section, the researcher will discuss and analyze the methodology or mechanisms to control thermal comfort design of buildings in a hot-dry climate at the urban level, architecture level, through the control of three building components. These components are the spatial control, the physical properties control of thermal comfort of the indoor environment, and the outdoor environmental control. Figure 2.7 explains the urban components control, three building components control, physical components control, spatial control, outdoor environment control and indoor environment control. The solutions are found to be suitable for hot-dry climates like Greater Khartoum.

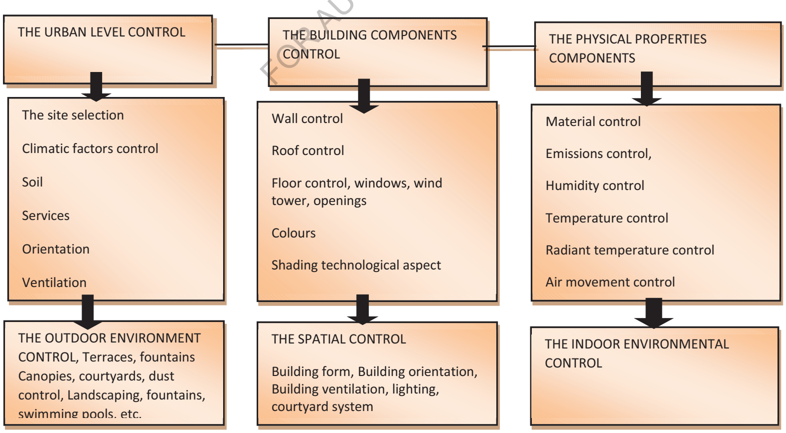


Figure 2.7: The urban components, three building components, and physical components control**.**

2.6.1 The Urban Planning and Design Analysis and Control

2.6.1.1 Site selection

Local factors that affect site selection include the slope, orientation, topography and land features. The five climatic factors, like temperature, wind, pressure, precipitation, and humidity as studied by Fajal (2002) in addition, became crucial during selecting the site locations.

2.6.1.2 The climatic factors

The research was conducted in Greater Khartoum, which is characterized to have a hot-dry climate. Thus, the design should incorporate solutions that would manage and deal with the building issues relevant to this climate.

2.6.1.3 Orientation

The orientation of the building should be perpendicular to the direction of the wind. Notably, some experiments proved that the greater velocities of air could be obtained inside a building if the orientation is kept at 45 degrees and offer more wind-shaded areas. Good orientation of a building makes the house healthier, and by studying the direction of sunrise and sunset at the building location; the design can be structured to ensure that the building has shades on the gardens and terraces.

2.6.1.4. Building layout

(i) Building layout on site:

Previously conducted studies on the movement of air around buildings in the tropics have proved that the distribution of buildings on the site, in fact, affects the movement of air around the buildings. Figure 2.8, Figure 2.9 and Figure 2.10 demonstrate the air movement through the staggered organization of buildings (Hassan, 2000). In the rural areas, it has been observed that the multi-story buildings are developed in the form of a network among the regions, which are still behind the first row of confrontation.

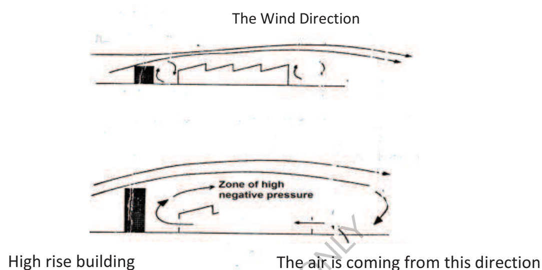


Figure 2.8 Air movement in case of a high-rise building in front of other low-rise building.
Source: Hassan (2000), P.150.

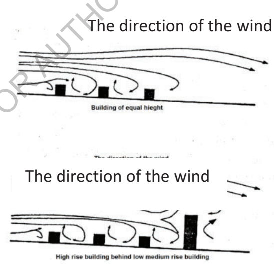


Figure 2.9: Shows the air movement besides high-rise building behind low-rise buildings.
Source: Hassan (2000) P.148.

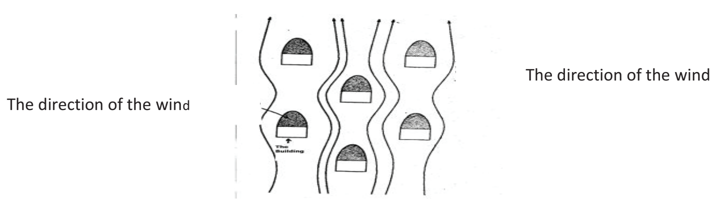


Figure 2.10 Air movement through staggered organization buildings. Source: Hassan (2000).

2.6.1.5 Natural ventilation

In Greater Khartoum, the climate is described as hot-dry climate, and accordingly, people are invariably intent on good ventilation, as cools the skin and dries up the sweat. Correspondingly, the architects' design windows to provide good ventilation to the buildings. Thus, window's location, size, and type also should be studied in-depth for an optimal eco-design. Idris (1984) discussed that natural ventilation could have an indirect effect on human comfort through its influence on the temperatures of the indoor air and inside surfaces. As well, as shows the air movement besides high-rise building behind low-rise buildings.

2.6.1.6 Ventilation control

It is very important to control the ventilation by natural means such as windows (Roaf, 2001). Incongruency, the following points for ventilation control constitute pertinent factors.

1. Use of pressure variations around the outside of the building causes wind effects.
2. Use of pressure differences caused by the pressure variations within the house.

There are several challenges in designing proper ventilation, including the variability of the wind, its speed, and direction. Nonetheless, a well-manipulated and assimilated ventilation can be of real advantage to the indoor climate of a house.

2.6.1.7 Vegetation

Vegetation has a moderating effect on the site climate in air temperature, humidity and dust prevention. It also provides protection from the sun glare. A building site can use the native plants that do not need much water as well as, plant long trees at a suitable distance from buildings to protect the construction of the building.

2.6.1.8 Site services

The system that flows to the town, i.e., the sanitary grid in Khartoum 2 and in other areas in first and third classes demonstrated the use of well and septic tank, pit latrine in some areas in third class, sand and gravel in illegal areas in Greater Khartoum; however, this system needs regular maintenance and cleaning.
The energy supply to houses in Greater Khartoum is usually provided by the National Grid. Therefore, other ways of providing energy, such as solar or wind energy systems could be adapted to manage the shortage of energy in some areas of Greater Khartoum. The water supply is also provided from a local main station.

2.6.1.9 Soil

In hot-dry areas, the high evaporation because of the excessive heat due to the sun, sometimes causes cracking of house in the external and internal walls, which affects the building safety. This can be attributed to the type of soil used for the construction. For example, the expensive clay soil, which expands in the rainy season and shrinks in the dry season, thus leading to foundations and walls crack (Center, E. R., 2017).

2.6.2 Architectural elements and components

(a) Roofs:

The roof component is highly vulnerable to solar radiation due to the complete exposure. As such, protection from solar radiation is one of the most difficult tasks and could be achieved through the following:

(i) The first is testing of building materials for roofs, which can be done with a thermal capacity assessment. It is performed by following a significant time "Time lag" because these materials store heat during the day and release it during the night.

(ii) The second is using of double roof over the main roof. A double roof system uses a ventilated air gap between an upper exposed roof and a lower protected roof. An example of this is the "Friendship Hall" in Khartoum which has the double roof.

(iii) The third is the use of roof thermal insulation on the outside concrete slab, which increases the time lag during the daylight hours. However, this method, which is meant to prevent loss of heat at night, presents practical feasibility issues. A more practical solution is to insulate the roof with natural insulation materials, cover this with lightweight concrete and then cover with tiles to provide protection against heat during the day and loss of heat during the night.

(iv) The fourth is the use of the bright, white or light coloured coating. The light colours use results in the reduction of heat absorption to the inside of the building. However, metal roofs should be completely avoided (Hassan, 2000).

The fifth is the application of green roof: Scientists discovered that green roofs minimize solar radiation to the roof surface. It also results in a reduction of heat island effect and surface runoff. Alexandria (2006) discussed the thermal effect of covering the building with an envelope of vegetation in the microclimate built environments, and for various other climates and urban canyon geometries. Jim (2008) discussed and evaluated the potential for greening the barren roofs in urban Hong Kong. Moreover, citywide ecological and economic benefits were assessed with reference to urban heat island effect. In addition, Matlock (2011) mentioned that green roofs help to reduce surface runoff by slowing the runoff velocity across the rooftop. Green roofs provide storage of water in the soil media and provide a cooling effect for buildings and surrounding areas. Green roofs, in addition, remove some pollutants. There are special requirements like the need for waterproofing and considering the part of life load and the weight of the plants in the structure. Makhzoumi (2014) stated that we can increase energy efficiency by using shades provided by plants in green roofs, green walls and green landscapes. This furthermore affects the indoor thermal comfort by reducing the temperature by 4 to 6 ˚C.

(v) (U.S.G.B.C., 2009) found that minimizing the solar reflectance index (SRI) it cool roof temperature and affect heat island effect in perfect solution such as;

1. Shades on site over parking areas, plazas and walkways.
2. Application of bright colour paints to buildings and roofs in order to reduce heat absorption.
3. Provide 50% underground parking and undercover parking.
4. Vegetated roof surfaces.
5. Roof slopes, Construction materials and the way of construction can also affect heat islands.

(b) Walls

Walls are the second component of the house, which could be protected from solar radiation by the following measures:

(1) The first thing that affects wall design is the choice of building materials. In Sudan, the widely accepted and used materials for walls are burnt mud bricks. These have the property of absorbing high temperatures during daylight hours, and this heat is released at night with the help of ventilation openings.

(2) The second factor that affects wall design is the windows.

(3) The third factor is the greening of the walls. Blanc (2014) concluded applying green walls on buildings reduces indoor temperature by 6˚ C. Similarly, Makhzoumi (2014) confirmed that the green walls reduce the temperature of the indoors as compared to the outdoors by 6˚ C.

(4) The fourth is wall insulations such as mineral wool, strawboards, wood-wool slabs, glass fibre products, and kapok, wool and cellulose fibres. These materials are known to minimize the heat flow from the outside to the inside of a building.

(c) Openings

In this section particularly, discusses the importance of windows in hot dry climate:

i. Window openings are smaller during the daylight hours and high in the walls to avoid thermal radiation, which is reflected from the ground. Correspondingly, windows protect the building from shades and bright sunlight.

ii. Increasing the window openings assists in natural ventilation of the rooms, particularly of the internal walls and ceilings.

iii. The optimal solution for the design of large openings is to keep the opening and closing of the windows under control, which allows a balanced airflow.

iv. The window frames that are painted in light colours reflect the solar radiation away from the windows towards the outside. In addition, using the sunscreen coat of paint reduces solar radiation inside the architectural space (Hassan, 2000).

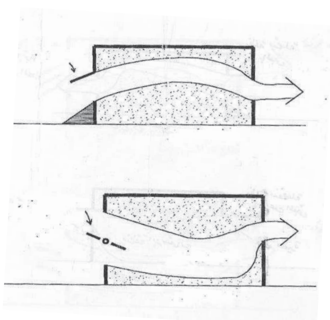
v. The fifth factor in window design is the provision of shade. Abu Sin (1991) stated that maximally possible shaded urban areas allow a cool breeze. These can especially be channelled through the urban network, canopies, shutters, and louvres, and in turn, can help control the entry of heat through windows.

vi. The sixth factor is the implementation and application of the appropriate technology. Magazine (2014) stated that smart windows could make air conditioning superfluous. KAUST (2013) discussed the growing attention and focus towards mechanisms on how to combine individual element technologies (insulation, glazing, solar screening, etc.). To minimize energy loss, Aoun (2011) discussed a smart blind control system that automatically adjusts the blinds or shading through a room-by-room level. This system controls the shading with the use of the HVAC system and minimizes energy consumption by 10%. See Figure(s) 2.11, 2.12, 2.13 and 2.14 that illustrate windows location and air movement.

(d) Daylight

1. Natural Lighting: The natural lighting is abundantly available and the corresponding solar gain over the Greater Khartoum ranges between (2,400-2,450) KWh/ $m^{2.}$ (Yassin, 2013). At present, several technologies are being applied in window designs to control the amount of daylight and avoid glare. Melki (2014) discussed that vernacular architectural window sizes, orientations, and shapes are affected by adopting an environmentally conscious approach.

2. Artificial lighting: Scholte (2012) discussed the use of LED lighting for green and sustainable buildings in the third conference of Saudi Green Building Forum. He stated that LED lighting is essential for energy saving, low energy consumption, reduction of energy in LEED system applications, BREAM, GSAS certification and low heat generation. In addition, LEED has also advised for mercury lamps towards ideal artificial daylight alternatives (U.S.G.B.C., 2009).



.**Figure 2.11** Shows air movement fixing method control.
Source: Hassan (2000)

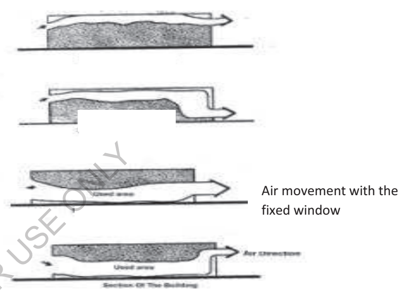


Figure 2.12. Shows the relation between the position of windows and air movement.
Source: Hassan (2000)

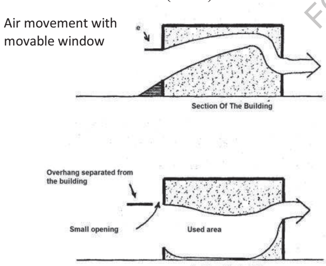


Figure 2.13. Shows air movement and overhanging Hassan (2000).

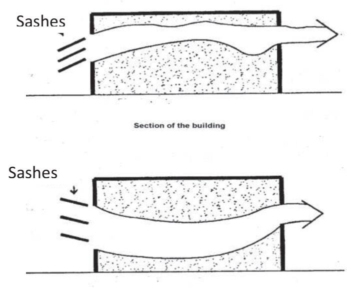


Figure.2.14: Shows air movement and sashes in upper and lower Hassan (2000).

(e) Floors

Floors are the third building component and several types of eco floors like recycled ceramic, stones and marbles are available. In addition, floor finish(s) like ceramic, marble; terrazzo tiles, concrete tiles, etc. are available in Greater Khartoum. Congruently, various points are important in the designing of floors, as mentioned below:

1. The first point pertains to adopting and constructing a design, which results in a comfortable floor.
2. The second point is constructing the floor from eco-friendly building materials such as green concrete, heavy-duty marbles, and other green products.
3. The third point is the use of recycling material from waste bricks, stones, rubber and organic materials.
4. The fourth essential factor to account for is that the floor should be slip resistant, strong, and impervious to heat and moisture.
5. The fifth factor pertains to the durability of the floor for both indoor and outdoor applications.
6. Lastly, the floor should be easy maintenance.

Thus, as regards the current study region, it is considered that eco floor, comprising of local building materials available in Greater Khartoum like stones, bricks, sand, gravel, and marble will be economic.

2.6.3 Indoor space control

2.6.3.1 Ventilation

Good ventilation to the house can be offered through the windows and doors. Figure 2.15 shows the cross ventilation that can be achieved through deep windows with canopy and sheds in the building.

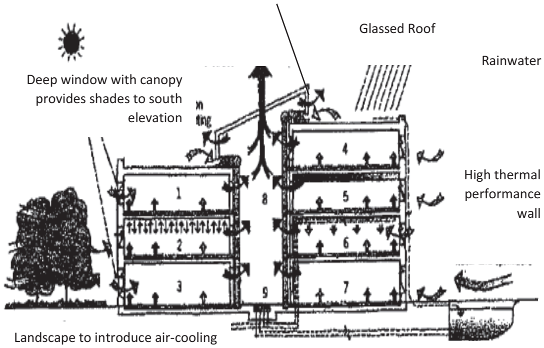


Figure 2.15. Cross ventilation through deep windows with canopy and sheds in the building. (Croome, 2003).

2.6.3.2 Orientation

The orientation for the spatial is designed in accordance with their function, and correspondingly, the majority of the time we orient the bedrooms to North-East or South-West according to the direction of the wind to have good ventilation. Hassan, (2000) mentioned that the kitchen and baths usually oriented to the East or West to avoid the spread of bad smell through the building; and the family halls often, oriented towards the North-South direction also to ensure good ventilation.

2.6.3.3 Passive cooling (internal courtyard, wind tower, high thermal mass and night ventilation)

1) Use of internal courtyards

The use of internal courtyards, if designed properly, can ensure that the temperature of a portion of the cool night air is retained during the daylight hours. Figure 2.16 shows the thermal performance of a large house with a courtyard.

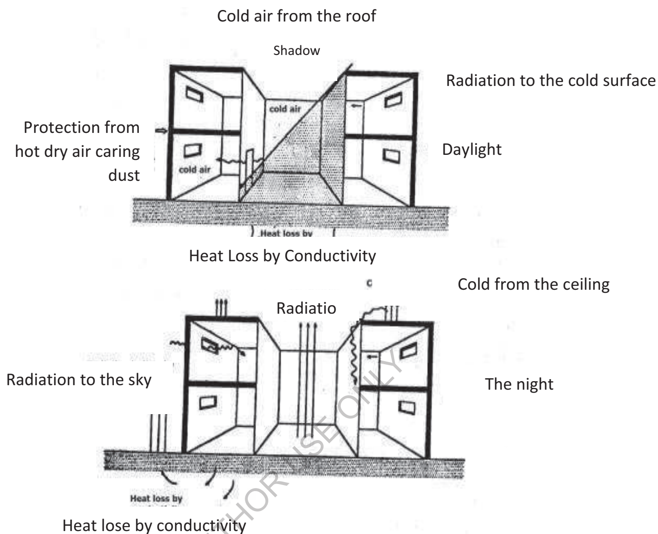


Figure 2.16: The thermal performance of a large house with a courtyard. (**Source:** Hassan (2000), P.175.).

Large courtyards provide good ventilation, especially when they open to another courtyard or street such that the cross ventilation is promoted. On the other hand, small courtyards provide more protection against hot and dusty winds in the hot-arid regions. Some courtyards contain fountains and trees to promote evaporative cooling and provide shade. Courtyards moderate the climatic extremes in several ways:

(i) The cool air of the summer night is kept undisturbed for several hours from hot and dusty wind, considering the surrounding walls are tall and the yard is wide.

(ii) The rooms draw daylight and cool air from the courtyard, which enhances ventilation and filters dust.

(iii) It provides privacy to the family and keeps their activities and noise away from neighbours.

(iv) The courtyard with its gentle micro-climate provides a comfortable outdoor space (Gallo, 1998). However, not all courtyards provide comfortable living spaces. This comfort factor is dependent on many factors, such as courtyard dimensions, orientation, surface finishes, shading, air movement and passive cooling features

(v) Social effect resulting from the courtyard encourages the family to spend part of their time in an outdoor environment - playing, sitting, reading, and celebrating, amongst other things.

(vi) Economically the construction of courtyard effects a reduced demand on indoor spaces thereby reducing indoor light and air conditioning energy requirements.

Littlefair (2006) discussed that in hot climates, a well-designed courtyard improves solar control, reduces heat transfer through the walls and glazing, and could, in fact, be used to provide natural ventilation, consequently taking advantage of its cool air. In addition, Wazeri (2010) concluded that the use of interior courtyards has been one of the useful solutions that have been adopted in ancient Nubian Architecture, especially evident in the Tushki village. The study proved that a square plan wind tower should not exceed a height of 6 metres in cases, wherein it is used for a building of 3 metres height. Moreover, the study revealed that the use of rectangular shape is better than the cubic shape; and its height does not exceed 1 metre over the water level, specifically when the water flow is 10 litres/min. Figure 2.16 shows the thermal performance of a courtyard inside a large building.

Santamouris (2006) also stated that a courtyard system is used to provide the building with natural light and ventilation as well as reduce its energy use. Correspondingly, Lau (2014) discussed the environmental performance of traditional courtyard houses in China and evidenced good performance in terms of providing natural lighting, natural cooling, visual daylight, and comfort. Thus, impressing the redundant need for using air conditioning systems in such constructions. Canan (2014) mentioned that in the current housing structures; balconies and terraces have replaced the courtyards, which, in fact, are mostly smaller than the traditional courtyards. Though, the courtyard systems provide better control to the micro-environment it depends on several factors, such as, courtyard dimensions, orientation, surface finishes, shading, air movement and passive cooling features; water elements provide moisture and evaporation producing a cooling effect in the courtyard. In consideration of courtyard dimensions, Wazeri (2010) mentioned that the courtyard height is 6 metres near a first-floor building, 8 metres high near a second-floor building; and the wet area should be 2.5 metres above the floor with a water flow rate of 20 litres/minute (Wazeri, 2010).

2) The cooling tower

A cooling tower consists mainly of two parts: (i) the catching device and (ii) the tower. The tower opens into either upstairs or downstairs rooms and is stopped about two meters above the level of the floor. The tower structure is subdivided by brick partitions to contain several shafts. Air movement is also carried out through a wind tower system. The dry air, which flows down to the bottom of the tower, is cooled by a wet surface, thereby reducing the temperature inside the house and making it a cool space. Gallo (1998) discussed the traditional cooling tower construction as well as Hassan (2000). Figure 2.17 shows the mechanism of a wind tower.

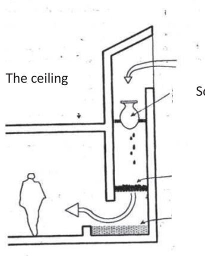


Figure 2.17: The system of the cooling tower. (Hassan, 2000).P.161

Wind tower consists of two operations in one functional day:

(i) Day operation

During the day, the tower walls cool down the air. When the wind blows, both the circulation and the rate of cooling increases, and the cooled air is passed through the rooms.

(ii) Night operation

The cooling tower absorbs heat during the day; the heated air is exhausted through the windows of the cooling tower. The air is passed through a wet surface when the wind blows at night, the air is cooled and passed through the rooms.

3) High thermal mass

Night ventilation is the use of the cold night air to cool down the structure of a building so that it can absorb heat gains during the daytime reducing the daytime temperature rise (Forroqure, 2014).

4) Night ventilation

A high thermal mass structure has the ability to absorb and store heat during the day as shown in Figure 2.22. (Forroqure, 2014).

2.7 Physical Properties and Control: The Indoor Environmental Quality (IEQ).

Indoor environment quality could be controlled by controlling the humidity, temperature, air movement, radiant temperature, noise, acoustic, ventilation, and lighting by traditional solutions such as adding wind towers.

2.7.1 Humidity control

(i) In tropical dry climates, increasing the amount of moisture to mitigate the impact of dryness has been linked with the process of cooling air. Cooling, in this case, is provided by water desert coolers.

(ii) Evaporative coolers produce a moderate reduction in air temperature and increase humidity. They operate by passing hot air over water-saturated pads, and the water evaporation effect reduces the air temperature.

(iii) Plants also add to the humid air in the surrounding environment.

2.7.2 Temperature control

(i) The construction materials used in the building of walls and ceilings have the thermal capacity to store high operating temperatures during daylight hours and dispose of these during the night.

(ii) Thermal insulation:

Several different types of thermal insulation materials, e.g. loose fills, rock wool, and boards are available and in use. Such construction material acts as a barrier and slows heat flow in summer and heat loss in winter, but it is only effective in case of a temperature difference between the inside and the outside of the building, or between two areas inside a building.

(iii) **Natural cooling**: This can be achieved through the strategic placement of windows and doors in the building design.

(iv) **Mechanical cooling**: by applying the HVAC system or other systems like the split unit and AC.

(v) **The desert cooler** concept works by blowing air with a fan to pass through straw dowsed with water into the building inside, and the generated cool air lowers the temperature inside of the building. This method is used in areas with warm dry climates, and areas with compact climates (Hassan, 2000).

2.7.3 Air movement control

Air movement could be ideally controlled in two ways: (i) Either natural control or (ii) mechanical control, like using the wind tower.

(i) Natural method: This is carried out through the design of windows, which facilitate the supply of clean air to the house (Hassan, 2000).

(ii) Mechanical method: This is done by using fans and air conditioning systems or Heating Ventilating Air Conditioning system (HVAC) (Hassan, 2000).

2.7.4 Radiation control

Radiation control can be achieved by

(i) Painting the internal walls and ceilings with white paint to act as a reflector of the sun glare.

(ii) Using cavity wall with insulation.

(iii) Using reflecting sheets.

2.7.5 Emission control

Emission control can be achieved by:

Minimizing CO_2 emissions resulting from cooking by using traditional methods. In addition, minimizing the use of Chlorofluorocarbons (CFCs), i.e., a group of manufactured chemical compounds that contain chlorine, fluorine, and carbon, in-home sprays or in refrigerators; and selection of the appropriate equipment in the kitchen such as ovens or refrigerators.

2.7.6 Materials control

The construction material has a great effect in controlling the solar heat from outdoors to indoors, part of this heat is reflected, absorbed or transmitted. Studying the construction building materials, their time lag, embodied energy and Life Cycle Analysis (LCA) for devising the control could be useful.

2.8 Outdoor Environmental Control

Buildings in hot-dry climate require protection from various climatic factors such as solar radiation, wind, and dust; and therefore, compact design is one of the best solutions. These outdoor environmental conditions have an ecological, economic and social effect on the inhabitants of a building.

2.8.1 Ecological effect

Many researchers discussed the effect of the outdoor environment on human beings such as; Lmdc (2005) discussed thermal comfort in an outdoor environment; he mentioned that bringing people outdoors reduces the demand for indoor spaces and provides increased opportunities for contact with the natural world. Reduced demand on indoor spaces, in turn, reduces indoor light and air conditioning energy requirements. In order to improve their health, urban dwellers are required to increase their exercise activities and inhale more fresh air during daylight since they spend a large portion of their time staying indoors. With the resultant increase in contact with the natural environment, the life-stress is lowered, and more rest and relaxation opportunities are made available to them. Correspondingly, creating opportunities for people to go outdoors and establish a connection with nature will additionally arouse their awareness of these atmospheres and their role in sustaining them.

2.8.2 Economical effect

Increasing and extending the amount of time in outdoor spaces that are comfortable, in fact, provides increased and extended opportunities for outdoor retailing and dining, and impacts direct economic benefits in both increased productivity and reduced medical costs. Also in Khartoum, outdoor celebrations are quite predominant, which reduces the cost of hiring celebration halls, also children play outdoor, older people sit together, some people pray outdoors.

2.8.3 Social effect

Outdoor spaces could enhance the level of social interaction that occurs in a neighbourhood. A comfortable outdoor space can be used easily and more frequently, and the increased presence of people outside further adds to the premises' security and works to deter crime.

2.8.4 Techniques to minimize the outdoor temperature

Evaporative cooling techniques such as sprinkling the courtyard with water also reduce the temperature of air, thereby cooling the surrounding air (Hassan, 2000). Most of the people in Khartoum city follow this practice and sprinkle the outdoors with water, usually at 5 p.m., in order to set up the outdoor environment to be wet and cool (Hassan, 2000).

(i) Use of fountains

The use of fountains will serve to cool ambient air and concurrently air is forced down, which works to reduce the temperature inside the house.

(ii) Use of swimming pools

Integrating swimming pools with the building design can lead to an increase of humidity in a hot dry air environment.

(iii) Windbreaks

This concept can be used, not only to lessen the impact of a strong hot or cold wind but also to cool down the surroundings. For example, shrubs and trees, wherein the air moisture will radiate from the leaves and transported by air currents creating an increased humidity, ultimately lowering the temperature in the surroundings.

(iv) Dust control

Several methods are available for dust control, such as:

(i) The phenomenon of air navigating through a natural green-covered area will reduce dust levels. This can be attributed to the fact that in dusty regions/environment, the air becomes a source of dust, and in absence of vegetation, the eroded dust particles are carried up by the wind current to the inside of the house.

(ii) Avoiding barren lands and planting of natural vegetation, if possible, even on unused plots in the centre of towns.

(iii) Adopting compact plans for groups of houses, in hot dry areas, to avoid the formation of dust at the site being landscaped, and thus, reduce dust. Compact plans also provide more shade; see Figure 2.18, Figure 2.19.

(iv) Using fences by a distance of 6 meters from the building.

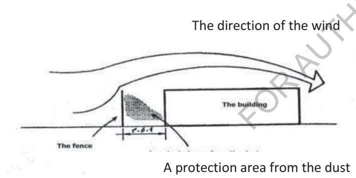


Figure 2.18. The dust movement in the case of a fence which is far from the building, D= 6.1 m. And the fence height only equal to the building height. **Source:** Hassan (2000), P.157.

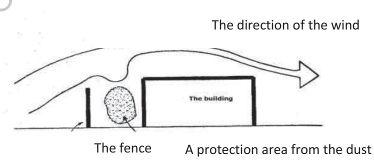


Figure 2.19. The dust movement in the case of a barrier lower than the building height. **Source:** Hassan (2000), P.155.

2.8.5 Outdoor thermal comfort

Steemers (2004) presented a study on outdoor thermal comfort; the study investigated whether thermal and, by implication, comfort conditions affect people's use of outdoor spaces, by studying the number of people using the spaces at various intervals. Steemers discussed landscaping and recommended providing the outdoor with protection from the wind, which is feasible with the use of vegetation as windbreakers as well as for shading. He also discussed the use of canopies made of various materials such as stone, which provide useful spatial variation in areas and provide environmental control from the sun and rain. Thomas (2006) also has discussed the same issues, in addition to Rick (2012) and Masdar (2014), who mentioned that the planning of Masdar city used shades for outdoor thermal comfort through canopies.

2.8.6 Vegetation

Vegetation in the landscape in the outdoor environment can be achieved by using plants, trees, and shrubs.

2.8.6.1 Landscapes and buildings

Shafiq (2010) stated in his article "Sustainability of traditional and contemporary architecture" that the use of plants and trees reduces the cooling bill by 15-35% and the application of window shades and sunscreen from plants ensure up to a 10% reduction in the cooling costs. This issue has also been discussed by UNEP (2012), wherein it announced the importance of urban greening; more trees provide shading, which tends to cool the city streets. In general, more vegetation tends to improve air quality because plants absorb or adsorb the air pollutants. UNEP further discussed the importance of the basic understanding of landscape design and its elements. According to Awad (2003), "The elements of landscape or landscape architecture design" are divided into two main parts, and specifically the elements of natural landscape working with flora and fauna.

2.9 Regulations and Standards

Regulations and standards between buildings need of setback from the north and south direction 1/3 of the height of the building to allow good ventilation to the building and from East and West direction about 2 meters. Hassan (1995) stated, “Building regulations and standards are implemented in few parts of the developing countries. The International Code Council (ICC) was established in 1994 as a non-profit organization dedicated to developing a single set of comprehensive and coordinated national model construction codes. The founders of the ICC are Building Officials and Code Administrators International, Inc. (BOCA) and International Conference of Building Officials (ICBO). They have regulations in buildings safety, building fire safety, and building resistance and moisture. They have a code for sustainable homes, which is the National standards for sustainable design and construction for new homes”.

Abdulla (1996) presented a paper in the "National seminar on environmental legislation in Sudan", wherein, he tried to highlight two important developments that had occurred at, and since, the United Nations Conference on Environment and Development (UNCED) in 1992. One of these was the action plan for Sustainable Development Agenda 21, and the other was Capacity 21, which highlighted environment protection. Subsequently, the International Green Construction Code (IGCC) was announced in 2010. Congruently, Walls (2014) stated that in the USA efforts were concentrated in establishing and coordinating institutions at a national level, and building capacities for incorporating issues of sustainability in the development process. In addition, the local regulations were not working in alignment with the international regulations. Abdalla (2003) discussed the objectives of National Sustainable Development Strategies. In addition, El Kheir (1990) discussed the national development policies and pointed out that industrial concentration in Khartoum has reached up to 90% of the total number of investments approved for the whole country; he also noted that scientific town planning regulations and rules for regions with hot climates had not been developed yet. The local building regulations for the National Capital of the Republic of Sudan and the environmental framework (Planning, 2014) by the Ministry of Housing in Khartoum stated that the primary setting is depicted at all five territorial levels and throughout its time horizon. The environmental framework of Khartoum Structure Plan (KSP) pertains both to the natural and man-made environments. A clear stance of KSP ramifies around the issues of desertification, green cover and hydrology at the inter-state regional and rural levels; while sanitation, vehicular pollution and urban green constitute the basic environmental themes at the urban level.

This overall environmental framework utilizes the concepts of prevention, mitigation and enhancement as its basic instruments, and monitoring and control as its guiding tools. In a wider context, the KSP environmental framework operates within the trans-national territorial level where regulations, procedures and environmental laws constitute the basic impetus for all the lower territorial levels.

2.10 Summary

The current chapter started by identifying sustainable development and entailed a discussion of the following elements:

- The three aspects of sustainable design in conjunction with the main principles of ecological design, such as sustainable site, indoor environmental quality, outdoor environment, building form, energy efficiency, water efficiency, building materials, etc. have been studied in this chapter.
- The principles of environmental thermal comfort, specifically the passive solutions by controlling the urban element and the architectural element in three building components: roofs, walls, and floors have been studied.
- The chapter explores several solutions to control the indoor environment, by controlling the sources of thermal comfort such as non-toxic building materials, lighting control, and the efficiency of energy usage, acoustics and noise emission control. In addition, ensuring a focus on the solutions suitable to the hot-dry climate, along with other traditional solutions such as the wind tower and the courtyard system; concurrently provided solutions to control the outdoor environment, by providing canopies, terraces, swimming pools and fountains. All

these solutions, which are essential for controlling the design in hot-dry climates, were studied in this chapter.

- Finally, the chapter reflected these solutions of environmental thermal control on the principles of sustainable ecological design. These principles will be further discussed in Chapter four and five.

CHAPTER THREE

RESIDENTIAL AREAS IN GREATER KHARTOUM

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3.1 INTRODUCTION

This chapter discusses the nature of the case studies employed in the current study, within the context of sustainable ecological design, such as the physical aspect of the location, geology, climatic conditions, temperature, rainfall, humidity, wind, topography, vegetation, earthquake, flood factor, and natural resources. Then, the chapter discusses the residential aspect of historical background in housing demand, housing demand growth, increasing migration towards Khartoum city, and its services. This is followed by discussions on the spatial aspects of building orientation, ventilation, residential block size and outdoor environment. Finally, the chapter studies the technological aspects of building materials in Greater Khartoum as well as the use of smart technologies in energy, and water efficiency, and thermal comfort control.

3.2 PHYSICAL ASPECTS OF GREATER KHARTOUM

3.2.1 Location

Khartoum state straddles at the confluence of the Blue, and White Nile that covers some 28,000 km^2. It lies at latitude 15° 36’ North, and longitude 32° 3 East, with an altitude of 380 meters above sea level. Figure 3.1 shows the political map of Sudan, and the location of Greater Khartoum. Figure 3.2 shows a satellite image from NASA, (2011). The northern states are a blanket of desert, broken only by the fertile Nile corridor. South Sudan is covered by green swathes of grassland, swamps, and tropical forests. Sudan is politically split into two countries.

Figure 3.1: the Political Map, 2015 (Washington DC, 2015).

Figure 3.2 Extent of the divisions in Sudan, 9-July-2011 (NASA, 2011).

3.2.2 Geology

Weathering and erosion of certain rock types have given rise to isolated arid hill masses, and a larger group of hills at the Al Sabaloka area. The weathering of the underlying bedrock has resulted in the formation of rocky outcrops, superficial deposits, and gravels. Furthermore, (Hassan, 2010) stated that comparative flatness is confined by limited detailed contour mapping carried out around Khartoum (El Bushra, 1976). The Occasional Jebeles (isolated hill) or series of hills corresponding to resistant rock outcrops make gently sloping ground surfaces. Sand dunes of Qoz Abu Dulu provide gently undulating topography, Wadi floors interrupt the otherwise relatively flat ground, and the river terrace provides slopes flanking the White, Blue, and the main Nile. In the places, the slopes are subjected to rapid erosion (Abu Sin, and Davies, 1991).

3.2.3 Climatic conditions

Khartoum's climate is characterised by its hot and dry nature. In addition, is characterised by intensive heat resulting from the blowing of dust storms (i.e., Haboobs) from the South East. This phenomenon, in fact, produces one of the most striking weather features experienced in the area (Figure 3.3; page 59).

3.2.4 Temperature

There are three well-marked seasons in the year. The cooler winter season covers the period mid-November to March, and the summer season covers the period April to October. The temperature range in winter is from a high of 29˚C to a low of 17˚C, and in summer, the temperature range is from 40˚C to 28˚C. See Figure 3.3; page 59.

3.2.5 Rainfall

In winter, the precipitation is effectively zero. The rainy season starts from July until the end of August with average rainfall in the capital region ranging from North to South at 100 mm to 200 mm. As per reports, Khartoum's highest annual rainfall was 420 mm in 1988. The chain of rain decreases markedly after mid-September. See Figure 3.3; page 59.

3.2.6 Humidity

The range of relative humidity in summer is 87% to 36%, in winter it is 30%, and in autumn, it is 40%. See Figure 3.3; page 59.

3.2.7 Wind

In summer, the wind direction is South East, and South West. In winter, the wind direction is North East, and North West. In June, during the summer season, the growing instability of weather can cause dust storms (also called Haboobs). However, robust Haboobs can occur in almost any month of the year. See Figure 3.3 on page 59.

3.2.8 Topography

Khartoum land slopes gently at both flanks of the River Nile down towards the center (Jebel Marra , and Jebel Meidoob). Fine silt is deposited along the beds of the streams, and rich clays are generally abundant in the area. When we design a neighbourhood study of the topography, and the contour lines as well as the sea level features, it is very important to avoid flood areas, and valleys.

3.2.9 Vegetation

The area is composed of land divided into three towns: Khartoum, Khartoum North, and Omdurman, and is 380 meters above sea level. The White Nile from the South, and the Blue Nile from South East unite in Khartoum, and provide a good source of water to the land. Another source is the rainwater in autumn, which is about 100 mm. The distribution of the vegetation in Greater Khartoum is affected by the soil, the water sources, and the geology. There is little binding vegetation here, but going further south, the vegetation gradually changes from desert to semi-desert to Savannah with long grasses, and large trees near the river Nile.

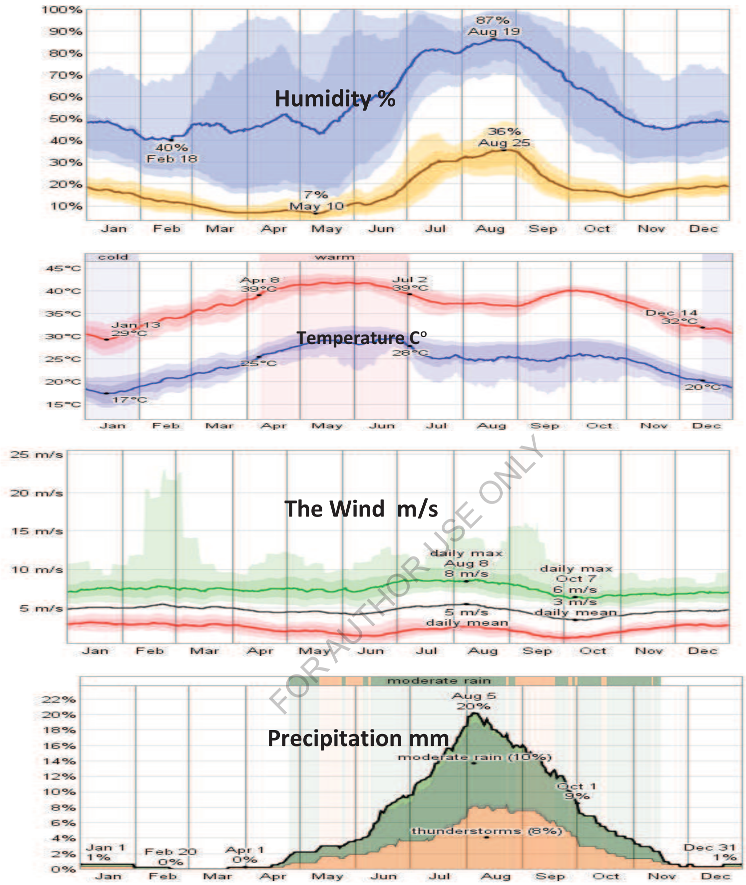


Figure 3.3: Precipitation of metrological data in Greater Khartoum (www.weatherspeak.com, 2014).

3.2.10 Earthquake and flood factors

It is very important to conduct studies on flooding in Greater Khartoum, in order to incorporate backup solutions during the sustainable design constructions. Abdulla (2008) stated in his M.Sc. research that Sudan suffered the most destructive floods during the last 20 years. Many cities, especially Khartoum (the capital of Sudan), have also been reported to get regularly affected by floods. Correspondingly, great losses were encountered due to the damages caused by the 2007 floods in Khartoum.

3.2.11 Natural resources of energy regarding Greater Khartoum

Several natural energy resources are available in Sudan, e.g. wind, and solar energy, hydroelectric energy, underground heat energy, biomass energy, and natural gas (Abdelmoneim, 2005) and (Abdelmoneim, H.2017). In addition, the measured solar energy in Sudan is considered satisfactory. The whole radiant energy upon smooth surfaces produces 10.1 watts/ m^2 a year in Northern Sudan. Solar energy increases, and reaches its highest point in the middle of Sudan, and further improves as we go northwards to the Northern Federal State, North Darfur, and North Kordofan. As per reports, here the radiation reaches 2300-2350 KWH/m^2 (Yassin, 2013).

Also, a high current of air prevails in most of the seasons in Khartoum, and Gazira, and it has been recorded that the wind generated power reaches an average of 237 GWH/m^2 (Makhlafi, 2012). See (Appendix-10) for residential, architecture, building, and technological aspect.

3.3 Summary

This chapter outlines the environmental conditions, historical background, and technological aspects, of Greater Khartoum.

- The environmental conditions including physical aspects such as location, climate, geology, temperature, rainfall, humidity, wind, topography, vegetation, and natural disasters.

- In addition, the historical background of the region has also been introduced in this chapter. Hamid, G. 2010 shows that migration has increased over the last 20 years, thereby, causing lack of or shortage in services such as housing, hospital, and education. The increasing demand for housing, vis-à-vis its short supply can be alleviated by building sustainable ecological buildings, and meeting the needs of people (Appendix-10, 10.1).
- Correspondingly, technological aspects affect the ecological building materials such as bricks, stones, clay, and concrete, which are available in Greater Khartoum.
- In addition, Greater Khartoum has natural resources such as wind, and solar energy, which warrant the need for these solutions especially for the suburban areas, which demonstrate a shortage of energy. Water is available in Greater Khartoum, which is sourced from River Nile, primarily constitutes underground, and rainwater. The corresponding needs are thus to manage water quality in accordance with the standards of the World Health Organization (WHO), minimize water consumption, and recycle grey water from the housing sector for use in landscape, and the outdoor environment.
- Consequently, residential buildings in Greater Khartoum were built from different types of building materials, and constructions; i.e., some exhibit the use of concrete skeletons, while others have used load-bearing systems. Similarly, some of them have an outdoor environment, while others do not, and some illustrate a good building mass, while others do not (Appendix-10).
- Finally, the case study conditions facilitate the identification, and selection of the standards, and optimal solutions for designing sustainable-eco-buildings.

CHAPTER FOUR

A REVIEW OF ENVIRONMENTAL ASSESSMENT METHOD

CHAPTER FOUR

A REVIEW OF ENVIRONMENTAL ASSESSMENT METHOD

4.1 INTRODUCTION

The aim of this chapter is to review and discuss the several assessment methods of thermal environment in built areas, in order to obtain an evaluation method suitable to the residential areas in Greater Khartoum. This chapter will review a number of methods, which are as follows:

i. *Physical assessment methods*

that measure the six basic factors of thermal comfort; the air movement, the air temperature, the air velocity, the radiant temperature, the metabolic heat, and the personal factors.

ii. *The Qualitative Assessment Method*

Hassan (1995) discussed in his research the urban and architectural components like streets, services, vegetation, building orientations and building ventilation including those by the professionals and users on two scales (planning and architectural). These have been explored from three standpoints, namely theory, professionals and users' perceptions.

iii. *The Sustainable Assessment Methods*

These methods include a general review of the rating systems, their categories, evaluation methods and certification.

4.2 QUANTITATIVE ASSESSMENT METHODS

The second method is a quantitative method, which is presented by Olgyay Building bioclimatic chart of the thermal comfort scales and the Predicted Mean Vote (PMV).

4.2.1 The thermal comfort scale

Hassan (1995) wrote about the thermal comfort scale and identified it as follows:

‘*The subjective assessment of the environment is obtained by introducing subjects into a climatic chamber where all the variables of climate are controlled and accurately recorded; subjects are then asked to vote on a given scale.*

The Bedford Scale details the following measure:

1. *Much too warm*
2. *Too warm*
3. *Comfortable warm* ⎫
4. *Comfortable* ⎬ *Comfort Zone*
5. *Comfortable cool* ⎭
6. *Too Cool*
7. *Much too cool*

4.2.2 The Predicted Mean Vote (PMV) scale index

Fanger, P.O., (1970), who used heat balance equations and empirical studies in the context of skin temperature to define the comfort parameter, developed the Predicted Mean Vote index (PMV) model. The standard thermal comfort surveys ask subjects about their thermal sensation on a seven-point scale from cold (-3) to hot (+3). Correspondingly, Fanger's equations are used to calculate the Predicted Mean Vote (PMV) (Fanger, 1970).

Innova (2002), furthermore discussed that the PMV-index predicts the mean value of the subjective ratings of a group of people in a given environment. The PMV scale is a seven-point thermal-sensation scale ranging from -3 (cold) to +3 (hot), where 0 represents the thermally neutral sensation.

The ASHRAE Scale:

The most commonly used scale in the last twentieth years is the **ASHRAE** Scale, which details the following measure:

3. Hot
2. Warm
1. Slightly Warm
0. Neutral
-1. Slightly Cool
-2. Cool
-3. Cold

Even when the PMV-index is 0, in a group, some individuals would be dissatisfied with the temperature level, irrespective of all being dressed similarly and displaying the same level of activity. Thus, it has been inferred that comfort evaluation differs a little from person to person.

4.2.3 Predicted Percentage of Dissatisfied (PPD) scale index

The Predicted Percentage of Dissatisfied index (PPD) is used to predict the number of dissatisfied people in a given thermal environment. In the PPD-index, people who vote, -3, -2, +2, +3 on the PMV scale are regarded as thermally dissatisfied. Figure 4.1 shows the relation between PMV and PPD scale index.

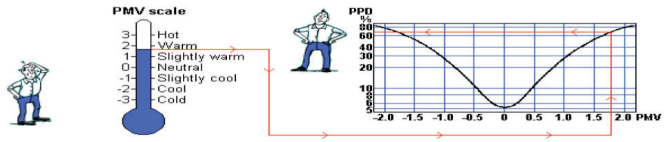


Figure 4.1: The relation between PMV and PPD Scale Index (INNOVA, 2002).

Innova (2002) stated that this can be evaluated by measuring PMV values at a few workplaces.

4.2.4 Adaptive model

Humphreys and Roaf (2012) discussed the adaptive principles and stated that *"A good understanding of adaptive thermal comfort is necessary for anyone designing a low-carbon building. Designing to reduce the need to heat and cool a building requires a great understanding of how to achieve thermal comfort without using energy"*. Here in Greater Khartoum, summer is very hot with temperature sometimes rising as high as 45˚C to 50˚C. The inhabitants, therefore, employ several adaptive mechanisms to cope with these extremely hot conditions. The variety of solutions include clothing, activity change, posture change, utilization of spatial amongst others. Also, more adaptation mechanisms inside the building could be by natural ventilation or by mechanical systems such as fans or air conditioning units.

4.2.5 Other parameters to achieve human thermal comfort

The indoor environment is affected by other parameters that cause discomfort to human beings, which include lighting, noise, acoustic, HVAC systems, amount of CO_2 emission. The climatic factors, individual activities, construction material, compound the list of factors causing discomfort. Managing the indoor environment with the outdoor environment, and managing the building with its orientation, ventilation, building mass, building form is very important to achieve the human thermal comfort balance.

The indoor environmental quality is one of the categories adapted in sustainable assessment method that will be discussed in the following section:

4.3 THE QUALITATIVE ASSESSMENT METHOD

Hassan (1995) presented the thermal environment in some major residential trends in the hot-dry climate of Greater Khartoum. The study is based on the assumption that the prevalent thermal problems in this area partly result from official and unofficial policies of the planning and architectural aspects of management of thermal performance. In this respect, the current study recognized two geographical scales to conduct the assessment: (i) The house-unit scale; and (ii) the urban scale.

Since quantitative methods were found not to be applicable for the scale of interest of the case studies; the method adopted was based on qualitative perceptions of professionals and users, the yardsticks used in assessing the samples, and the perceptions of the involved groups.

4.4 SUSTAINABLE-ECO-BUILDING METHODS

Sustainability has widely spread globally, regionally and has recently started locally. The industrial sectors, including the building sector, have started to recognize the environmental impact of their activities; starting in the 1990s in Sudan. Moreover, significant changes were needed to mitigate the environmental impact of the building sector with a focus on the buildings' design, built and operated. One of the key drivers of this transformation was public policy, and another was the growing market demand for environmentally sound products and services. Thus, in order to reduce environmental impacts, a yardstick for measuring environmental performance was needed (Hapio, 2008).

The environmental rating systems have been added recently since 1999. The first system to be established was the BREEAM in 1999 and it was followed by many others such as LEED, which was started in the USA, in the year 2002.

4.4.1 Definition of methods

Environmental rating systems, such as the Leadership in Energy and Environmental Design (LEED), is defined as**:**

'Rating systems are groups of requirements for projects that want to achieve LEED certification. Each group is geared toward the unique needs of a project or building type' (Council, 2014).

4.4.2 Building rating systems

Rating systems have become a universal trend where many countries around the world are increasingly adopting a rating system for building constructions. Currently, there are about 40 rating systems around the world. Figure 4.2 presents some global systems around the world. The pioneering BREEAM system is an international system for evaluating sustainable green buildings and applicable in all types of climates; followed by GREEN GLOBS in Canada in 2000, LEED in the USA in 2002, CASBEE in Japan in 2002, and Green Star in Australia in 2008. Further, the rating systems are spread widely through the European continent, Asia, and America; and recently were introduced in Africa by the Green Building Councils or NGOs. Detailed on appendix-11. Table 4.1 and Figure 4.2 provide a summary of some global systems around the world.

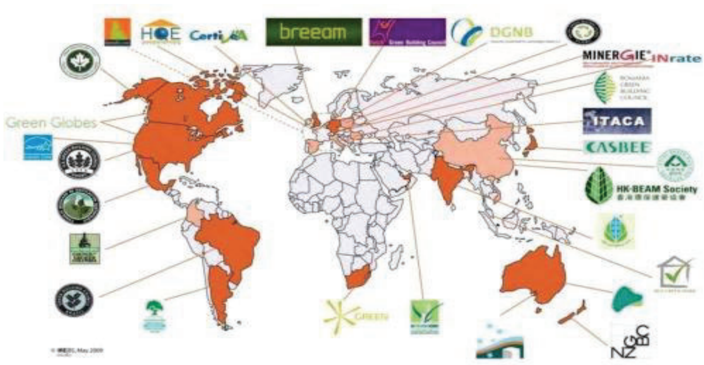


Figure 4.2: Rating systems around the world (Reed, 2009) and (Sustainable.com, 2014)

Table 4.1. Summary of the rating system around the world.

The Organization	Rating System name	Country	Year Of start
Australia Green Building Council (Council, 2015)	Green Star	Australia	2008
Green Building Council Brazil (Brasil, 2015)	LEED Brazil	Brazil	2007
Indian Green Building Council (IGBC) (Council, 2015)	GRIHA	India	2005
Green Building Council Indonesia (Indonesia, 2015)	(GBCI) / Green ship	Indonesia	2009
Green Building Council Malaysia (Malysia, 2015)	GBI Malaysia	Malaysia	2008
Mexico Green Building Council (Council, 2015)	LEED Mexico	Mexico	2007
Global Sustainable Assessment System (GSAS).	GSAS	Qatar	2009
Dutch Green Building Council (Council, 2015)	BREEAM	Netherlands	2008
United State Green Building Council (Council,u.s.g.b,1996)	LEED	United State	2006
BREEAM Green Building Council	BREEAM	United Kingdom	1999
ESTIDAMA Green Building Council	ESTEDAMA	United Arab Emirates	2009
Living Building Challenge (Institute, 2019)	International living Future Institute	Seattle	2016

Source: Adapted by the researcher.

4.4.3 Comparison between five global systems

The aim of this comparison is to outline the main categories developed by these global rating systems. These are the sustainable site, indoor environmental quality, materials, water efficiency, power supply systems, and innovations. Sub categories were added in accordance with their social, cultural, economic and legislative conditions.

4.4.3.1 The previous studies

A study was presented by WAN (2014) in a paper on Energy Star, Green Globes, BREEAM, CASBEE, NABERS, High-quality environmental standards, HK BEAM, Green Mark Scheme, GB Tools, and GBI. The paper discussed each system's process, content, main categories, and issues and also rationalized the GBI system in Malaysia. Second, a study was conducted by Fenner (2008) that discussed LEED and BREEAM; tackling the main categories, rating methods, assessment costs, and accessibility vision for the future. Third, Chaimosy (2006) provided analysis of the development of LEED and Green Globes; and analysed the Life Cycle Analysis (LCA), providing a preliminary assessment of its environmental relevance. Fourth, Fowler (2006) provided a report that deeply analysed LEED, CASBEE, GB Tools and Green Globes. The report revised the methods' usability, durability, and main categories. Fifth, a paper was written by Haapio (2007) that studied the existing environmental assessment tools and the main categories. The paper also assessed buildings and users of the tools.

The researcher conducted a comparison between the five selected sustainable building assessment methods in order to determine common principles between them. These global systems are as follows: Leadership in Energy and

Environmental Design (LEED), the Environmental Assessment Methods (BREEAM), Green Star Rating System of the Green Building Council of Australia, Qatar Global Sustainability Assessment System (GSAS), ESTIDAMA Environmental Assessment System, and Saudi Green Building Forum (SGBF). The details of the comparison were added to (Appendix-11).

4.4.3.2 Objectives of the comparison

(i) To identify the definition of the rating system.

(ii) To introduce the international sustainable rating systems for purposes of discussion in the study: ESTIDAM and GSAS, LEED V4, Australia Green Star Building Rating System (AGB) and BREEAM.

(iii) To study and discuss the systems in the process, categories, sub-issues, development, applicability, similarities and differences.

(iv) To assess if they are suitable for application in hot dry climates or a modified version is necessitated in the study area.

(v) To give guidelines for a sustainable assessment method for hot dry climates.

Appendix-11 presents comprehensive information about the globally sustainable building assessment methods, LEED, BREEAM, AGBC of Australia, GSAS, ESTIDAMA and SGBF in the main process, main categories, weighing and method of evaluation.

4.4.4 The main categories of global assessment methods.

Table 4.2 concludes the main categories of the global assessment methods and the common points, i.e., sustainable site, indoor environmental quality, energy, water, and materials.

Legend for Table 4.2:

- ● signifies an applicable solution to the building
- ○ signifies a non-applicable solution to the building

Correspondingly, the architect or professional associate decides if the solution is applicable or not applicable to the building.

Table 4.2. The main categories of global building assessment methods

The main Categories	LEED V4	Australia green star rating system	BREAM	ESTIDAMA	GSAS
Sustainable Site	●	●	○	○	●
Indoor environmental quality	●	●	○	○	●
Energy and atmosphere	●	●	●	●	●
Water Efficiency	●	●	●	●	●
Material and resources	●	●	●	●	●
Innovation in design	●	●	●	●	●
Regional priority	●	○	○	○	○
Management and operation	○	●	●	○	●
Transportation	○	●	●	○	○
Land Ecology	○	●	●	○	○
Urban community	○	○	○	●	●
Culture and economic value	○	○	○	○	●
Integrated development process	○	○	●	●	○
Natural system	○	○	●	●	○
Pollution	○	○	●	○	○
Health	○	○	●	○	○

Source: Abdelmoneim, H. 2016

From the table 4.2, which presents a comparison between the five global systems the researcher highlights the following points:

I. The five global systems demonstrate similarities for the following factors: Sustainable site, indoor environmental quality, building materials, energy and water.

II. Additional diverse categories were added by these countries to solve specific local - environmental, social and economic problems.

III. Lastly, from the researcher's perspectives, within the context of Khartoum residential buildings, categories like; outdoor environment, land ecology, health and integrated development process could be significantly useful. See (appendix-11) for a complete comparison.

4.5 Locally

Khalil (2014) stated that developing countries need to adopt sustainable development objectives. And even though sustainability assessment tools began to appear in response to their needs and residential projects, it is difficult to implement the same due to the different environmental, social and economic conditions. Khalil (2014) presented a review of the residential project sustainability assessment tools in both developed and developing countries. The results are optimally reflective of the national sustainable development priorities. Khalil (2014) used LEED-ND, BREEAM, and CASBEE systems for his study and discussed that his study reflects the social and economic needs of Greater Khartoum. He furthermore suggested to include energy, natural system, materials, society, services, business and creative design in evaluating sustainable projects in Greater Khartoum.

Sustainable assessment method for projects that have been presented by Khalil is undoubtedly a good start for assessment methods. However, we need to think of applying sustainable assessment tools to evaluate residential buildings in Greater Khartoum in all other parameters such as sustainable site, indoor environment, outdoor environment, services including energy, water, and materials.

4.6 PROPOSED METHOD OF ASSESSMENT

Before embarking on the details of the proposed method of assessment, it is necessary to note the following:

a. Comparison analysis and discussions were conducted on the different sustainable assessment methods. This revealed similarities and differences between their main categories. The similarities included sustainable site, indoor environmental quality, energy, water and materials. The differences were the additional categories that each country added to suit their local environment, social and economic aspects; and also, to address their local problems like the waste, pollution, health well-being, ecological features, cultural values, innovation, regional priority, environmental design process, transportation, and site management. See Table 4.6.

b. The current research proposed to incorporate the five common categories between the global standards, which are the sustainable site, indoor environment, energy, water, and materials. It also included some sub-issues suitable to our local environment, such as heat island effect, site development, alternative transportation access, energy performance optimization, on-site renewable energy, waste management construction, materials reuse, recycled content, regional materials, certified wood, and Life Cycle Analysis (LCA).

c. From the comparative analysis, the researcher inferred certain relevant aspects needed in conducting an in-depth study of the residential buildings in Greater Khartoum. These aspects included the outdoor environment, land ecology, health, and integrated development process, which could, in fact, be useful for Khartoum residential buildings.

d. The research is proposing a sustainable assessment method, which is perceived to be suitable for the hot-dry climate and provides solutions that improve the indoor environment.

e. Why do we need to add a new sustainable assessment method that is suitable to Greater Khartoum?

The globally sustainable building assessment methods were introduced in specific countries with the custom purpose to solve the local environmental, cultural, economic, and social problems. For instance, Australia introduced management, transportation, and land ecology, ESTIDAMA liveable community, and integrated design process, and GSAS social, and culture. Evidently, all these countries had their own sustainable evaluation methods, and corresponding similar as well as different categories for solving their local social, economic, and environmental problems. Other categories; such as studying the outdoor environment, building forms, environmental design processes, and drainage systems were also considered.

f. The need to add more categories to solve the local environmental, social, and economic problems

The research introduced categories; the following building forms, outdoor environment, and environmental design process because they are important for areas with hot-dry climates like Greater Khartoum. Figure 2.6 shows these additional sustainable principles in addition to the five global or fixed principles for ecological design that have been demonstrated in this chapter. These principles are discussed in the following paragraphs:

i) The Outdoor Environmental Quality: This was integrated for the intersecting social and environmental impact because people use the outdoor environment for social activities, like sitting, welcoming their guests, celebrating, and sometimes sleeping in hot summers. In addition, the researcher added solutions, such as the use of canopies, terraces, areas with shade, plants , and trees, fountains, and the like to cool the air surrounding the buildings.

ii) The Building Form: This principle was included for the associated economic and environmental impact. Studying the building form with solar angle was deemed necessary. As this aspect of building form provides more shade to the building, and cools the air around the building, and for energy efficiency, studying the windows, vertical, and horizontal sunscreens, wind towers, and courtyard system was seen to be more effective.

iii) Environmental design process: It is essential to study this aspect for two primary reasons. Firstly, to control the whole design process including the eight categories, and secondly for academic reason, to educate the architects, and engineers, and the community about sustainability. Fig.4.3 shows the main principles of sustainable eco buildings for research method of assessment.

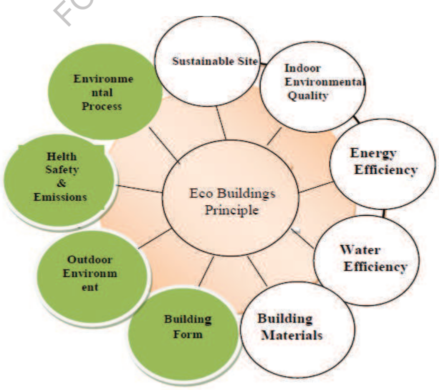


Figure 4.3: Diagrammatic presentation shows the main principles of eco-building and additional principles according to environmental requirements. **Source:** Adopted by the researcher in the green circles.The white cilcles adopted by RIBA and U.S.G.B.C and other global councils.

The Green circles are new principles of Eco Design adapted by researcher

The white circles are basic principles of eco-design from RIBA, USGBC, and others NGOs. Like sustainable site, indoor environmental quality, energy efficiency, water and building materials.

4.7 Summary

A comprehensive literature review was done in chapter two in Sustainable Development principles and Thermal Environment. In addition, chapter three is focus in Greater Khartoum conditions; environmentally, residential and technically.

In the current chapter, three methods for the assessment of the environment were reviewed, namely, (i) the quantitative assessment methods; (ii) the qualitative assessment methods, and (iii) the sustainable environmental assessment methods.

- Correspondingly, the researcher studied five sustainable environmental assessment methods, which are BREEAM, LEED, GSAS, GREEN STAR, and ESTIDAMA.
- The comparison revealed several similarities, and differences among the five global systems, thus highlighting five common categorizations: The sustainable site, energy, water, indoor environment, and materials.
- The evaluation method employed in this study is point-based. As observed, each system added more categories with the purpose to address its local environmental, social, and economic concerns.
- In alignment, several other categories were also pointed out by the researcher, which, in fact, highlighted the need to add these categories for the use of evaluating residential buildings in Greater Khartoum. These categories can be presented as (i) The outdoor environment; (ii) The building forms; and (iii) The environmental design process. In the following section, details of the research proposed method are discussed.

CHAPTER FIVE

METHODOLOGY

CHAPTER FIVE
METHODOLOGY

5.1 INTRODUCTION

The objective of this chapter is to describe the methodology of the study. It aims at introducing a sustainable-eco-building evaluation method for testing the case studies, i.e. the residential buildings in Greater Khartoum. Consequently, the research presented a review of sustainable assessment methods in chapter four. Moreover, the study discussions led to a rationalization for the study's method of assessment. Consequently, three additional categories were found to be necessary during the study, i.e., the outdoor environment, the building form, and the environmental design process.

The research method of assessment is structured accordingly to cover the new building construction operation and maintenance. As illustrated in Figure 5.1, the methodology illustrates the mechanism of incorporating principles of sustainability into the nature of the case studies. This chapter details the evaluation method of the research and its application to all the case studies included in the current study. It also details the main categories, the sub-issues, the scale of evaluation, and the problems faced in the design, and construct of the assessment method. After identifying the fieldwork methodology; the study defined and conducted fieldwork steps, and data collection. Wherein, data sources, i.e., owners, and professionals were interviewed for data collection. The chapter includes the criteria for selecting the case studies and samples from the study areas. The tools used in the survey, and the process of documentation, and presentation of information are also discussed in this chapter.

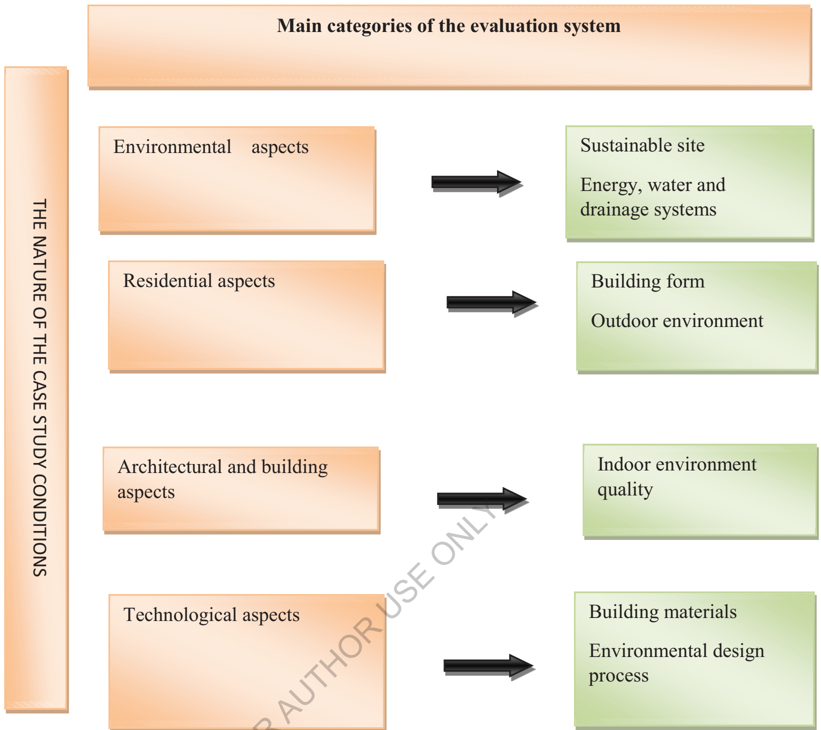


Figure 5.1: The nature of the case studies showing the eight main categories of the evaluation system (adapted by the researcher).

The nature of the case studies in the context of the environmental, spatial, technological, residential aspects of residential buildings in Greater Khartoum has been studied in chapter three, continued in Appendix-10.

5.2 Environmental, culture, social and economic background about Greater Khartoum

- Greater Khartoum straddles at the confluence of the Blue, and White Nile that covers some 28,000 km^2. It lies at latitude 15° 36’ North, and longitude 32° 3 East, with an altitude of 380 meters above sea level.

- Khartoum’s climate is characterised by its hot and dry nature. In addition, the intensive heat resulting from the blowing of dust storms (i.e., Haboobs) from the South East direction. Moreover, it is rich by natural resources such as solar energy wind energy, hydroelectric energy, underground heat energy, biomass energy, and natural gas.

- Many local building materials are available, such as stones, sand, gravel, clay, concrete, bricks and hollow blocks.

- Greater Khartoum characterized by malty culture residents from north, south, east and west of Sudan and this can reflect on building elevations and spatial areas.

- The outdoor environment is very important for Sudanese people and it has high significance, which could be attributed to excessive social activities oriented towards outdoor ambience. For example, sitting, welcoming guests, celebrations ceremony or sleeping at night, praying and sitting with the family.

- On the other hand, there are many problems like massive heat facing the buildings most of the year during May extend to Oct, dry air, rainy season sometimes flooding. In addition problems of services; the energy shortage most of the time, and water shortage, low quality of water, and high prices of providing the services.

- All these environmental, social, economic issues took into account when designing the research method of assessment.

5.3 The Study Method Of Assessment

- The methodology starting by studying a comprehensive literature review during the period (2013 to 2019).
  In sustainable development and thermal environment in chapter two, in addition, the environmental, economic and social background about Greater Khartoum in Chapter three.
- Consequently, the methodology is based on an in-depth analysis of existing rating systems and entails assessing their suitability for application, and subsequent modification to suit Khartoum. A pilot study applying LEED was done to compare the rationale for the modification, and is presented in the following discussion:

(i) The global systems are not applicable to the current study focusing on Greater Khartoum because they were designed for a specific culture with indigenous social and economic aspects pertaining to different countries. A few of the solutions offered by them will not be suitable for the study area's climate, social, and economically affordable resources. The researcher applied LEED v4 system to 48 case studies (Appendix-2), and it found that several solutions are not applicable in Sudan for an economic reason like the subway in the transportation system, applying of solar energy panels, etc. The results were recorded by LEED V4, and showed a lower grade, i.e., 6.66 % are silver; 39.5 % are certified, and 52% are not certified.

(ii) Therefore, the researcher contemplated including additional principles, which would be applicable to the Greater Khartoum climate, social, culture, and economic factors.

(iii) These aspects have been discussed in chapter three, and correspondingly these solutions present feasibility in terms of affordability to the people as per the available resources. The researcher also has deliberated on several passive solutions as discussed in chapter two, like architecture elements, courtyard system, wind tower, studying building ventilation, and orientation addressing the indoor environment. Furthermore, building landscape has been addressed in an outdoor environment, building form towards providing more shades to cool down the air surrounding the building. In addition, the environmental design process which controls the whole process with an educational value about sustainability to the community has also been discussed.

(iv) The importance of missing factors: The researcher analysed the required factors within the context of three primary sustainability aspects (i.e., economically, socially, environmentally). It was considered imperative that concurrently the solutions should be of passive nature, integrated within the design itself, and economic. Thus, the researcher identified <u>three additional principles.</u>

See Figure 5.2, which shows the relationship between the principles of sustainable eco buildings set up by SEBAM.

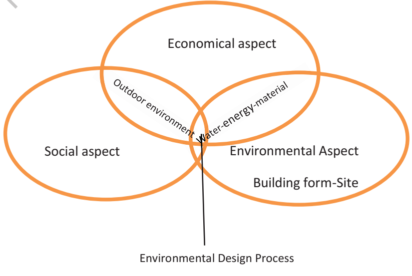


Figure 5.2: The relationship between principles of the sustainable eco building set up by SEBAM.
Source: Adapted by the researcher.

(i) The social aspect identified by studying the outdoor environment is considered as one of the main principles of SEBAM. Particularly, in Greater

Khartoum, the outdoor environment has high significance, which can be attributed to excessive social activities oriented towards outdoor ambience.

(ii) The economic aspect has been purposely identified in studying of the energy efficiency, water efficiency, and material quality. These elements were identified through a comparative analysis of the five global standards. In addition, the researcher added the Environmental Design Process (EDP) to control the whole design process and also to enhance academic value to the community in lectures, conferences and workshops.

(iii) The environmental aspect has also been identified in studying building form, and as discussed in chapter two, pertains specifically to give more shades and cool down the surrounding air.
The study method of assessment will be explained and detailed in the following paragraphs.

5.3.1 Development of the study method of assessment

The research method of assessment has been developed using different methods:

1. An intensive literature review in the area of the study.
2. Analysis and identification of five global assessment methods of sustainable buildings and their main categories.
3. After studying the environmental conditions in Greater Khartoum, the researcher identified three categories specifically suitable to the hot-dry climate.
4. Specific sub-issues were developed to support the research method of assessment in the field of sustainable buildings (see Appendix-6). Certain solutions were included when reviewing the literature on traditional solutions such as the use of courtyard systems, wind towers,

domes and vaults' effects on solar radiation absorption. More solutions were also included based on several practical experiences, such as the use of vertical and horizontal sunscreens, orientating the building at 45˚, and the use of wells and septic tanks in drainage systems. Technological solutions, globally and regionally, have also been introduced using the energy simulations programme to achieve energy efficiency and BIM software to develop eco building designs in computers.

5. Local natural resources in wind energy, solar energy, eco-building materials were studied and imposed in the research method of assessment.

5.3.2 Scale of evaluation

The study adopts a 5-category semantic differential scale, which is subsequently used in the research method of assessment to evaluate residential buildings in Greater Khartoum. Table 5.1 shows the evaluation scale.

Table 5.1: The scale of evaluation

The Mandatory	Meaning	Evaluation and justification	Points are given for evaluation
Positive	Means it's applicable		From 1 to 2
	More Positive impact on the environment	Better	2
	The Positive impact on the environment	Good	1
Fair	Means it's inapplicable	Fair	0
Negative	The negative impact on the environment	Bad	-1
	The too negative impact to the environment	Worse	-2

Source: Adapted by the researcher.

This kind of scale is called (semantic differential scale) - it could be 3, 5 or 7, point scale. Each point is according to its importance and impact on the environment. See (Appendix-1) and (Appendix-2).

5.3.3 Justifications of the Points Scaling System

(i) Justification of the weight for each major category

In general, SEBAM has eight main categories, and the sustainable site has six main issues with a total of 12 points. Indoor environmental quality has seven main issues with total 30 points, outdoor environment has eight main issues with total 9 points, and building form has eight main issues with total 8 points. Material and resources has thirteen main issues with 34 points, water supply and drainage system six main issues with 16 points, power supply has four main issues with 16 points and environmental design process with one point. (See Appendix-1).

For example, site selection takes one point to reduce the environmental impact from the location, which includes the study of accessibility, plot size, plot orientation, site content, views and neighbours. The construction system earns 3/12 equivalent weight of 0.25 to study the construction like concrete (0.08), loadbearing (0.08) and steel (0.08). Controlling systems earn 3/12 points for parking control (0.25), construction activity control (0.08) and natural water features control (0.08). Transportation earns 3/12 points for public transportation access (0.08), bicycle storage (0.08) and fuel control (0.08). Outdoor environmental control earns 2/12 points equivalent weight of 0.25 for the maximized outdoor environment (0.08) and landscape on site (0.08). Heat island effect takes 1 point. The total points for “sustainable site” are 12 points according to the detailed issues and sub-issues of the category. Each issue was evaluated according to the scale for the study method of assessment and in consideration of its importance and impact on the environment.

(ii) Explanation of the scale itself used in Table 5.1:

- Some solutions received (0) points like the use of generator because it has one positive result like cover the electricity shortcut; on the other hand, it has one negative result increase the CO_2 emission, so it was evaluated as zero points.
- Some solutions received (2) points, because of more positive impact on the environment, like the use of the courtyard system, use of wind tower because, and additionally due to higher significance compared to other solutions.
- Some solutions received (-1) point, because of their negative impact on the environment, like the use of air condition window type or split unit, which thus highlight the imperative selection of the eco solutions.
- Most of the solutions scored (1) point, because of their positive impact on the environment, due to their quality of good solutions like the heat island effect.

5.3.4 Method of evaluation

The suggested sustainable-eco-building evaluation method for hot-dry climates, such as Greater Khartoum, which is applied in this research at the level of eco buildings on 48 case studies in Greater Khartoum, is shown in Appendix-1.

Consequently, this contains eight main categories: sustainable site, indoor environmental quality, building forms, outdoor environment, materials and resources, water supply and drainage systems, power supply systems, and environmental design processes. Accordingly, the total points that should be scored are 125 points to indicate adherence to a sustainable eco-building.

(i) Moreover, this system is intended to be better than five other global systems that were reviewed earlier in chapter four (detailed in Appendix-11), as it includes three key categories that are deemed important for Khartoum.

(ii) Accordingly, SEBAM was proved better than other global systems for this particular study on comparison with LEED v4 system, see (Appendix-2) In addition, (Appendix-3). The researcher applied LEED v4 system to 48 samples and revealed limitations of many solutions for the Khartoum region, in terms of economic principles like the subway execution in the transportation system, application of solar energy panels, and more (See Appendix-3); the results are presented in tables and figures. The results demonstrated a lower grade through the application of LEED system (i.e., 6.66 % are silver, 39.5 % are certified and 52% are not certified). On the other hand, SEBAM results demonstrated that 20.8% are good, 25 % are pass, and 54 % are weak. The researcher thus inferred that the SEBAM system gives a more realistic result than LEED tends to underestimate the environmental performance of Sudanese houses.

In addition, the researcher applied five global systems in one case study in Greater Khartoum (the result is recorded in Appendix-10). In comparison, evidently, the result by SEBAM scored more points, because it covers missing or neglected aspects. This neglect results in underestimating of performance. In addition, it could be safely inferred that SEBAM is theoretically better as it adds more passive solutions, with optimal suitability to hot-dry climates, such as Greater Khartoum. Also as regards building orientation, building ventilation, wind tower, courtyard system and other solutions, the researcher has detailed the description in Section 5.3, expanding on its eight main categories.

Moreover, These levels of evaluation were included in reference to the British Standards of Green Buildings (BREEAM, 2014) that uses the same method of evaluation (i.e., weak, pass, good, very good, excellent), and thus presents better suitability and applicability in Greater Khartoum educational scale. Similar to BREEAM, this method gives five main evaluation ranges of points.

The study identified the minimum points as 40 points. This can be explained as follows: In 2009, LEED V3 had minimum credits of 38 points; now LEED V4 has announced the minimum credits to be 40 points. GSAS requires 50 points for a minimum equivalent to 2 stars; ESTIDAMA requires 55 points for a minimum equivalent to 2 pearls, and BREEAM requires 40 points for a minimum to pass. The researcher decided to identify 40 points because, until 2017, this standard has been identified as the minimum qualification criteria amongst the global requirements that are applicable and suitable to the case study conditions. The following levels were identified after a review of the global methods in chapter four:

< 40	Weak
(41 - 44 points)	Pass
(45 - 59 points)	Good
(60 - 75 points)	Very good
(76 – 126 points and more)	Excellent (see Appendix-1 and Table 5.2)

5.3.5 Reasons for scale

Table 5.2 shows the evacuation scale, the range of points and the reason for specific evaluation.

Table 5.2. The evaluation scale, the range of points, weight and reasons.

Evacuation	Range in points	Relative weight	Reason
Weak	**< 40**	**< 0.32**	The researcher identified the minimum acceptable points are 40 because the globally sustainable assessment method identifies minimum acceptable points as 40 like LEED system. This level shows the limited solutions like

			limited plot area, landscape and poor structure system.
Pass	**41-44**	**0.328-0.352**	In addition; the researcher identified this range as pass, after the survey of 48 samples, it was noticed that the limitation of good solutions. This level shows the basic solutions, like limited plot area, lack of landscape, good/bad ventilation and right orientation.
Good	**45-59**	**0.288-0.376**	In addition, the researcher noticed after survey; most of the houses designed by famous architect have good solutions got points ranging from 44 to 49; so this level shows the good solutions like building ventilation, building orientation, local building material, good landscape.
Very good	**60-75**	**0.48-0.6**	The researcher identifies this level for special solutions like the use of natural resources of energy such as solar energy, wind energy. Few houses were found including this level.
Excellent	**76-125**	**0.608-1**	This level is identified for excellent achievement for those houses achieve points between 76 to 125 points.

Source: Adapted by the researcher

The Sustainable-Eco-Buildings Assessment Method (SEBAM) combines the main principles of sustainable-eco-building, which are the sustainable site, indoor environmental quality, building material, energy efficiency, and water efficiency, with passive solutions as identified in chapter two. Consequently, the method takes into account the environmental, spatial, architectural, residential, and technological conditions of the case studies. Additionally, plus three categories suitable to the local environmental, social and economic aspects were identified and integrated into the study analysis. Thereby, making the assessment method better and relevant. See (Appendix-1).

5.4 THE MAIN CATEGORIES OF SEBAM

Table 5.3 shows the main categories of the assessment method.

The comparison between five global sustainable building assessment methods identified five global categories, which are Sustainable Site (SS), Indoor Environmental Quality (IEQ), Material and Resources (M&R), and Water Supply and Drainage System (WS &DS). Furthermore, three categories were identified after studying the environmental conditions in Greater Khartoum, which are Outdoor Environmental Control (OTC), Building Form (BF) and Environmental Design Process.

Table 5.3. The main categories of the assessment method

item	Category	symbol	points	Equivalent weight
1	Sustainable Site	SS	12	10%
2	Indoor Environmental Quality	IEQ	30	24%
3	Outdoor Thermal Control	OTC	9	7%
4	Building Forms	BF	8	6.4%
5	Materials and Resources	M & R	34	27%
6	Water Supply and Drainage Systems	WS&DS	16	12.8%
7	Natural Power Supply	NPS	15	12%
8	Environmental Design Process	EDP	1	0.8%

(Source: Adapted by the researcher)

Table 5.3 shows the main categories of the assessment method. The following paragraphs explain precisely the meaning of each category.

5.4.1 Sustainable Site (SS)

Sustainable site deals with issues outside the building, i.e., the land that is being developed and the surrounding community. Appendix-5 shows the total points for the sustainable site, wherein, 12 points equal to 10% from 125 points. The sustainable site category contains six sub-issues. These are: site selection (1/12) equivalent weight (0.083); construction system (3/12) equivalent weight (0.25); controlling systems (3/12), i.e., parking control, construction activity control and natural water features. Alternative transportation (3/12), i.e., public transportation access, bicycle storage, and low emitting fuel. Improve thermal environment (2/12) equivalent weight (0.16), i.e., maximized open space and enhanced landscaping on site; and the study of the heat island effect (1/12) equivalent weight (0.083). All these sub-issues are detailed in Appendix-1 and Appendix-2, each sub-issue scores one or two points according to its importance and positive impact on the environment.

5.4.2 Indoor Environmental Quality (IEQ)

The Indoor Environmental Quality (IEQ) section deals with materials and systems inside the building that affect the health and comfort of the occupants and construction workers. The indoor environmental quality category of the method of assessment consists of seven sub-issues. See Appendix-1 and Appendix-2 for details on the assessment method, Appendix-5 for the requirements and benchmarks for the main categories of the assessment method of the research.

The total points that should be achieved are 30/125, which are equivalent to 24%. Indoor environmental quality has seven main issues and sub-issues. The first issue is the building orientation (4/30) which is equivalent to (0.13) and includes applying the building orientation to the North-South direction (1/30) which is equivalent to (0.03), to East-West direction (2/30) which is equivalent to (0.06). The second issue is to control building dimensions by applying surface-volume ratios, which should be between 0.12 to 0.16 to avoid exceeding solar radiation on the building (1/30). The third issue is roof thermal control (5/30) which is equivalent to (16.6) and includes roof thermal insulation (1/30), white colours (1/30), double roof (2/30), and green roof (1/30). The fourth issue is the study of wall thermal control (12/30) which is equivalent to (0.40) and includes building materials (1), windows (5) which is equivalent (0.16), shading devices (4/30) which is equivalent to (0.13), wall paints and colour (1), and green walls (1). The fifth issue is the study of floor thermal control (1/30); choosing the floor finishing material from an eco-floor material manufactured from recycled construction building materials such as concrete, stones, bricks, ceramics, and has long-term of durability, easy to clean, easy to maintain, durable to pressure, non-slippery, heat and moisture resistant. The recycling content is suitable to most of the residential buildings. The sixth issue is the design of thermal comfort (4/30) which is equivalent to (0.13) and includes individual thermal comfort (1/30), controlling the natural ventilation e.g. maximize the windows (1/30), the use of traditional solutions such as wind tower (1/30) and the courtyard system (1/30) that improves the air movement and air temperature in buildings. The seventh issue is supporting these solutions by mechanical means (3/30) which is equivalent to (0.10) such as using of fans, desert coolers or HVAC systems, which help in controlling the air temperature, air humidity and filtering the air from dust. These solutions vary in different residential areas. However, the use of an air conditioning system is evaluated as -1 point because it has a negative impact on the environment. Each sub-issue scores one or two points according to its importance and positive impact on the environment.

5.4.3. Outdoor Thermal Control (OTHC).

The researcher added the outdoor thermal control category. Table 1 in Appendix-1 mentions the details of the sub-issues of outdoor thermal control category. The total points achieved is 9/125 points, which are equivalent to (7), this number comes from detailed issues and sub-issues of outdoor thermal control category. Each sub-issue scores 1/9 points, which are equivalent to (0.11) or 2/7 points, which is equivalent to (0.22) according to their importance and positive impact on the environment. People in Greater Khartoum are aware of the outdoor environment because the climate is hot and dry. They spend part of their time, especially at nights, in the gardens, and furthermore, these outdoor settings are utilized during holidays and celebrations.

The issues as identified during the study analysis are (i) provide shades to the building in the North-South direction (2/9); (ii) provide shades to the East-West direction (1/9); (iii) provide shades using balconies (1/9); (iv) enhance landscaping on site using plants and trees that provide shades (1/9); (v) fifth issue is to build fences to protect the site from dust (1/9); (vi) build swimming pools (1/9); and (vii) apply fountains to change the dry climate into a humid climate (1/9) and also address eco building in (viii) design of the terraces (1/9). See Appendix-1 for the assessment method of the research and equivalent percentage, Appendix-2 for details, and Appendix-5 for the requirements and benchmarks for the main categories of the assessment method.

5.4.4. Building Form (BF)

The importance of including the building form parameter has been discussed in chapter two. Correspondingly, several works of literature has reviewed and discussed the significant issue of building form; Roaf (2001) discussed the concept to constitute the first principle of eco-building; Alwakil (1989) and MED-ENEC (2010) discussed the building form as one of the important solutions of passive solutions, particularly for the Middle East.

The researcher concurs that the building form could constitute a part of the indoor environment or a part of the environmental design process like other principles. Correspondingly, the factors of water, energy, material, and site present environmental, economic and social alignment, while, the outdoor environment shows environmental and social alignment (see Figure 2.2). Although, the building form presents association with the indoor environment, outdoor environment, and environmental design process; the researcher needs to highlight the pertinent issue of studying the building form as one of the important components of the passive solutions. The significance of studying this can also be attributed to the imperative need of studying the relation between solar angle and building form, identify, *and* select the best solution, which resultantly provides optimal shades to the building. The ideal shades would subsequently help in cooling the surrounding air of the building. See Appendix-1 for details on the sub-issues of building forms. Total points that should be achieved in the study analysis are 8. Each sub-issue scores 1 point according to its importance and positive impact on the environment.

In addition, LEED V4 did not add building form as a separate category, and likewise, the Council U. S. G. B. (2014) stated, "*Provide shade from structures covered by solar panels that produce energy used to offset some non-renewable resource use. Provide shade from architectural devices or structures that have a solar reflectance index SRI of at least 29. Implement a maintenance program that ensures these surfaces are cleaned at least every 2 years to maintain good* *reflectance".* This was added under the sustainable site category in LEED V3 and LEED V4. Further, Council U. S. G. B. (2014) mentioned, "*Naturally ventilated buildings must comply with a local standard that is equivalent to ASHRAE Standard 62.1-2007"*. It can be safely inferred that no specific category or sub-issue has been defined to specifically deal with the significant concept of building forms.

It is essential to deal with building forms to control building shades and natural ventilation through building orientation. The total points of building form are 8/125 points, which are equivalent to (6.4). These 8 points come from the detailed sub-issues. The research draws details such as linear forms (1/8) which is equivalent to (0.125), U-shaped forms (1/8), L-shaped forms (1/8), cubic forms (1/8), circular forms (1/8), courtyard systems (1/8), use of vaults (1/8), and use of domes (1/8).

See Appendix-1 for the assessment method of the research, Appendix-2 for details, and Appendix-5 for the requirements and benchmarks for the main categories of the assessment method of the research.

5.4.5 Materials and Resources (M & R)

The materials and resources category has 13 credits with a total of 34 points. See Appendix-1 for details on the sub-issues of materials and resources category. Each sub-issue scores one or two points based on their importance and positive impact on the environment.

Materials and resources consist of 13 sub-issues. For sustainability, the total points of 34/125 points which equivalent to (27) should be achieved. This number of 34 points is achieved through the detailed issues and sub-issue of building material category. The first issue is the material used in the base like bricks, cement, gravel and stone (6/34) which are equivalent to (0.176). The second issue is the material used in walls like bricks, stone (9/34) which is equivalent to (0.264). The third issue is the material used in the roof like cement, bricks and wood (3/34) which is equivalent to (0.088). The fourth issue is the materials used in finishing such as wood and carpet (5/34) which is equivalent to (0.147). The fifth issue is the recycling of building materials such as recycled ceramic (2/34) which is equivalent to (0.058). The sixth issue is wall claddings (1/34) which is equivalent to (0.029). The seventh issue is indoor décor (3/34) which are equivalent to (0.088). The eighth issue is construction waste management (1/34) equivalent to (0.029), the ninth issue is calculating the embodied energy (1/34) which is equivalent to (0.029), and the tenth issue is life cycle analysis (LCA) (1/34). Which is equivalent to (0.029) the eleventh issue is adopting technologies (1/34) which is equivalent to (0.029) the twelfth issue is applying regional materials like wood and stones (1/34) which is equivalent (0.029) and the thirteenth issue is low emitting building materials (1/34) which is equivalent to (0.029).

See Appendix-1 for the assessment method of the research, Appendix-2 for details, and Appendix-5 for the requirements and benchmarks for the main categories of the assessment method of the research.

5.4.6 Water supply and drainage system (WS and DS)

The water supply and drainage system category have seven credits. The total points that should be achieved are 16/125 points, which are equivalent to (12.8). This number of 16 points comes from the detailed issues and sub-issues of water supply and drainage system. See Appendix-1 for details on the sub-issues of water supply and drainage system. Each sub-issue scores one or two points according to their importance and positive impact on the environment.

The first issue is choosing the appropriate technology for the drainage system (5/16) which is equivalent to (0.312). The second issue is studying the water source (3/16) which is equivalent to (0.187). The third issue is water efficiency (4/16) which is equivalent to (0.25). The fourth issue is rainwater container (1/16) which is equivalent to (0.062). The fifth issue is grey water recycled in the site location (1/16) which is equivalent to (0.062). The sixth issue is to reduce water usage (1/16) which is equivalent to (0.062). The seventh issue is to use water sense labelled products (1/16) which is equivalent to (0.062). Thus, on computation, it becomes a total of 16 points.

Most areas of Khartoum in the first and second urban areas use a septic tank and percolating well system due to the lack of a public sewerage system, which, in fact, is available in most of the new urban areas. This system is connected to an artesian well, which is usually about 15 to 50 meters in depth underground or until reaching the underground water bed. This system needs regular cleaning to secure continuous water flow and avoid clogging. Taking into consideration the continuous risks of floods during the raining season, regular maintenance is essential in order to guarantee an efficient system. See Appendix-1 for the assessment method of the research and Appendix-2 for details.

5.4.7 Power Supply System (PS).

The power supply system category has four credits with a total of 15/125 points, which are equivalent to (12). This figure of 15 points is deduced from the analysis a detailed issue and sub-issues of the power system. See Appendix-1 for details on the sub-issues of the power supply system category. Each sub-issue earns one or two points according to their importance and positive impact on the environment.

The first issue is studying the source of energy, i.e., an eco-building should cater to optimal use of natural resources such as solar energy and wind energy (6/15) which is equivalent to (0.4). The second issue is energy efficiency (1/15) which is equivalent to (0.06). The third issue is studying the applications (5/15) which is equivalent to (0.33). It has been observed that Khartoum gets adequate sunshine around the seasons, and can this availability of solar energy can be further utilized as a source of power in all buildings for various activities, lighting, cooking, heating, and cooling; storing this energy in batteries. The fourth issue is adaptive technologies, like photovoltaic technologies, using simulations and energy smart panels (3/15) which are equivalent to (0.20). Thus, it provides a total of 15 points.

See Appendix-1 for the assessment method of the research, Appendix-2 for details and Appendix-5 for the requirements and benchmarks for the main categories of the assessment method of the research.

5.4.8 Environmental Design Process (EDP)

The main scope of design is to apply the sustainable categories in the whole design process**.** The term holism has been used to describe the view that a whole system must be considered rather than simply its individual components, as shown in Figure 5.2. It is essential that a building should attempt to address all of the principles of green design in a holistic manner (Hyde, 2008). Correspondingly, the architects should consider the eight categories of the method of assessment of this research to be applied in the design process at all design levels. The total points in this category is one (1/125) which are equivalent to (0.008).

See Appendix-1 for the assessment method of the research points and equivalent. Appendix-5 for the requirements and benchmarks for the main categories of the assessment method of this research.

(i) Pre-building phase:

Pre-building phase is the design phase for the primary, developed and final designs; adopting the sustainable eco-building categories as its main goals.

(ii) Building phase:

Building phase is for the construction and system operations. In this level, one should deal with contractors and suppliers, applying appropriate technologies in mechanical systems, construction of waste disposals, and noise control from a site.

(iii) Post -building phase:

This level deals with users, after the construction of the building. The building should be maintained regularly in order to guarantee long life and durability. The building should be evaluated using an appropriate method of assessment. The more points you get the higher is the building level.

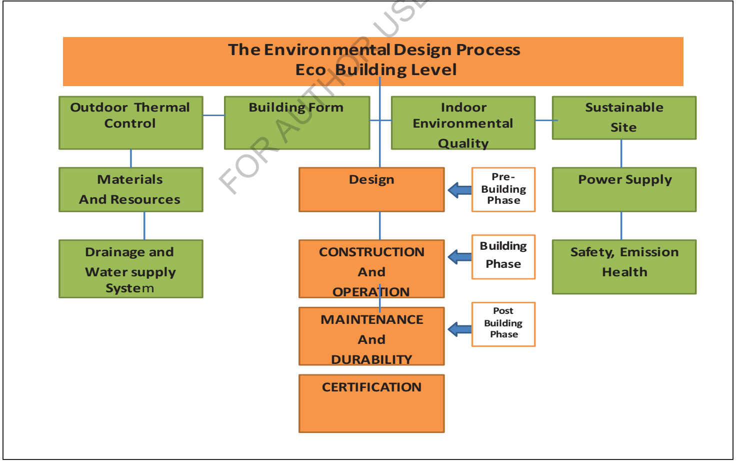


Figure 5.3: The environmental design process of eco- buildings. (Adapted by the researcher).

5.5 THE REQUIREMENTS AND BENCHMARKING

Benchmarking is the standard which is used for indoor and outdoor environmental quality and pertains to energy efficiency, water efficiency, testing method for materials and water quality, outdoor lighting quality, and air ventilation quality (see other benchmarking and requirements for all sustainable-eco-building categories in Appendix-5).

5.6 FIELDWORK PROCEDURES

For study purposes, a survey in different areas of Greater Khartoum was carried out over twelve potential settlements considered suitable for a detailed study. The study sample included some villas, and apartments. Through the methodology adopted in this research, it has been found that the system is suitable for hot-dry climates. It enabled the evaluation of the efficiency of eco designs applied in forty-eight case studies which were randomly sampled in Greater Khartoum, i.e., Khartoum, Khartoum North and Omdurman, during a period extending from 2013 to 2016 (see the locations of the case study samples in chapter six).

5.6.1 Method of selection of the samples

The case studies selected for this research are residential buildings in Greater Khartoum. The physical conditions have been discussed in chapter four. Greater Khartoum has a hot dry climate that affects the urban, architectural, physical, environmental and technological conditions; discussed previously in chapter two and three.

Allocated plot areas have encountered several changes in their dimensions and planning in the past, which are mostly government owned. The present residential areas are planned and classified into four classes based on income levels, building materials and services.

The infrastructure of Greater Khartoum that includes the environmental, residential, spatial and material aspects was discussed in chapter four. The energy supply in Greater Khartoum is sourced from the National Grid supplied from the Meroe and Rosaries dams. In addition, the water is supplied from the main station, the River Nile, underground water and rainwater. The building materials used in the first and second class residential areas are cement, bricks, and glass. The building materials used in the third class areas are bricks, wood and steel for roofing, doors, and windows; and illegally used light materials such as papers, strew or fabric.

The nature of each case study has been discussed in chapter three, the objectives and the hypothesis of this research has been discussed in chapter one. The selection of the sample was based on a set of criteria that covered a wide range of data particularly suitable for this study. Table 5.4 lists some neighbourhoods in Greater Khartoum with their date of origin and class level. The samples were divided into four groups based on the date of origin, the first group are the first class (El Taief, Kafoori and Al Rouda) the date of origin (1975-1992). The second group is the second class (Khartoum 2) date of origin (1951). The third group is the third class (Al Sahafa, Al Shabia and Al Morada) date of origin (1953-1963). The fourth group is the illegal area and does not have any specific date/period of origin. Table 5.4 shows a list of selected neighbourhoods in Greater Khartoum with their planning conditions and date of origin.

Table 5.4. List of some neighbourhoods in Greater Khartoum

Neighbourhood	Planning condition	Date of origin
El Taief	1st class	1975
Khartoum 2	2nd class	1951-1952
Al Shabia	3rd class	1961-1963
Al Morada	2nd /3rd class	1953
Al Sahafa	3rd / 4th class	1963

Kafoori	1st class	1992
Al Rouda	1st class	1992
Illegal	Unclassified	Existing/ demolished

Source: Hassan (1995).

(i) The case studies were divided into four groups according to their date of origin.

(ii) Group one covered the period of time from 1992 to 2017 in El Taief in Khartoum, Kafoori in Khartoum North and Al Rouda in Omdurman with plot area variation from 400 m^2 to 600 m^2.

(iii) Group two covered the period of time from 1951 to 1992 in Khartoum with plot areas from 800 m^2 to 400 m^2.

(iv) Group three covered the period of time from 1953 to 1963 in Al Sahafa middle, Al Shabia and Al Morada.

(v) Group four included the illegally constructed residential areas in West Sarya and as the area is an unplanned area, no specific date is available.

(vi) Samples cover different buildings types, villas, apartments, and single houses.

(vii) The sampled residential buildings were designed by specialist or consultant architects, and built by sub-contractors or by people in illegal areas.

(viii) The samples presented good solutions in mass because of their ventilation and orientation and windows design. Subsequently, the researcher applies research method of assessment (SEBAM) for further details.

(ix) Samples are selected for:

a. Studying the indoor environment, windows, ceilings, walls, floors, ventilation and lighting.

b. Studying the outdoor environment, parking, gardens, fountains, swimming pools, fences and terraces.

c. Studying their technical solutions in services such as water supply, waste management, and drainage systems.

d. Studying their building materials, recycled and eco building materials.

5.6.2 Samples size

Table 5.5: Shows the total number of houses in each neighbourhood and sample size. Note that the total number of houses was counted from Google Earth, 2019

Groups	Town	Name of the Area	Number of the samples	Number of houses in each neighbourhood	Sample size	Sample size %
1.Khartoum	1.1 Khartoum	El Taief	8	1000	0.008	0.8%
	1.2 Khartoum	Khartoum 2	5	1000	0.008	0.8%
	1.3 Khartoum	Al Sahafa Wasat	8	2000	0.004	0.4%
	1.4 Khartoum	Illegal, East and West Sarya	3	300	0.01	1.0%
2.Khartoum North	2.1 Khartoum North	Kafoori	5	500	0.01	1.0%
	2.2 Khartoum North	Al Shabiya	7	1000	0.007	0.7%
3.Om-Durman	3.1 Omdurman	Al Rouda	5	500	0.01	1%
	32 Omdurman	Al Mawrada	7	500	0.01	1%
			48	6800 sample house	0.007	0.7 %

Source: Google Earth Satellite image, 2019

Sample size = number of selected samples /Total number of houses

= 48 / 6800

=0.7 %

This sample size does not meet the 95%. Confidence level statistically; the researcher need more than 200 samples to achieve that. This sample size is in the limitations point 5.6.4.

5.6.3 Data Source

(i) Interviews with specialists and professionals

Unstructured interviews with the professionals are very important as they significantly contributed to developing the suggested assessment method.

The following points were considered to conducting the interviews with professionals:

a. The first type of interviews was carried with the specialists in the field of sustainable and ecological design; in the settings of conferences and workshops. These interviews were thus due to the particular set of academically oriented constructs were conducted in different periods during the research. Numerous discussions with professionals were held with a focus on the application of solar energy systems in Sudan (see Appendix-6). Sub-issues regarding the source of natural recourses of energy such as solar and wind energy were also included under the energy category.

(ii) Interviews with owners

Structured interviews with the building owners were integral to the collection of data of house units. This data constituted an essential part of the sustainable assessment method for this research. Meetings were held with the owners of the sample house units to fill in the research method of assessment sheet for data analysis. The interviews were taken at Khartoum, Khartoum North and Omdurman, in addition to the meetings with the owners of the house sample units.

a. Initially, the owners were asked questions pertaining to general information such as the location, plot size, the name of the owner, the name of the architect, the built-up area, the starting date of construction, and the finishing date of construction.

b. Following which, the owners were asked about the details of the main categories as outlined in the sustainable-eco-building sheet (see Appendix-1) and their answers were recorded accordingly for further evaluation (see Table 5.1).

c. Finally, the collected data was analysed (analysis presented in chapter six).

5.6.4 The limitations

The limitations of sample size because of the following reasons:

a. The samples of this study are different types of residential buildings including houses, villas and apartments from different areas in Greater Khartoum including the first class, second, third and illegal areas.

b. The researcher starts by the fact that large sample size gives more accurate and meaningful results with no hesitation, and gives more power to the study.

c. However, in this the research there are some reasons cause the limitations of sample size

(i) The economic reason, the more sample size you take in the survey it will cost money in transportation and in the analysis.

(ii) Conflict reason in the illegal areas, it is difficult to enter these areas alone because it's not safe.

(iii) The same result for the same group because of the limited solutions for sustainable-eco-buildings assessment method (SEBAM), the researcher notice that buildings in the first group got results between (40 to 50), while buildings in the third group got results between (20 to 30) and illegal areas got results between (16 to 17).

On the other hand Scott, 2016 stated that "*the mean value of a continuous outcome variable in one group differs significantly from that in another group from that in another group*". (Scott, 2016).

(iv) The logistical reason, (eg, large surveys are usually conducted by teams, not individuals).

5.6.5 Method of documentation

The survey tools used to collate data was all- expansive due to the varied nature of the methods used in the construction industry. Which included drawings, plans, sections, elevation sketches as well as photos of the house from the inside and outside. The idea was to show the criteria regarding the sustainable building principles of research method of assessment in the indoor and outdoor environment, site, energy, water, building forms and materials.

5.6.6 Presentation of fieldwork results

The fieldwork results are presented in chapter six, for each sample, in the form of tables, photos, pie and bar diagrams, etc. It included information about the name of the owner, name of the area, plot number, the plot size, name of the architect, the date of starting the construction, date of finishing the construction, the location as identified by Google maps, and the description of the house spaces. Further, many data were collected from each building as regards the site, indoor environment, outdoor environment, energy, water, form, and design process. Site visits and meetings with the owners were carried out, while applying the system sheet collected these data. The results were presented in tables, figures, and pie charts in chapter six. In addition, bar presentations have been used to present the relation of the points achieved to the available points. The pie charts present the statistics for the percentage for each category.

5.6.7 Method of analysis

(i) Application of sustainable-eco-building assessment method (see Appendix-1) for forty-eight case studies, then calculating the total number of points for each case study to get the result as good, pass, very good or excellent (see Table 7.1).

(ii) The tables, figures and pie diagram were designed using Microsoft Office Word software.

(iii) Microsoft Office Excel software formulas were used to calculate the average results for the main categories and sub-issues.

(iv) The percentage of each category was calculated through the formula:

(Number of points achieved / The number of points available) x *100.*

5.7 DISCUSSION OF ANALYSIS

The discussions pertained to the results derived from the analysis for each specific group. The discussions started by:

(i) Analysis of the average results for the main categories, and evaluation of the main categories of the sustainable-eco-building assessment method.

(ii) Followed by, an analysis of the sub-issues of each criterion.

(iii) Application of the procedure to case studies selected in the three cities.

(iv) General conclusions for the discussion and justifications are included in chapter seven in a table at the end of the chapter.

5. 8 Summary

This chapter discussed the sustainability assessment method in its scale, main categories, sub-issues and the method start by the following:

- The researcher reviewed the globally sustainable assessment methods, which presented several similarities and differences in their main categories. The similarities are found in the sustainable site, indoor environmental quality, energy, water, and materials. The differences are evident, similarly.
- In the additional categories, that each country added in order to align the solutions with their local environment in terms of social and economic aspects and achieve locally customised solutions.
- Then; the researcher has reflected upon the environmental, spatial, residential and technological aspects of the principles of sustainable-eco-buildings.
- Furthermore, the researcher has introduced, in the current study, three additional categories to the five common categories from the global

standards. Namely, (i) the outdoor environmental quality, (ii) building forms, and (iii) environmental design process (see Chapter Two).

- After that; the methodology was used to explain the research method of assessment, and Sustainable-Eco-Building Assessment Method (SEBAM) in main categories, which include sustainable site, indoor environmental control, outdoor environment, building forms, energy efficiency, drainage and water supply systems, building materials and environmental design process, the relative weight of main and subcategories is also explained. Furthermore, the system development, evaluation method. Finally; the fieldworks methodology, identifying the criteria of selecting the samples; and samples size, tools, documentation, analyses, and interviews were discussed in this chapter. In the following section, the fieldworks results and main observations will be presented.

CHAPTER SIX

FIELDWORK RESULTS

CHAPTER SIX

FIELDWORK RESULTS

6.1 INTRODUCTION

The aim of this chapter is to present the fieldwork results. The samples (48 case studies) were selected from different areas of Greater Khartoum. The chapter presents a general summary of information for each sample is given with results on sustainable- eco- building assessment method. The results are shown in figures, tables, pie charts and photos, subsequently analysed and discussed in chapter seven.

The survey was conducted in residential areas of Greater Khartoum. It includes El Taief (10 case studies), Al Sahafa Wasat (8 case studies) and Khartoum 2 (5 case studies). Then in the illegal areas of West Sarya (3 case studies); in Kafoori, Khartoum North (5 case studies), Al Shabia (7 case studies). In Omdurman in Al Rouda (5 case studies) and Al Mourada (7 case studies). Figure 6.1 shows the locations of selected samples in Greater Khartoum.

The presentations are in the form of photos, short notes and documents for each house i.e. plot size, the built-up area, and construction date. Further documentation shows the main items of sustainable design, which were identified in chapter two and discussed in chapter five. Information about these specific main categories is summarized in tables and figures for each sample.

6.2 SELECTION OF THE SAMPLES

The presented residential areas were selected from different areas in Greater Khartoum to represent the different residential building samples. Table 6.1 provides a list of the selected neighbourhoods and the number of house samples.

Table 6.1. The selected neighbourhoods and the number of samples

Groups	Town	Name of the Area	Number of the samples	Planning condition
1.Khartoum	1.1 Khartoum	El Taief	8	First class
	1.2 Khartoum	Khartoum 2	5	Second class
	1.3 Khartoum	Al Sahafa Wasat	8	Third class
	1.4 Khartoum	Illegal , East and West Sarya	3	Illegal
2.Khartoum North	2.1 Khartoum North	Kafoori	5	First class
	2.2 Khartoum North	Al Shabiya	7	Third class
3.Om- Durman	3.1 Omdurman	Al Rouda	5	First class
	32 Omdurman	Al Mawrada	7	Third class
Total number of samples=48				

Source: Adapted by the researcher

6.2.1 Samples' random selection techniques have been discussed in chapter five (point 5.5).

6.2.2 Samples' size

Table 6.2 shows allotment of land according to 1990-2017 plans

Table 6.2. Allotment of land according to 1990-2017 plans by income level

Income Group	Class	Percentage
High	First	5%-10%
Middle	Second	10%-20%
Low	Third	70%-75%
Lower	Fourth and illegal	5%

Source: Planning (2016).

Sample size = number of selected samples /Total number of houses

= 48 / 6800 =0.7 %, (See Table 5.5).

This sample size does not meet the 95%. Confidence level statistically; the researcher need more than 200 samples to achieve that. This sample size is in the limitations. See 5.6.4 in chapter 5.

6.3 NEIGHBOURHOODS AND HOUSE SAMPLES IN KHARTOUM

In the current study, four neighbourhoods in Khartoum were selected for the study. These include El Taief, Khartoum 2, Al Sahafa neighbourhoods and illegal areas. Khartoum consists of many neighbourhoods including El Taief, Khartoum 2, Al Sahafa Wasat neighbourhoods. Figure 6.2 shows Satellite photographs showing general layout of the selected neighbourhoods.

a. Greater Khartoum
b.El Taief /Khartoum
c. Khartoum two/Khartoum
d. Al Sahafa /Khartoum
e. Kafoori /Khartoum North
f. Al Shabia/Khartoum North
g. Al Rouda/Omdurman
h. Al Mawrada/Omdurman
I. Illegal areas in Khartoum

Figure 6.1: Satellite photographs showing general layout of the selected neighbourhoods. Source: Google map.

6.3.1 El Taief neighbourhood

For all study purposes, eight samples were selected from El Taief neighbourhood. These areas are located in the middle of square 23 and 22 in

Khartoum, and three samples are located on the Abdella El Taieb Street. (See Figure 6.2.). The area shows a shortage in water supply, and the water is sourced from the National Grid. Majority of people living in this neighbourhood use water recycling and present high water efficiency. The drainage systems are private; consisting of septic tanks and wells. The area sources its energy from the National Grid. Also the area showed maximized outdoor spaces in order to provide enough space for gardens. A wide range of building materials is used; such as bricks, gravel, sand, cement in building construction. Ceramic tiles, marble and porcelain tiles have been used in floors finishing. Cement tiles for the outdoor, and wood for roll-up window shutters is also evident. The buildings is constructed with R.C. Figure 6.2 and Table 6.2 show the samples' locations in El Taief.

Figure 6.2: The locations of case studies in El Taief neighbourhood (8 samples)
Table 6.3: The location of case studies samples in El Taief neighbourhood

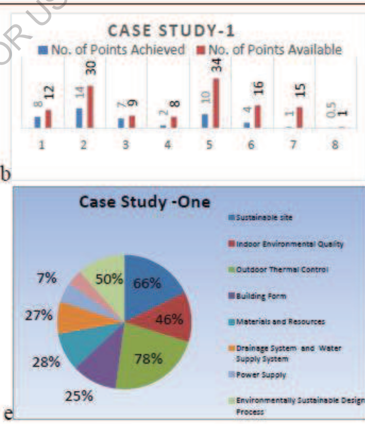
No. 1 Plot No: 365/1 Block No: 5	No. 5 Plot No: 9,10 Block No: 22
No. 2 Plot No: 214 Block No: 23	No. 6 Plot No:- Block No:
No. 3 Plot No: 215 Block No: 23	No. 7 Plot No: 847 Block No: 22
No. 4 Plot No: 215 Block No: 23	No. 8 Plot No: 14 Block No: 20

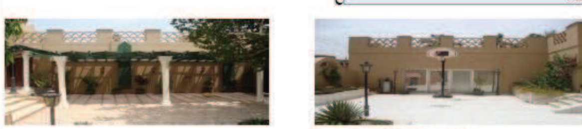
Sample No. 1, El Taief neighbourhood. Plot No: 365/1 Block No: 5

The sample was built in Khartoum city during the period 2000 – 2004. It was designed by architect Jack Ishkhanes. The windows are oriented to East-West direction, but the windows of the guest buildings are oriented to the North-South direction. As regards ventilation, it has been designed towards North-South direction for the main building and towards East-West for the guest building. For the outdoor thermal control the outdoor environment is well designed; there is a garden; additionally, there are fences, isolated car parking, balcony, terraces, and trees for providing shade. The architect has demonstrated the use of linear form, keeping the long side perpendicular to the wind direction and courtyard. Construction design elements have been used to provide shade in front of the main entrance, i.e., shade in front of the guesthouse, and vertical and horizontal sunscreens around the windows, the house is made of bricks, concrete and aluminium glass. Fig.6.3 sample 1.

	Main Categories	No. of Points Achieved	No. of Points Available	Number of credit
1	Sustainable site	8	12	66%
2	Indoor Environmental Quality	14	30	46 %
3	Outdoor Thermal Control	7	9	78%
4	Building Form	2	8	25%
5	Materials and Resources	10	34	29 %
6	Drainage System and Water Supply System	4	16	27%
7	Power Supply	1	15	7 %
8	Environmental Sustainable Design Process	0.5	1	50%
	Total points	47	125	GOOD

a





Pl.c The Main entrance

Pl.d The North elevation

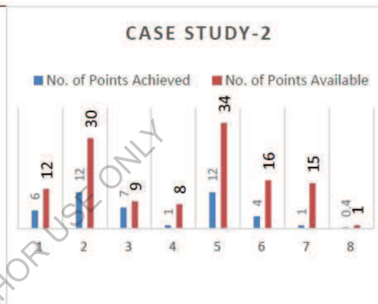
Figure 6.3: Sample 1, plot 365/1, block 5, El Taief. Table (a), Figure (b), Pl (c) and (d) and Pie (e) show the results of sample 1.

Sample No. 2. El Taief neighbourhood, Plot No: 214 Block No: 23

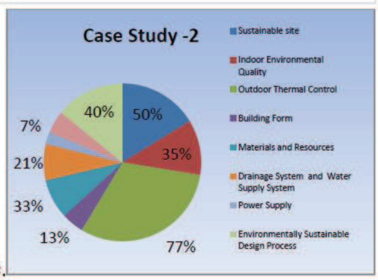
This house is located in El Taief neighbourhood in Khartoum town. It was built between 1984-1990 and is designed by architect Seif Sadig. The architect used the cubic form, the building is oriented to 45 degrees. Shade is available in many elements such as balconies and terraces. Ventilation is through large windows, which are oriented at 45-degree angle and covered by roll-up shutters; controlling the lighting and dust. The outdoor environment is well designed; there is a garden, in addition to fences and isolated car parking Figure 6.4. shows sample 2.

Main Categories	No. of Points Achieved	No. of Points Available	No Of Credit
Sustainable site	6	12	50%
Indoor Environmental Quality	12	30	35%
Outdoor Thermal Control	7	9	77%
Building Form	1	8	12.5%
Materials and Resources	12	34	33%
Water Supply System	4	16	21%
Power Supply	1	15	7%
Environmental Sustainable Design Process	0.40	1	40%
Total	**44 %**	125	Pass

a.



b.



e.

Pl (f) The South elevation

PL.(c): The East elevation

PL(d):The car parking

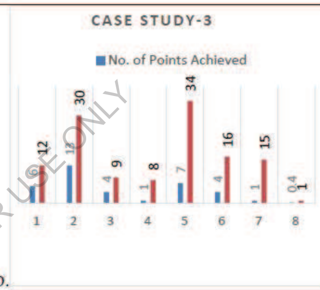
Figure 6.4: Sample 2, plot 214, block 23, El Taief, Table (a), Figure (b), Pl (c), Pl (d), Pl (f) and Pie (e) show the results of sample

Sample no. (3). El Taief neighbourhood. Plot No: 215, Block No: 23

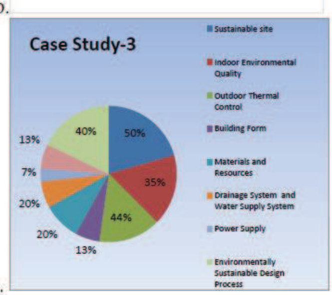
This house is located in El Taief neighbourhood in Khartoum town. It was built in the 1980s, designed by the architect Hassan Allam. The architect used the linear form and the building was oriented towards the North-South direction. Ventilation is maintained through large windows designed in the construction. This house has a large amount of glass without any protection. Some windows are oriented to the North-South direction, while others are located towards the East-West direction without providing any sun protection. The outdoor environment is well designed. There is a garden, in addition to fences, isolated car parking, a balcony, terraces and trees to provide shade.

Main Categories	No. of Points Achieved	No. of Points Available	No Of Credit
Sustainable site	6	12	50 %
Indoor Environmental Quality	13	30	35 %
Outdoor Thermal Control	4	9	44 %
Building Form	1	8	13 %
Materials and Resources	7	34	20 %
Water Supply System	4	16	20 %
Power Supply	1	15	7 %
Environmental Sustainable Design Process	0.4	1	40 %
Total	37%	125	PASS

a.



b.



e.

Pl. (f): South elevation

PL.(c):The North elevation

PL(d):West elevation

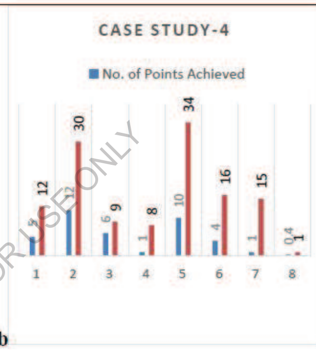
Figure 6.5: Sample 3, plot 215, block 23, El Taief, Table (a), Figure (b), Pl (c), Pl (d), Pl.(f) and Pie (e) show the results of sample 3

Sample No. 4. El Taief neighbourhood, Plot No: 215-Block No: 23

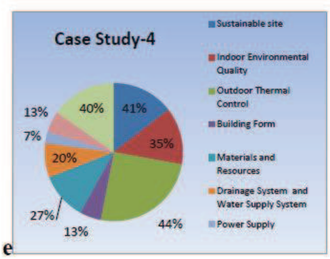
This house is located in El Taief neighbourhood in Khartoum town. It was built in the late 1990s, and was designed by a Chinese company for building construction, using curtain walls, glass, aluminium and roof clay tiles. With a linear form oriented to the north-south. There are many elements that provide shade such as balconies in the North and in the East-South facades. Ventilation is maintained through large windows directed towards the North-South direction. The outdoor environment is poorly designed; there are gardens, fences, a balcony, outdoor spaces and terraces (see Figure 6.6).

Main Categories	No. of Points Achieved	No. of Points Available	No Of Credit
Sustainable site	5	12	41%
Indoor Environmental Quality	12	30	35%
Outdoor Thermal Control	6	9	44%
Building Form	1	8	13%
Materials and Resources	10	34	29%
Water Supply System	4	16	20%
Power Supply	1	15	7%
Environmental Sustainable Design Process	0.4	1	40%
Total points	40%	125	PASS

a.



b



e

Pl.(f):South -East elevation

PLc:The south elevation

PL d: The East elevation

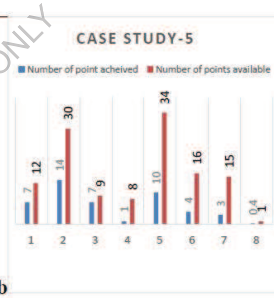
Figure 6.6: Sample 4, plot 215, block 23, El Taief. Table (a), Figure (b), Pl (c), Pl (d), Pl. (f) and Pie (e) show the results of sample 4.

Sample No. 5. El Taief neighbourhood, Plot No: 9, 10 - Block No: 22

This house was constructed during the period 2002-2007. Abdall Mohammed Mualla designed the house using glass and aluminium mixed with the traditional Islamic style such as; Mashrabia and arches. The architect used the linear form and the building is oriented towards the North-South direction. The architect has used a solar heating system. There are many elements that represent shade; there are balconies oriented to the North-direction and to the East-South direction. Ventilation is maintained through large windows directed towards the North-South direction, while other small windows are oriented towards the East-West direction. The outdoor environment is well designed and shows a large garden, in addition to high fences, shaded and isolated car parking, and large terraces (see Figure 6.7) shows sample 5.

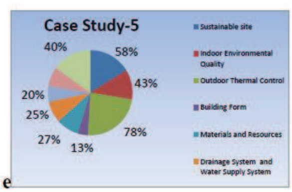
Main categories	Number of point acheived	Number of points available	
Sustainable site	7	12	58 %
Indoor Environmental Quality	14	30	43 %
Outdoor Thermal Control	7	9	78 %
Building Form	1	8	13%
Materials and Resources	10	34	29 %
Water Supply System	4	16	25 %
Power Supply	3	15	20%
Environmental Sustainable Design Process	0.4	1	40%
Total	48%	125	Good

a.



b

PL.f: Solar heating system



e

Pl c: The East elevation

Pl d: The North elevation

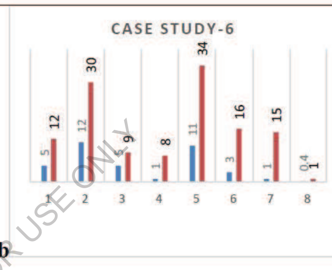
Figure 6.7: Sample 5, plot 910, block 22, El Taief. Table (a), Figure (b), Pl (c), Pl (d), Pl.(f) and Pie (e) show the results of sample 5.

Sample No. 6. El Taief neighbourhood, Plot No:300 - Block No: 68

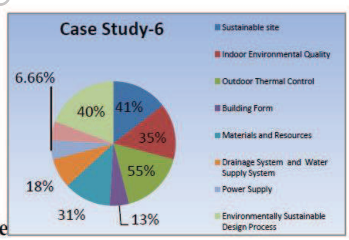
This apartment building is one of residential building including six apartments; located in Arkawit neighbourhood in Khartoum town. It was built during the period of 2002-2005. This building was designed by architect Abdelhalim Khider used glass, aluminium, and cladding. The architect used the cubic form with shades and balconies facing the North direction. Ventilation is maintained through the large windows directed towards the north and south. The building is oriented to the North-South direction. The outdoor environment is well designed and presents the construction of balconies (see Figure 6.8).

Main Categories	No. of Points Achieved	No. of Points Available	No Of Credit
Sustainable site	5	12	41%
Indoor Environmental Quality	12	30	35%
Outdoor Thermal Control	5	9	55%
Building Form	1	8	13%
Materials and Resources	11	34	32%
Water Supply System	3	16	18%
Power Supply	1	15	6.66%
Environmental Sustainable Design Process	0.40	1	40%
Total	38%	125	Pass

a.

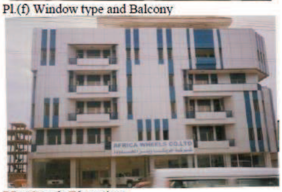


b



e

Pl.(f) Window type and Balcony



PLc:South Elevation

PLd :South -East Elevation

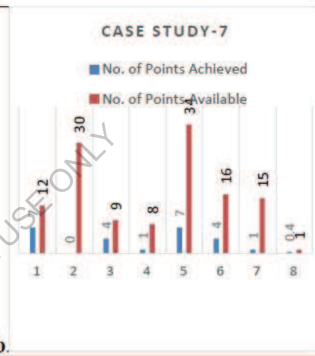
Figure 6.8: Sample 6, plot (300), block (68), Arkawit. Table (a), Figure (b), Pl (c), Pl (d), Pl (f) and Pie (e) show the results of sample 6.

Sample No. 7. El Taief neighbourhood, Plot No: 847 - Block No: 22

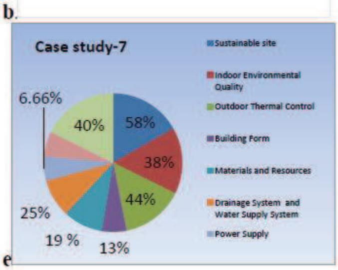
This apartment is one of 24 apartment buildings located in Khartoum town's El Taief neighbourhood. It was built during the period of 2002-2005. In this building, the architect has used glass and aluminium and cladding. The architect used the cubic form which is oriented to the East-West direction. There are many elements that provide shade such as balconies in the North direction. Ventilation is through large windows, which are directed towards the North and South directions. The outdoor environment is well designed and there are balconies (see Figure 6.9).

Main Categories	No. of Points Achieved	No. of Points Available	No Of Credit
Sustainable site	7	12	58%
Indoor Environmental Quality	1 3	30	38%
Outdoor Thermal Control	4	9	44%
Building Form	1	8	13%
Materials and Resources	7	34	20 %
Water and drainage Supply System	4	16	25%
Power Supply	1	15	6.66%
Environmental Sustainable Design Process	0.40	1	40%
Total points	38%	125	Pass

a.



b.



e

Pl (f) : South-West elevation

PL(c):East elevation

PL(d):North elevation

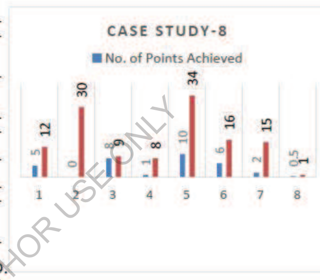
Figure 6.9: Sample 7, plot (847), block (22), El Taief. Table (a), Figure (b), Pl (c), Pl (d), Pl. (f) and Pie (e) show the results of sample 7.

Sample No. 8. El Riyadh neighbourhood, Plot No: 14, Block No: 20

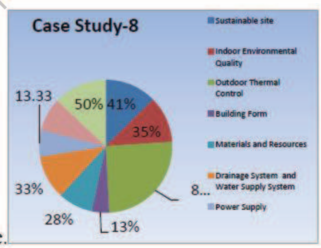
This house is located in El Riyadh neighbourhood in Khartoum city, designed by architect Murtada Muaz. It was built during the period of 2002-2005. The architect used glass, aluminium and cladding, a cubic form is used, and the building is oriented towards the East-West direction. There are many elements that provide shade such as balconies in the North direction. Ventilation is maintained through large windows directed towards the North and South directions. The outdoor environment is well designed; there are balconies and a swimming pool (see Figure 6.10).

Main Categories	No. of Points Achieved	No. of Points Available	No Of Credit	
Sustainable site	5	12	41%	
Indoor Environmental Quality	1 1	30	35%	
Outdoor Thermal Control	8	9	88%	
Building Form	1	8	13%	
Materials and Resources	10	34	29%	
Water Supply System	6	16	75%	
Power Supply	2	15	13.33 %	
Environmental Sustainable Design Process	0.5	1	50%	
Total	45	125	Good	

a.



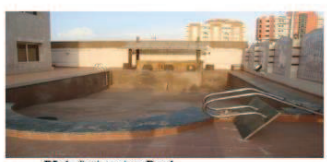
b.



e.

PLf: :West Elevation

PLc: Large Garden



PLd: Swimming Pool

Figure 6.10: Sample 8, plot 14, block 20, El Taief. Table (a), Figure (b), Pl (c) and (d) and Pie (e) show the results of sample 8.

6.3.2 Khartoum 2, Gereif West, Arkawit neighbourhoods

Three samples were selected from Khartoum 2 neighbourhood, one sample from Gereif West neighbourhood and the other sample from Arkawit neighbourhood, which is located in middle of Khartoum.

Water is sourced from the National Grid and the water deficiency is high, thus indicating a water supply shortage. Drainage systems include septic tanks and wells. The area's energy is supplied from the National Grid. The architects used a wide range of building materials such as marble, bricks, ceramic and cement tiles on the outdoor, and used roof clay tiles for windows. The buildings are constructed with R.C. skeletons and brick walls. Figure 6.11 and Table 6.3 show the locations of the samples in Khartoum 2.

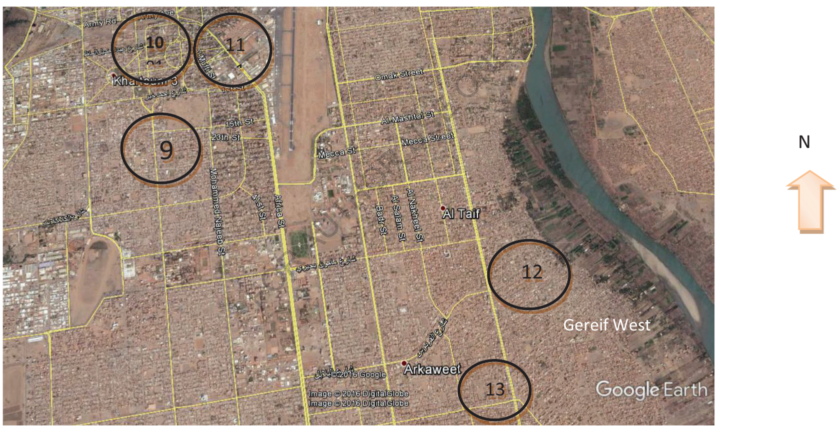


Figure 6.11: The location of the case studies in Khartoum 2 neighbourhood, Gereif West and Arkweit.

Table 6.4. The location of case studies in Khartoum 2 neighbourhood, Gereif West and Arkweit.

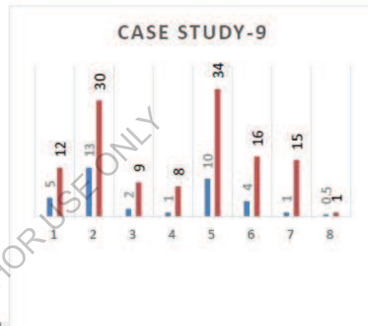
Sample No. 9. Plot No: 19, Street No: 53, Khartoum 2	Sample No. 12. Plot No: 365/1, Block No: 5, Gereif West
Sample No. 10. Plot No: 33, Street No: 47, Khartoum 2	Sample No. 13. Plot No: 285 Block No: 48, Arkweit
Sample No. 11. Plot No: 26, Street No: 49, Khartoum 2.	

Sample No. 9. Khartoum 2 neighbourhood, Plot No: 19, Street No: 53

This house is located in Khartoum 2 and was built in 1965. This house was designed by subcontractors and consists of five bedrooms, divided into three sections for three families in one big house. The house has one saloon, one veranda covered by a steel structure and false ceiling; it also has three bathrooms, and one is outside. The house is designed as large house, with large windows and brick walls. The indoor environment has several rooms with one saloon, one family hall and veranda. The architect used a linear form; walls are oriented to the East-West direction to allow good ventilation (see Figure 6.12).

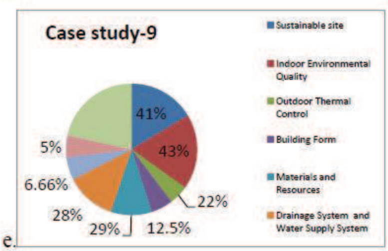
1	Sustainable site	5	12	41%
2	Indoor environmental quality	13	30	43%
3	Outdoor thermal control	2	9	22%
4	Building form	1	8	12.5%
5	Materials and resources	10	34	29%
6	Water supply system	4	16	28.5%
7	Power supply	1	15	6.66%
8	Environmental Design Process	0.5	1	50%
	Total	34.5%	125	Weak

a.



b.

Pl. f: Ceramic tiles on floor.



e.

PL c: North elevation

Pl.d:Courtyard with shade

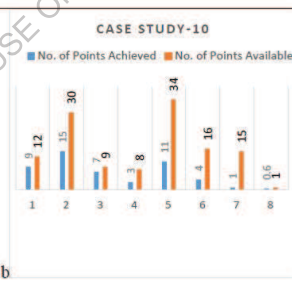
Figure 6.12: Sample 9, plot (19), street (53), Khartoum 2. Table (a), Figure (b), Pl (c), Pl (d), Pl. (f) and Pie (e) shows the results of sample 9.

Sample No. 10. Khartoum 2 neighbourhood, Plot No: 33, Street No: 47

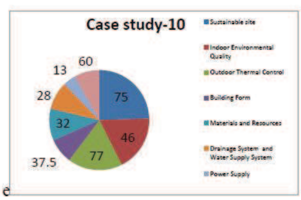
This house is located in Khartoum 2 neighbourhood. It was built during 1994-1998. The architect designed it as a villa with three stories. The ground floor consists of two separated saloons; one for men, the other for women. There is a kitchen and a section for services. There are three bathrooms. The first and second floors consist of four flats, two per each floor. The windows are oriented towards the North-South direction. The house is designed as a large villa, with large windows, brick walls, a concrete skeleton on ceiling, and aluminium windows with reflective glasses. The indoor environment uses nontoxic building materials, with exhaust fans for bathroom and kitchen. The building is oriented towards the East-West direction for good ventilation. The balconies are located in the North and West direction for shades. The entrance is of double height, covered with canopy for shades (see Figure 6.13).

	Main categories	No. of points achieved	No. of points available	No of credit
1	Sustainable site	9	12	75 %
2	Indoor environmental quality	15	30	46 %
3	Outdoor thermal control	7	9	77%
4	Building form	3	8	37.5%
5	Materials and resources	11	34	32 %
6	Water supply system	4	16	28 %
7	Power supply	1	15	13%
8	environmental design process	0.60	1	60%
	Total	51	125 points	Good

a.



b



e

Pl. (f): West elevation

PL.:c: North-West elevation

PL.d: :North-West entrance

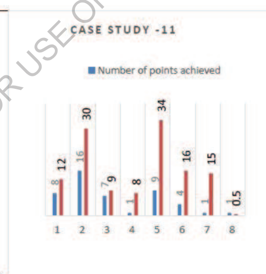
Figure 6.13: Sample 10, plot (33), street (47), Khartoum 2. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 10.

Sample No. 11. Khartoum 2 neighbourhood, Plot No: 26, Street No: 49

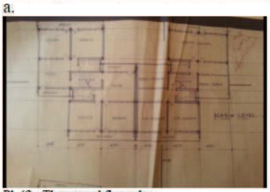
This house is located in Khartoum 2 neighbourhood and was built in 1980. A famous architect designed it as a four-storied building. The ground floor consists of two separated saloons, as men's part and women's part, with a kitchen, and three bathrooms. There is a section for services. The first, second and third floors consist of six flats; two per each floor. The windows are oriented towards the North-South direction. The house is designed as a multi-storied building, with large windows, brick walls, concrete ceiling and reflective glasses. The indoor environment uses nontoxic building materials, with exhaust fans for the bathroom and kitchen. The building is oriented towards the East-West direction. There are balconies in the North and East directions for providing shades. The architect used the linear form. The outdoor environment is a small courtyard shaded by the building itself (see Figure 6.14).

No.	Main categories	No. of points achieved	No. of points available	No of credit
1	Sustainable site	8	12	66%
2	Indoor environmental quality	14	30	50 %
3	Outdoor thermal control	4	9	77.7%
4	Building form	1	8	12.5%
5	Materials and resources	9	34	26 %
6	Water supply system	4	16	28%
7	Power supply	1	15	6.66%
8	Environmental design process	1	.5	50%
	Total	42 %	125points	Good

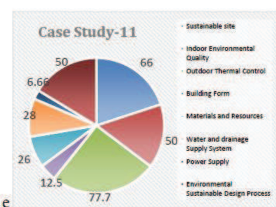
a.



b.

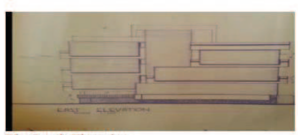


Pl. (f) : The ground floor plan



e.

Pl..c:South Elevation



Pl.: South Elevation

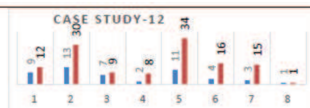
Figure 6.14: Sample 11, plot (26), street (49). Khartoum 2. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 11.

Sample No. (12): Geraif West, Plot No: 365/1, Block No: 5,

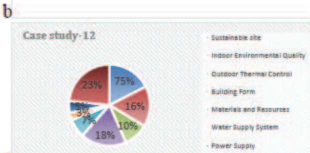
This house was designed by the architect Dr. Othman El Kheir and built- in Gerif West neighbourhood in Khartoum during 1996-1999. It attempts to demonstrate several features significant to the designer. In this case, the keywords were environment, traditions and modernity. Great consideration has been given to orientation and shading. Natural ventilation is made easier by the intrinsically narrow plan and the open multi-level interior. A wind catcher further accentuates this, along with underground brick ducts for supplying cool filtered air. Small high-level openings siphon the hot air and enhance conventional currents. The incorporation of plants in the interior is combined with a water sprinkling system for irrigation and climate modification. Solar energy provides the back-up supply for lighting and low-demand appliances. The structure is a composite RC frame and brick load-bearing walls system. The frame constitutes a stiff core holding brick vaults and combating the resulting lateral forces. The area framed by the RC skeleton recedes upwards from the ground level to the first level, leaving the third level for load-bearing walls. Perpendicular vaults acting as buttresses frame openings and casting shadows further assist this (see Figure 6.15).

	Main Categories	No. of points achieved	No. of points available	No of credit
1	Sustainable site	9	12	75 %
2	Indoor environmental quality	13	30	40 %
3	Outdoor thermal control	7	9	42%
4	Building form	2	8	25%
5	Materials and resources	11	34	32 %
6	b.Water supply system	4	16	12.5%
7	Power supply	3	15	20%
8	Environmental design process	1	1	100%
9		50%	125	Good

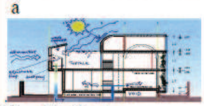
a



b

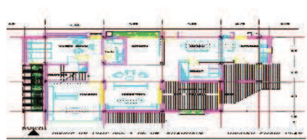


e



PL. a:The Section

PL.c: East elevation



PL.d :The ground floor plan

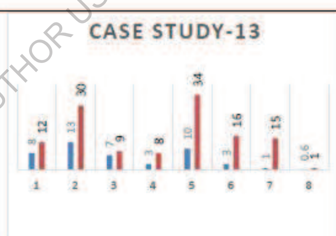
Figure 6.15: Sample 12, plot (365/1), block (5), Geraif West. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 12.

Sample No. (13): This house was in Arkawiet, Plot No: 285, Block No: 48, Khartoum

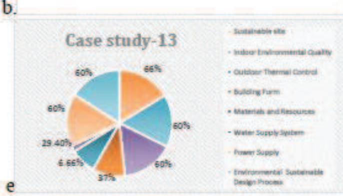
This house is in Arkawiet, Khartoum and was built in 2001 by the architect Jack Ishkhanesh. It follows the linear form and complemented with roof clay tiles. Also, the architect used glass and aluminium in windows. The long side is perpendicular to the wind direction. There is a courtyard around the back garden, which allows ventilation to the rooms. There are many elements for providing shade such as balcony, roof clay tiles, terraces and secondary wooden roof on the first floor. Ventilation is maintained through orienting the main building towards the North-South direction and orienting the services section towards the East-West direction. Windows are oriented to the direction of wind. The outdoor environment is in artful design; there is a garden, in addition to fences, isolated car parking, balcony, an outdoor space, terraces and shades. Trees and terraces are used to provide shade (see Figure 6.13).

	Main Categories	No. of points achieved	No. of points available	No of credit
1	Sustainable site	8	12	66%
2	Indoor environmental quality	13	30	60%
3	Outdoor thermal control	7	9	60%
4	Building form	3	8	37%
5	Materials and resources	10	34	29%
6	Water supply system	3	16	18.7%
7	Power supply	1	15	6.66
8	Environmental design process	0.60	1	60%
	Total	46	125	Good

a.



b.



e

Pl.f: The outdoor garden

PL.c: south-west elevation

PL.d:The main entrance

Figure 6.16: Sample 13, plot (285), block (48), Arkawiet. Table (a), Figure (b), Pl (c), Pl. (f) and Pl. (d) and Pie (e) shows the results of sample 13.

6.3.3 Al Sahafa Wasat neighbourhood

These samples were selected from the Al Sahafa Wasat neighbourhood which is located in the middle of Khartoum. General description of sample house units of Al Sahafa Wasat neighbourhood: Water comes from the National Grid, water efficiency is moderate and there is a shortage of water supply with an odour problem. Drainage systems use wells and septic tanks. Energy comes from the National Grid. The architects used limited building materials such as bricks, sand, gravel and concrete for building construction. False ceiling under wooden roof. Ceramic for the indoor and recycled ceramic tiles on the outdoor, in addition to steel and wood on windows. The building is constructed with R.C. skeleton and brick walls. People use ecological building materials; they use concrete, burnt bricks, cement, hollow blocks and thermal hollow blocks.

There is minimum outdoor area, and there are no gardens inside the plot area. There were small garden in front of the houses and it is poorly designed. The architects used the linear forms and the buildings were oriented to the East-West directions.

Ventilation is through large windows that are directed towards the North-South direction. The indoor environment has roof insulation, white colour, and horizontal sunscreens. The site is located near public transportations. The site also has enhanced parking control, and load bearing systems.

The samples are simply designed, most of the houses has two or three bedrooms, with one or two saloons, the kitchen and also the bathroom are located outside the house.

Figure 6.17 and Table 6.4 show the locations of the samples of the case studies at Al Sahafa Wasat neighbourhood.

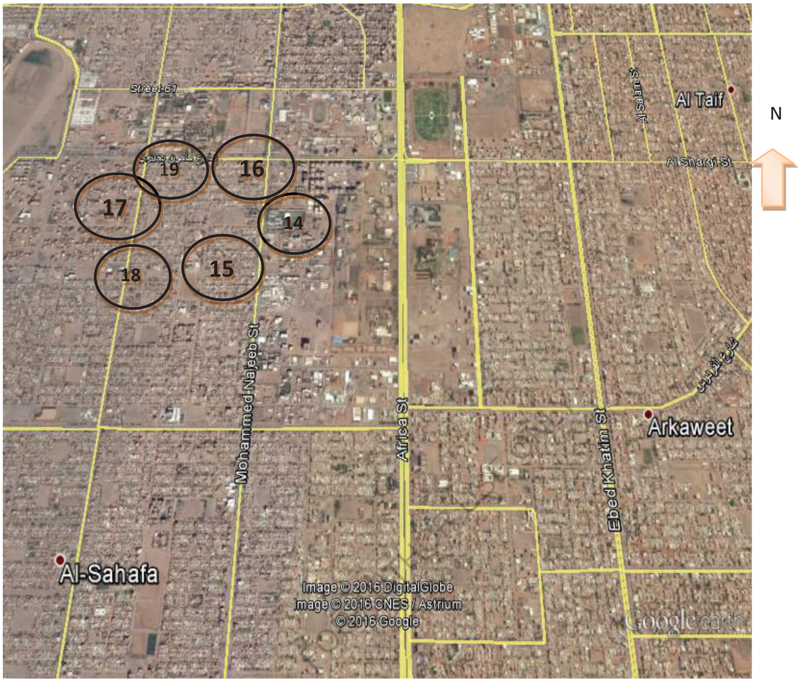


Figure 6.17: The locations of the samples of the case studies at Al Sahafa Wasat neighbourhood.

Table 6.5. The locations of the samples of the case studies at Al Sahafa Wasat neighbourhood.

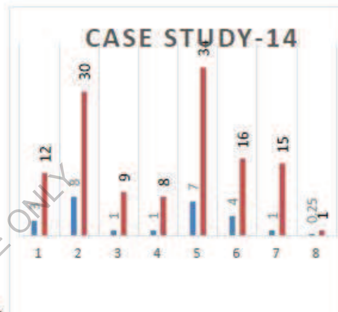
No. 14. Plot No: 71, Block No: 30	**No. 17. Plot No: 132, Block No: 33**
No. 15. Plot No: 77, Block No: 30	**No. 18. Plot No: 130, Block No: 30**
No. 16. Plot No: 78, Block No: 30	**No. 19. Plot No: 129, Block No: 33**

Sample No. 14. Al Sahafa Wasat neighbourhood, Plot No: 71, Block 30

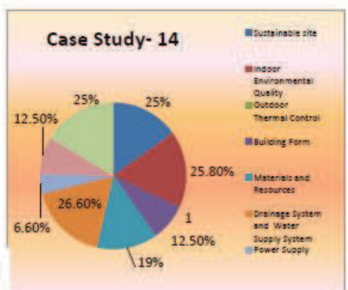
This house is located in AL Sahafa Wasat, Khartoum. It was built during the period of 2000-2003. Sub-contractors designed the house. In this building, the architect concentrated on the natural ventilation, which is observed in the windows sizes and their locations in the North and South directions. The house consists of four bedrooms, a saloon, a family hall, and a kitchen. The bathroom is outside the building (see Figure 6.18).

	Main categories	No. of points achieved	No. of points available	NO. of credit
1	Sustainable site	3	12	25%
2	Indoor environmental quality	8	30	25.8%
3	Outdoor thermal control	1	9	33 %
4	Building form	1	8	12.5%
5	Materials and resources	7	34	19%
6	Water and drainage system	4	16	26.6%
7	Power Supply	1	15	6.6%
8	Environmental design process	025	1	25%
	Total	25	125 points	weak

a.



b.



e

Pl f The South elevation

PL.c: The South Elevation, family entrance, with windows

PLd: The first floor is under construction

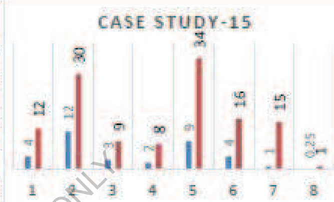
Figure 6.18: Sample 14, plot (71), block (30), AL Sahafa Wasat. Table (a), Figure (b), Pl c and Pl d and Pie e shows the results of sample 14.

Sample No. 15. Al Sahafa Wasat neighbourhood, Plot No: 77, Block No: 30

This house is located in Al Sahafa Wasat neighbourhood in Khartoum. It was built during the period of 1989-1992 and sub-contractors designed it. The architect concentrated on the natural ventilation; this is clear from the window sizes and their orientation to the North-South direction. The house consists of four bedrooms, a saloon, a family hall, and a kitchen. The bathroom is outside the building (see Figure 6.19).

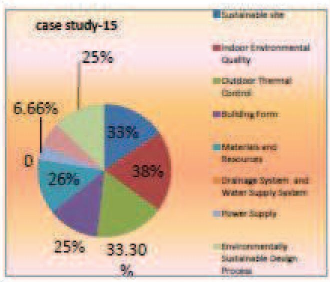
	Main Categories	No. of points achieved	No. of points available	NO. of credit
1	Sustainable site	4	12	33%
2	Indoor environmental quality	12	30	38 %
3	Outdoor thermal control	3	9	33.3%
4	Building form	2	8	25%
5	Materials and resources	9	34	26 %
6	Water and drain supply system	4	16	2%6.6
7	Power supply	1	15	6.66%
8	Environmental design process	0.25	1	25%
	Total	36	125 Pts	Weak

a.



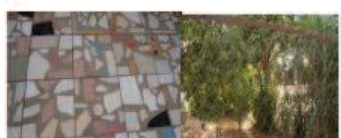
b.

Pl f: the windows and doors design



e.

PLc: The South elevation .Men's entrance , outside bath



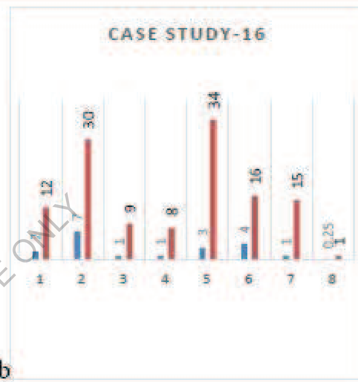
PL.d: Recycling content

Figure 6.19: Sample 15, plot (77), block (30), AL Sahafa Wasat. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 15.

Sample No. (16): Al Sahafa Wasat neighbourhood, Plot No:-78, Block No: 30. This house is located in Al Sahafa Wasat neighbourhood in Khartoum. It was built during the period of 1960-1965. Sub-contractors designed the house. In this building, the architect concentrated on natural ventilation; it is clear from the window sizes and their locations in the North and South directions. The house consists of three bedrooms, a saloon, two family halls and a kitchen. Three bathrooms are located outside the building (see Figure 6.20).

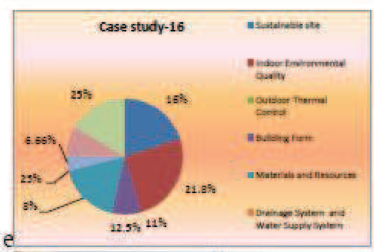
Main categories	No. of points achieved	No. of points available	No of credit
Sustainable site	2	12	16 %
Indoor environmental quality	7	30	21.8 %
Outdoor thermal control	1	9	11%
Building form	1	8	12.5%
Materials and resources	3	34	8.8 %
Water supply and drainage system	4	16	25
Power supply	1	15	6.66%
Environmental design process	0.25	1	25%
Total	19	125 points	Weak

a

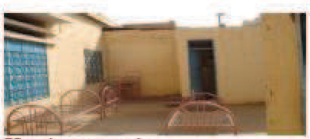


b

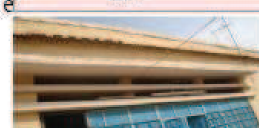
Pl f The window design



e



PLc: the courtyard



PLd: The horizontal sun scree

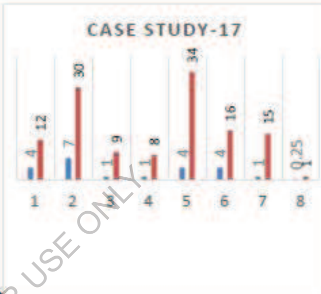
Figure 6.20: Sample 16, plot (78), block (30), AL Sahafa Wasat. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 16.

Sample No. 17. Al Sahafa Wasat neighbourhood, Plot No: 132 Block No: 33

This house is located in Al Sahafa Wasat neighbourhood in Khartoum. It was built during the period of 1974-1980. This house is designed by sub-contractors. In this building, the architect concentrated on the natural ventilation; which is clear from the window sizes and their locations in the North and South directions. The house consists of three bedrooms, a saloon, two family halls, a kitchen, and two bathrooms which are located outside the house (see Figure 6.21).

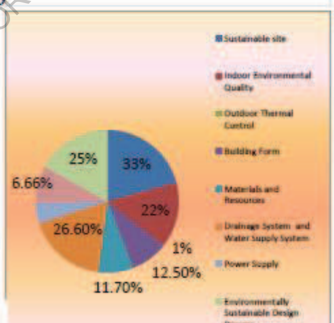
Main categories	No. of points achieved	No. of points available	No of credit
Sustainable site	4	12	33 %
Indoor environmental quality	7	30	22 %
Outdoor thermal control	1	9	11 %
Building form	1	8	12.5%
Materials and resources	4	34	11.7%
Water supply system	4	16	26.6%
Power supply	1	15	6.66%
Environmental design process	0.25	1	25%
Total	17	125 points	Weak

a



b

Pl.f Wooden roof



e

PL.c :House sample 17

PLd The North elevation, family entrance, with large windows.

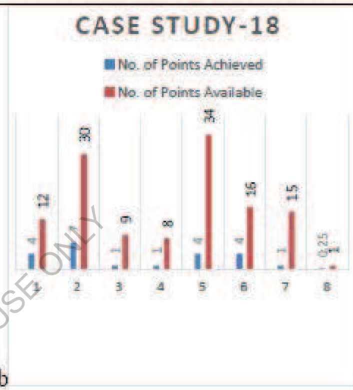
Figure 6.21: Sample 17, plot (132), block (33), AL Sahafa Wasat. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 17.

Sample No. 18. Al Sahafa Wasat neighbourhood, Plot No: 130 Block No: 30

This house is located in Al Sahafa Wasat neighbourhood in Khartoum. It was built during the period of 1977-1981. Sub-contractors designed the house. In this building, the architect concentrated on the natural ventilation, which is clear from the window sizes and their location in the North and South directions. The house consists of three bedrooms, a saloon, two family halls, a kitchen and three bathrooms which are located outside the house (see Figure 6.22).

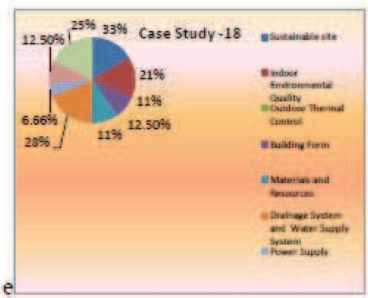
Main categories	No. of points achieved	No. of points available	No of credit
Sustainable site	4	12	33%
Indoor environmental quality	7	30	21 %
Outdoor thermal control	1	9	11%
Building form	1	8	12.5%
Materials and resources	4	34	11 %
Water supply and drainage system	4	16	28%
Power supply	1	15	6.66%
Environmental design process	0.25	1	50%
Total	22	125	Weak

a

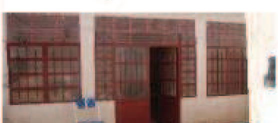


b

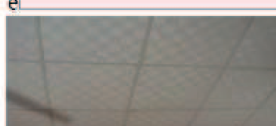
Pl f: the courtyard



e



PLc: Zinc+wooden roof and the main elevation



PLd: False ceiling to minimize the solar radiation

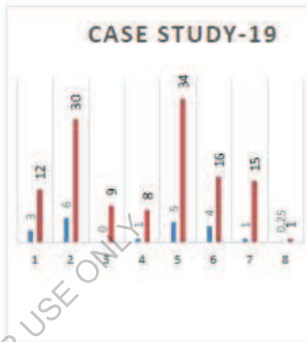
Figure 6.22: Sample 18, plot (130), block (33), AL Sahafa Wasat. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 18.

Sample No.19. Al Sahafa Wasat neighbourhood, Plot No: 129, Block No: 33

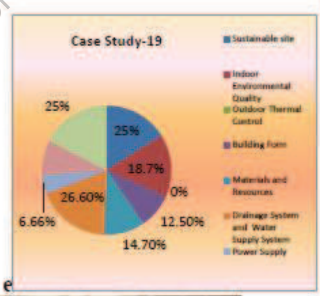
This house was built in the early seventies. Sub-contractors designed the house. In this building, the architect concentrated on the natural ventilation, which is clear from the window sizes and their locations in the North and South directions. The house consists of three bedrooms, a saloon, two family halls, a kitchen and three bathrooms, which are located outside the house (see Figure 6.23).

Main categories	No. of points achieved	No. of points available	NO. of credit
Sustainable site	3	12	25 %
Indoor environmental quality	6	30	18.7%
Outdoor thermal control	0	9	0%
Building form	1	8	12.5%
Materials and resources	5	34	14%
Drainage system and water supply system	4	16	26.6%
Power supply	1	15	6.66%
Environmental design process	0.25	1	25%
Total	21	125	weak

a



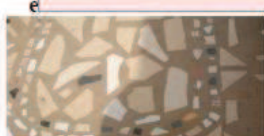
b



e

Pl f: The window design

PLc: The North elevation



PLd: Recycling ceramic for outdoor

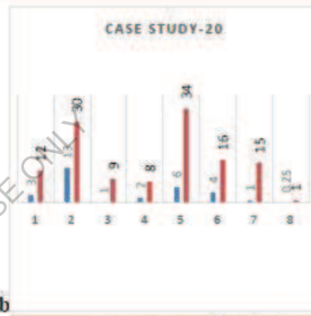
Figure 6.23: Sample 19, plot (129), block (33), AL Sahafa Wasat. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 19

Sample No. 20. **Al Sahafa Wasat neighbourhood,** Plot **No: 57, Block No: 30**

This house is located in Al Sahafa Wasat in Khartoum. It was built in the early seventies. This house is designed by sub-contractors. In this building, the architect concentrated on the natural ventilation, which is clear from the window sizes and their locations in the North and South directions. The house consists of three bedrooms, a saloon, two family halls, a kitchen and three bathrooms, which are located outside the house. There is small outdoor area, however, no gardens. The architect used the U-shaped form and the building is oriented to the East-West direction (see Figure 6.24).

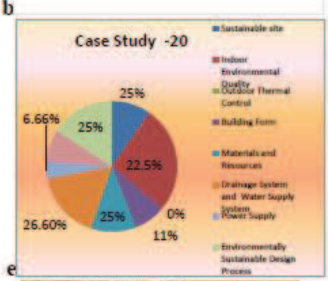
Main categories	No. of points achieved	No. of points available	NO. of credit
Sustainable site	3	12	25%
Indoor environmental quality	13	30	22.5%
Outdoor thermal control	1	9	11%
Building form	2	8	25%%
Materials and resources	6	34	17 %
Drainage system and water supply system	4	16	26.6%
Power supply	1	15	6.66%
Environmental design process	0.25	1	25%
Total	29	125	Weak

a



b

Pl f The window design



e

PL.c: The courtyard

PL.d: The garden is infront of the house

Figure 6.24: Sample 20, plot (57), block (33), AL Sahafa Wasat. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 20.

6.4 Neighbourhoods and house samples in Khartoum North

Khartoum North (Bahri, al-Kharṭūm Baḥrī) is the third-largest city in Greater Khartoum. It is located on the East bank of the Blue Nile near its confluence with the White Nile with bridges connecting it to Khartoum to its South and Omdurman to its West. It is thought to have a population of over a million. However, the last Sudanese census occurred in 1993 where its population was only 900,000. These samples were selected in Kafoori neighbourhood, square 11. Water comes from the National Grid, water efficiency is high, and there is shortage of water supply. Drainage systems consist of septic tanks and wells. Energy comes from the National Grid. The architects used a wide range of building materials such as burnt brick, concrete, sand and gravel in building construction. Marble, ceramic for flooring in the indoor, and cement tiles for the outdoor. The building is constructed with R.C. skeleton and brick walls. Fig 6.25 and Table 6.6 show the locations of the samples in Kafoori.

6.4.1 Kafoori neighbourhood

Figure 6.25: The locations of the samples of the case studies in Kafoori neighbourhood.

Table 6.6. The locations of the samples of the case studies, blocks and plot numbers in Kafoori.

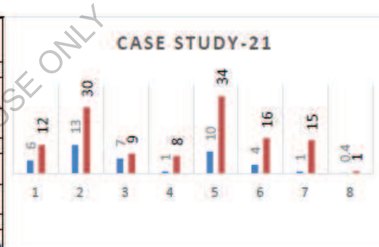
Sample No. 21. Plot No: 33, Block No: 11, Kafoori.	Sample No. 24. Plot No: 240, Block No: 11, Kafoori.
Sample No. 22. Plot No: 66, Block No: 11, Kafoori.	Sample No. 25. Plot No: , Block No: 11, Kafoori.
Sample No. 23. Plot No: , Block No: , Kafoori.	

Sample No. 21. Kafoori neighbourhood, Plot No: 33, Block No: 11

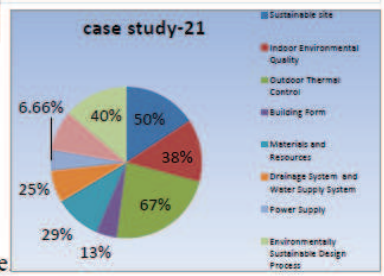
This house is located in Kafoori neighbourhood in Khartoum North. It was built during the period of 2002-2005 and designed by Consultant-China Company. In this building, the architect represents a modern style mixed with Islamic architectures; which is clearly visible from the window styles, the separation of the saloon, the use of glass and aluminium, and wall claddings. The architect used the linear form and the building is oriented to the North-South direction. There are many elements such as shades, balconies and terraces in the North direction. Ventilation is through large windows that are directed towards the North and South directions. The outdoor environment is well designed; it consists of a large garden, high fences, a balcony, outdoor spaces, terraces and a swimming pool (see Figure 6.26).

	Main categories	No. of points achieved	No. of points available	NO. of credit	
1	Sustainable site	6	12	50 %	
2	Indoor environmental quality	13	30	40%	
3	Outdoor thermal control	7	9	67%	
4	Building form	1	8	13%	
5	Materials and resources	10	34	29%	
6	Drainage system and water supply system	4	16	27%	
7	Power supply	1	15	6.66%	
8	Environmental design process	0.4	1	46%	
	Total	43	125	Pass	

a

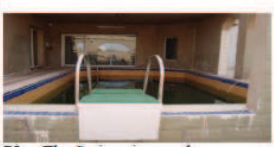


b



e

Pl f: The West elevation



PL.c:The Swimming pool

PLd:The Main entrance

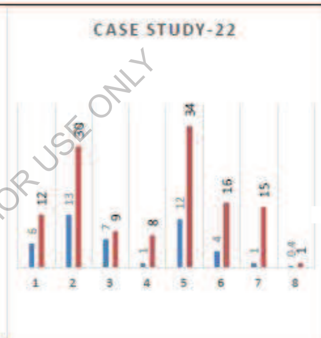
Figure 6.26: Sample 21, plot (33), block (11), Kafoori. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 21.

Sample No. (22): Kafoori neighbourhood, Plot No: (66), Block No: (11)

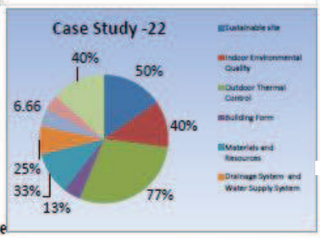
This house is located in Kafoori neighbourhood in Khartoum Bahri. It was built during the period of 2002-2005. The architect represented a modern style in this building; which is clearly visible from the window styles, the use of glass and aluminium, and wall claddings. The architect used the cubic form and the building was oriented to the East-West direction. There are many elements that provide shades such as balconies in the North direction and terraces. Ventilation is through large windows which are directed towards the North and South directions. The outdoor environment is well designed. There is a large garden, in addition to high fences, balconies, a large outdoor space and terraces (see Figure 6.27).

	Main categories	No. of points achieved	No. of points available	NO. of credit
1	Sustainable site	6	12	50%
2	Indoor environmental quality	13	30	40 %
3	Outdoor thermal control	7	9	77 %
4	Building form	1	8	13 %
5	Materials and resources	12	34	35 %
6	Water supply system	4	16	25 %
7	Power supply	1	15	6.66%
8	Environmental design process	0.40	1	40%
	Total	44	125	Pass

a.



b.



e

Pl (f) : East elevation

PL.c: The East Elevation

PL.d: The NorthElevation

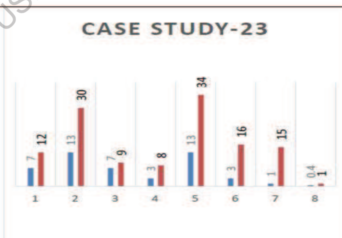
Figure 6.27: Sample 22, plot (66), block (11), Kafoori. Table (a), Figure (b), Pl (c) and (d), Pl (f), and Pie (e) shows the results of sample 22.

Sample No. (23): Kafoori neighbourhood, Plot No. (77), Block No. (11)

This house is located in Khartoum Bahri town. Jack Ishkhanes designed this house. In this building, the architect represents a Nubian style mixed with a modern style; this is clear in the use of glass and aluminium, and a large cantilever around the house which is covered by roof clay tiles. The architect used the cubic form. The long side is perpendicular to the wind direction and there is a courtyard around the swimming pool. This gives a good view and ventilation to the rooms. There are many elements that provide shades such as the large cantilever, which represents a large amount of the shades in all directions. Ventilation is towards the North-South direction for the main building and towards the East-West for services section. Windows are oriented to the direction of the wind (i.e. the North-South direction). The outdoor environment has an isolated car parking, a balcony, a large outdoor space, terraces, shades, and trees that are used to provide shades. Building materials. Skeleton. See Fig 6.28.

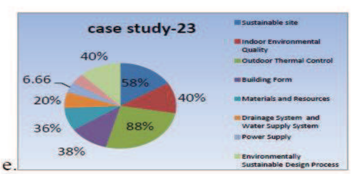
	Main categories	No. of Points Achieved	No. of Points Available	NO. Of Credit
1	Sustainable site	7	12	58%
2	Indoor environmental quality	13	30	40%
3	Outdoor thermal control	7	9	88%
4	Building form	3	8	38%
5	Materials and resources	13	34	38 %
6	Water supply system	3	16	20%
7	Power supply	1	15	6.66 %
8	Environmental design process	0.4	1	40 %
	Total	47	125	Good

a.



b.

Pl. (f): The East elevation



e.

Pl c: The NorthElevation, courtyards

Pl d: The Garden

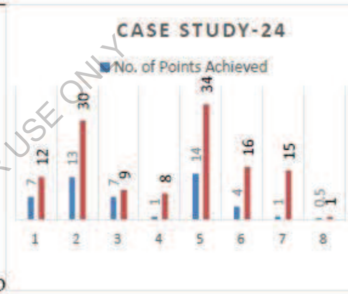
Figure 6.28: Sample 23, plot (77), block (11), Kafoori. Table (a), Figure (b), Pl (c) and Pl. (d), Pl. (f).and Pie (e) show the results of sample 23.

Sample No. (24): Kafoori neighbourhood, Plot No. 240, Block No (11)

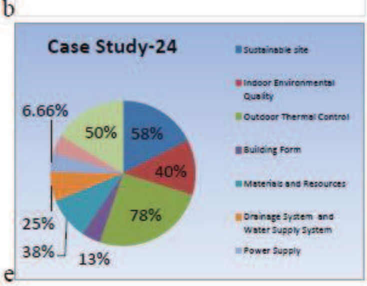
This house is located in Kafoori neighbourhood in Khartoum Bahri town. It was built during the period of 2002-2005. It was designed by the architect Fareed Osman. In this building, the architect represents a modern style mixed with Islamic architectures; which is clearly visible in the window styles, the entrance of the house made of glass and aluminium, and wall claddings. The architect used the linear form and the building is oriented to the North-South direction. There are many elements that provide shade such as balconies in the North, terraces and shades over the entrance. Ventilation is through large windows. The outdoor environment is well designed. There is a small garden, fence, a balcony, a maximized outdoor space, and a fountain in front of the house (see Fig.).

	Main categories	No. of points achieved	No. of points available	NO. of credit
1	Sustainable site	7	12	58%
2	Indoor environmental quality	13	30	40%
3	Outdoor thermal control	7	9	78%
4	Building form	1	8	13%
5	Materials and resources	14	34	41%
6	Drainage system and water supply system	4	16	25%
7	Power Supply	1	15	6.66%
8	Environmental design process	0.50	1	50%
	Total	43	125	Pass

a



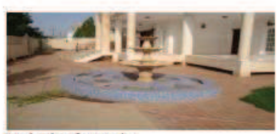
b



e

Pl f: The East elevation

PLc:The South elevation



PLd:The fountain

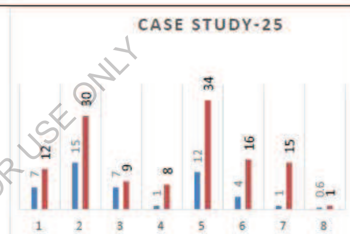
Figure 6.29: Sample 24, plot (240), block (11), Kafoori. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 24.

Sample No. 25. Kafoori neighbourhood Plot No: 67, Block No: 11

This house is located in Kafoori neighbourhood in Khartoum Bahri town. It was built during the period of 2002-2005. The architect and consultant, Aldaak, represents a modern style mixed with Islamic architecture; which is clearly visible in the window styles, the separation of the saloon, the privacy of the rooms, the use of glass and aluminium, and wall claddings. The architect used the linear form and the building is oriented to the North-South direction. There are many elements that represent shade such as balconies in the North and terraces. Ventilation is through the large windows that are oriented towards North-South direction. The outdoor environment was well designed (see Figure 6.30).

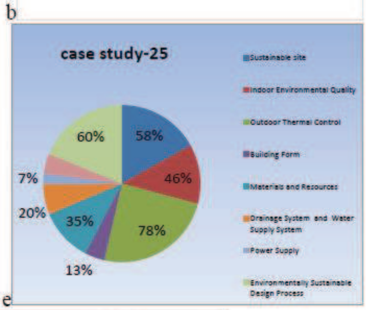
Main categories	No. of points achieved	No. of points available	NO. of credit
Sustainable site	7	12	58%
Indoor environmental quality	15	30	46%
Outdoor thermal control	7	9	78%
Building form	1	8	13%
Materials and resources	12	34	35%
Drainage system and water supply system	4	16	20%
Power supply	1	15	7%
Environmental design process	0.60	1	60%
Total	47	125	Good

a



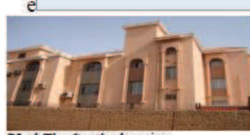
b

Pl f: The window design



e

PLc:The Garden , elevation



PL:d:The South elevstion

Figure 6.30: Sample 25, plot (67), block (11), Kafoori. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 25.

6.4.2 Al Shabia neighbourhood

Al Shabia neighbourhood is located in Khartoum North. There are seven sample units located in the neighbourhood, house unit No. 26 to No. 32.

Water is supplied from the National Grid, water efficiency is moderate, and there is a shortage of water supply. The drainage system consists of septic tanks and wells. Energy is drawn from the National Grid. The architects have used limited building materials such as ceramic for the indoors and recycled ceramic tiles for the outdoors, in addition to steel on windows.

General description of sample housing units in Al Shabia neighbourhood:

The sample units face a transportation line. There is a minimum outdoor area with no gardens due to a limited plot area range of 200 sq. m to 300 sq. m; residents use the outdoor courtyard as a sitting area to welcome their guests.

The architects have used the linear form and the buildings are oriented in the East-West direction. Canopies provide shades to windows.

The buildings have been constructed with concrete ceilings; some houses have wooden ceiling. Bricks or cement blocks have been used for the walls and recycled ceramic for the floors. The building has good ventilation through large windows in the North-South direction and people use fans and water desert coolers to improve air movement through the house.

The houses are simply designed; each house consists of two or three bedrooms, and one or two saloons. The kitchen and the bathroom are located outdoors.

Figure 6.31 and Table 6.7 show the locations of the sample housing units in the Al Shabia neighbourhood.

Figure 6.31: Satellite image of the locations of the sample house units in Al Shabia neighbourhood, Khartoum North.

Table 6.7. The locations of the sample house unit in Al Shabia neighbourhood.

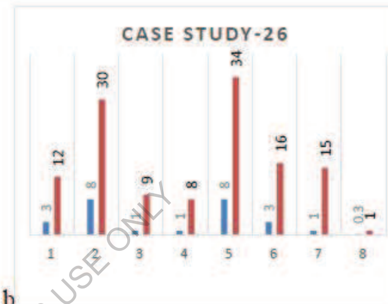
Sample No. 26. Plot No: 293, Block No: 6/7, Al Shabia	Sample No. 29. Plot No: 7, Block No: 6/7, Al Shabia
Sample No. 27. Plot No: 4, Block No: 6/7, Al Shabia.	Sample No. 30. Plot No: 8, Block No: 6/7, Al Shabia
Sample No. 28. Plot No: 6, Block No: 6/7, Al Shabia.	Sample No. 31. Plot No: 10, Block No: 6/7, Al Shabia

Sample No. 26. Al Shabia neighbourhood, Plot No: 293, Block No: 6/7

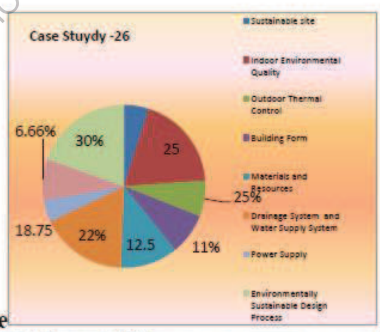
This house is located in Al Shabia, Khartoum North. It was built in the late nineties and was designed by sub-contractors. The plot area is 300 m^2. In this building, the architect concentrated on the natural ventilation, which is clearly visible from the large window sizes that are located in the North and South directions. The house has one floor, which consists of three bedrooms, a salon, a hall; a kitchen and a bathroom (see Figure 6.32).

Main categories	No. of points achieved	No. of points available	NO. of credit
Sustainable site	3	12	25%
Indoor environmental quality	8	30	25%
Outdoor thermal control	1	9	11%
Building form	1	8	12.5%
Materials and resources	8	34	23 %
Drainage system and water supply system	3	16	18.7%
Power supply	1	15	6.66%
Environmental design process	0.30	1	30%
Total	25%	125	Weak

a



b



e

Pl f The recycled ceramic tiles

PL:c:The wooden roof with false ceiling

PL:d:Out side the plot garden

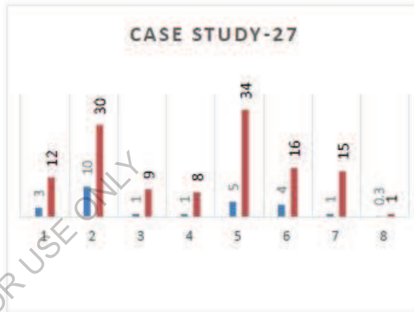
Figure 6.32: Sample 26, plot (293), block (6/7), Al Shabia. Table (a), Figure (b), Pl (c) and (d) and Pie (e) show the results of sample 26.

Sample No. 27. Al Shabia neighbourhood, Plot No: 4, Block No: 6/7

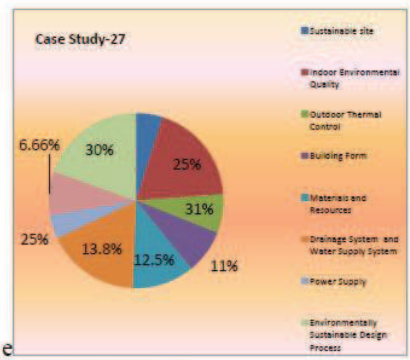
This house is located in Khartoum North. It was built during the period of 1995-1997. The plot area is 300 m^2. Sub-contractors designed the house. In this building, the architect concentrated on the natural ventilation; which is clear from the large windows that located in the North and South directions. The house has one floor, and consists of three bedrooms, a saloon, a hall, a kitchen and a bathroom (see Figure 6.33).

Main categories	No. of points achieved	No. of points available	NO. of credit
Sustainable site	3	12	25 %
Indoor environmental quality	10	30	31%
Outdoor thermal control	1	9	11%
Building form	1	8	12.5%
Materials and resources	5	34	14%
Drainage system and water supply system	4	16	25%
Power supply	1	15	6.66%
Environmental design process	0.30	1	30%
Total	25%	125	Weak

a



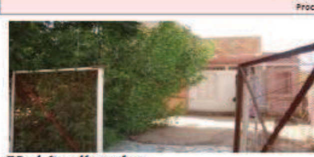
b



e

Pl f: The windows and doors design

PL.c:The Baranda with correcgated sheets



PL.d:Small garden

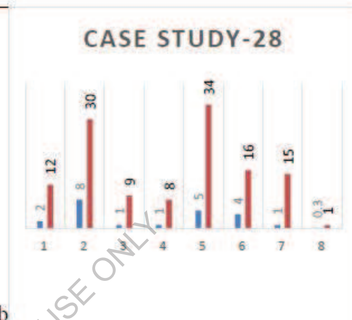
Figure 6.33: Sample 27, plot (4), block (6/7), Al Shabia. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 27.

Sample No. 28. Al Shabia neighbourhood, Plot No: 6, Block No: 6/7

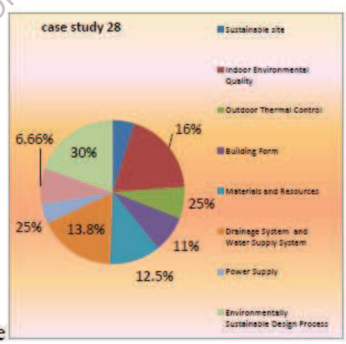
This house is located in the north of Al Shabia neighbourhood. It was built during the period of 2004-2006. The plot area is 300 m^2. Sub-contractors designed the house. In this building, the architect concentrated on natural ventilation; which is clear from the large windows that are located in the North and South directions. The house has one floor, and consists of three bedrooms, a saloon, a hall, a kitchen and a bathroom (see Figure 6.34).

Main categories	No. of points achieved	No. of points available	NO. of credit
Sustainable site	2	12	16%
Indoor environmental quality	8	30	25%
Outdoor thermal control	1	9	11%
Building form	1	8	12.5%
Materials and resources	5	34	14.7 %
Drainage system and water supply system	4	16	25%
Power supply	1	15	6.66%
Environmental design process	0.30	1	30%
Total	22%	125	Weak

a

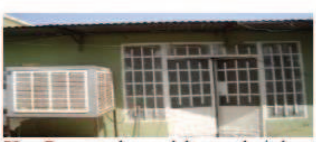


b



e

Pl f:The courtyard with recycled ceramic floor



PL:c: Desert cooler, steel doors and windows

PL.d: The South elevation, zinc roof

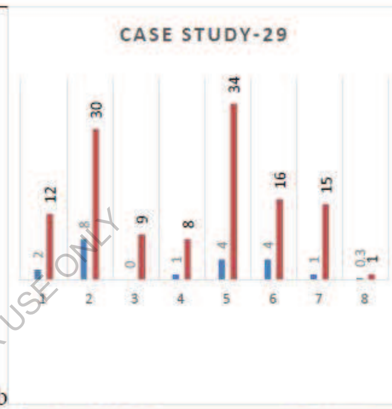
Figure 6.34: Sample 28, plot (6), block (6/7), Al Shabia. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 28.

Sample No. 29. Al Shabia neighbourhood, Plot No: 7, Block No: 6/7

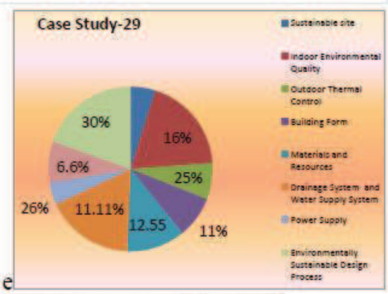
This house is located in north of Al Shabia. It was built in the mid-sixties. The plot area is 300 m^2, and the house is designed by sub-contractors. In this building, the architect concentrated on the natural ventilation; which is clear from the large windows that are located in the North and South directions. The house has one floor and consists of three bedrooms, a saloon, a hall, a kitchen, and a bathroom (see Figure 6.35).

Main categories	No. of points achieved	No. of points available	NO. of credit
Sustainable site	2	12	16%
Indoor environmental quality	8	30	25%
Outdoor thermal control	0	9	11%
Building form	1	8	12.5%
Materials and resources	4	34	11.7%
Drainage system and water supply system	4	16	26.6%
Power supply	1	15	6.66%
Environmental design process	0.30	1	30%
Total	20%	125	Weak

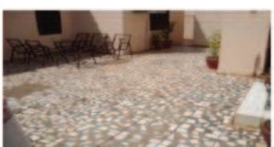
a



b

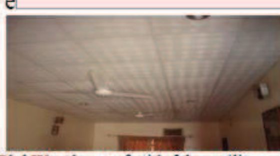


e



Pl f: The courtyard with recycled ceramic tiles

Pl.cThe Baranda with steel structure



Pl.d.Wooden roof with false ceiling.

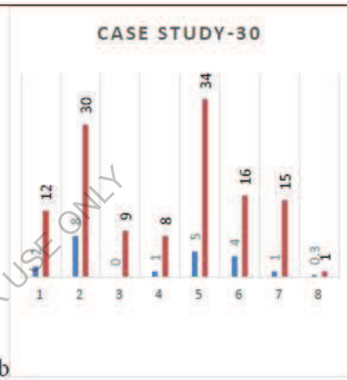
Figure 6.35: Sample 29, plot (7), block (6/7), Al Shabia. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 29.

Sample No. 30. Al Shabia neighbourhood, Plot No: 8, Block No: 6/7

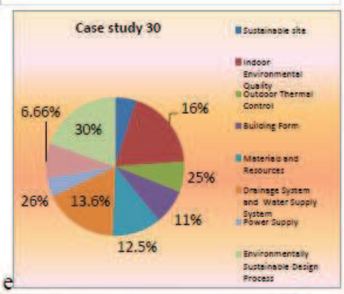
This house is located in Al Shabia neighbourhood in Khartoum North. It was built during the period of 2000-2002. The plot area is 300 m^2. Sub-contractors designed the house. In this building, the architect concentrated on the natural ventilation; which is clearly visible from the large windows that are located in the North and South directions. The house has one floor, and consists of three bedrooms; a salon, a hall, a kitchen and a bathroom (see Figure 6.36).

Main category	Point achieved	Point available	NO. of credit
Sustainable site	2	12	16%
Indoor environmental quality	8	30	25%
Outdoor thermal control	0	9	11%
Building form	1	8	12.5 %
Materials and resources	5	34	14.7 %
Drainage system and water supply system	4	16	26.6 %
Power supply	1	15	6.66 %
Environmental design process	0.30	1	30%
Total	21%	125	Weak

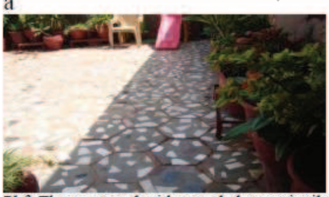
a



b

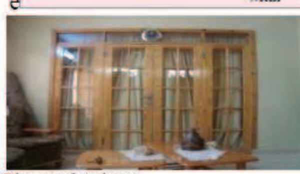


e



Pl f: The courtyard with recycled ceramic tiles

PL:c: The North elevation , window style



PLd: The wooden doors

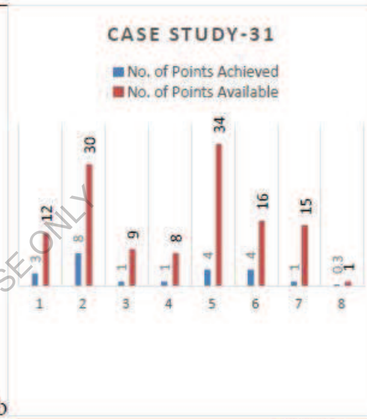
Figure 6.36: Sample 30, plot (8), block (6/7), Al Shabia. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 30.

Sample No. 31. **Al Shabia neighbourhood**, **Plot No: 10, Block No: 6/7**

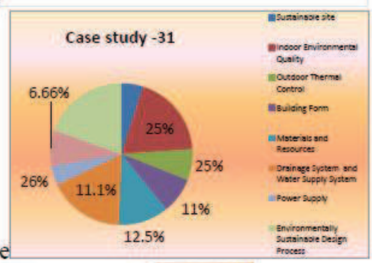
This house is located in Al Shabia neighbourhood in Khartoum North. It was built during the mid-sixties. This house is designed by sub-contractors. The plot area is 300 m^2. In this building, the architect concentrated on the natural ventilation; which is clear from the large windows that are located in the North and South directions. The house has one floor, and consists of three bedrooms, a saloon, a hall, a kitchen, and a bathroom (see Figure 6.37).

Main categories	No. of points achieved	No. of points available	NO. of credit
Sustainable site	3	12	25 %
Indoor environmental quality	8	30	25%
Outdoor thermal control	1	9	11%
Building form	1	8	12.5%
Materials and resources	4	34	11.7%
Drainage system and water supply system	4	16	26.6%
Power supply	1	15	6.66%
Environmental design process	0.30	1	30%
Total	22%	125	Weak

a



b



e

Pl f: the courtyard with recycled ceramic tiles

Pl.c: The North elevation

Pl:d The Baranda covered by steel roof

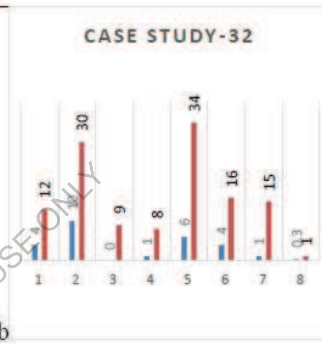
Figure 6.37: Sample 31, plot (10), block (6/7), Al Shabia. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 31.

Sample No. 32. Al Shabia neighbourhood, Plot No: 15, Block No: 6/7

This house is located in Al Shabia neighbourhood in Khartoum North. It was built during the period of 1946-1966. Sub-contractors designed the house. The plot area is 300 m^2. In this building, the architect concentrated on natural ventilation; which is clearly visible from the large windows that are located in the North and South directions. The house has one floor, and consists of three bedrooms, a saloon, a hall, a kitchen and a bathroom. There is a small outdoor area there, however, no gardens (see Figure 6.38).

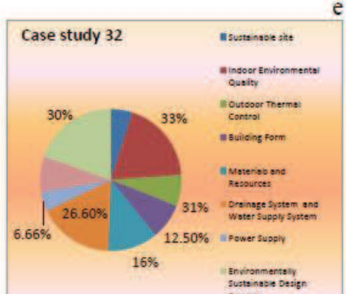
Main categories	No. of points achieved	No. of points available	NO. of credit
Sustainable site	4	12	33%
Indoor environmental quality	10	30	31%
Outdoor thermal Control	0	9	11%
Building form	1	8	12.5%
Materials and resources	6	34	17%
Drainage system and water supply system	4	16	26.6%
Power Supply	1	15	6.66%
Environmental design process	0.30	1	30
	26%	125	Weak

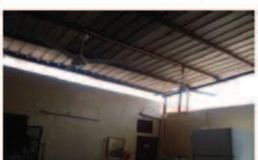
a



b

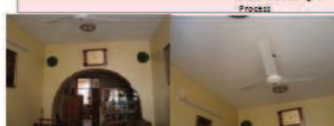
e





Pl f: The Baranda covered by steel roof

PL.c: The small garden outside the plot



PLd: The use of bright colours , use of fans to improve the air movement

Figure 6.38: Sample 32, plot (15), block (6/7), Al Shabia. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 32.

6.5 Neighbourhoods and house samples in Omdurman

Omdurman is the largest city in second largest city in Greater Khartoum, lying on the Western bank of the River Nile. It has a population of 2,395,159 (2008) and it is the national Centre of commerce. It forms the cultural and industrial heart of the nation. Omdurman consists of many neighbourhoods some of its new neighbourhoods are Al Rouda to the North, and Al Mourada to the East.

6.5.1 Al Rouda neighbourhood

Omdurman is the second largest city in Greater Khartoum and is a historical city. The sample house units are from Al Rouda neighbourhood (5 Case study), from unit No. 33 to No. 37.

General description for sample house units in Al Rouda neighbourhood:
Water comes from the National Grid, water efficiency is high, and there is shortage of water supply. Drainage systems consist of septic tanks and wells. The architects used a wide range of building materials such as burnt bricks, sand, gravel, stones. Stabilized soil blocks, hollow blocks in building construction. Marble and ceramic for the indoor floor, and cement tiles and recycled ceramic for the outdoor floor. The building is constructed with R.C. and walls are made of bricks.

Different building forms are found such as cubic form, linear form and L-shaped form (sample No.33).

The outdoor environment was well organised. One sample has garden outside the plot (sample No.36).

Figure 6.39 and Table 6.8 show the locations of the sample house units in Al Rouda neighbourhood.

Figure 6.39: The locations of the sample house units in Omdurman- Al Rouda neighbourhood, Omdurman.

Table 6.8. The locations of the sample house units in Al Rouda.

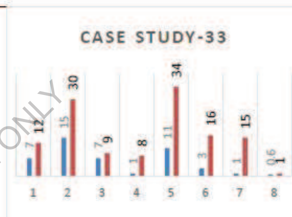
Sample No. 33. Plot No: 518, Block No: 518, Al Rouda	Sample No. 36. Plot No: 228, Block No: 228, Al Rouda.
Sample No. 34.), Plot No: 918, Block No: 918, Al Rouda.	Sample No. 37. Plot No: 238, Block No: 238, Al Rouda.
Sample No. 35. Plot No: 814, Block No: 814, Al Rouda.	

Sample No. 33. Al Rouda neighbourhood, Plot No: 518, Block No: 518

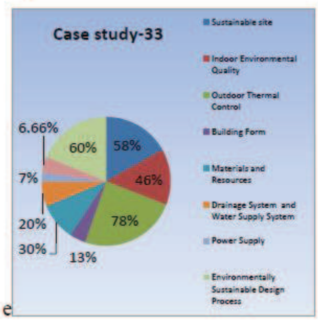
This house is located in Omdurman- Al Rouda neighbourhood in Omdurman. It was built during the period of 2004-2006. This house was designed by architect Hisham Mohamed Ahmed Al Brir. The architect represents a modern style in this building; which is clearly visible from the use of glass and aluminium on the windows. The architect used the cubic form and the building is oriented to the East-West direction. There are many elements that provide shades, such as balconies in the North and terraces (mass case shade). The outdoor environment is well designed. It consists of balconies, a large garden, high fences, and terraces (see Figure 6.40).

Main categories	No. of Points Achieved	No. of Points Available	NO. Of Credit
Sustainable site	7	12	58%
Indoor Environmental Quality	15	30	46%
Outdoor Thermal Control	7	9	78%
Building Form	1	8	13%
Materials and Resources	11	34	32%
Drainage System and Water Supply System	3	16	20%
Power Supply	1	15	7%
Environmental Sustainable Design Process	0.60	1	60%
Total	45%	125	Good

a



b



e

Pl f : The large garden with plants

PL.c:The window style

PL.d:The East Elevation-The South Elevation

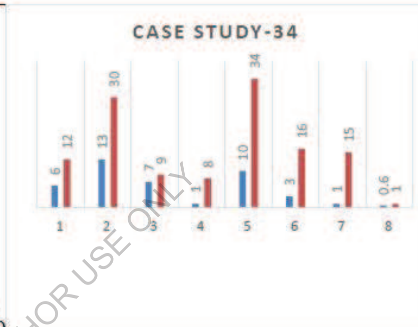
Figure 6.40: Sample 33, plot (518), block (518), Al Rouda. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 33.

Sample No. 34. **Al Rouda neighbourhood, Plot No: 918, Block No: 918**

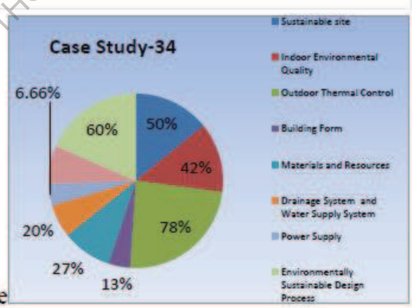
This house is located Al Rouda neighbourhood and was built during the period of 2004-2006. The architect was Mkarus. The architect represents a modern style in this building and the windows are made of glass and aluminium. The architect used the cubic form and the building is oriented to the East-West directions. There are many elements that provide shades, such as balconies in the North and terraces (mass case shade). Ventilation is through large windows. The building consists of balconies, a large garden, high fences, and terraces (see Figure 6.41).

Main categories	No. of points achieved	No. of points available	NO. of credit
Sustainable site	6	12	50%
Indoor environmental quality	13	30	40%
Outdoor thermal control	7	9	78%
Building form	1	8	13%
Materials and resources	10	34	29%
Drainage system and water supply system	3	16	20%
Power Supply	1	15	6.66%
Environmental Sustainable Design Process	0.60	1	60%
Total	42%	125	Pass

a



b



e

Plf: north elevation

Pl.c The canopy provides shades-

Pl.d: East elevation

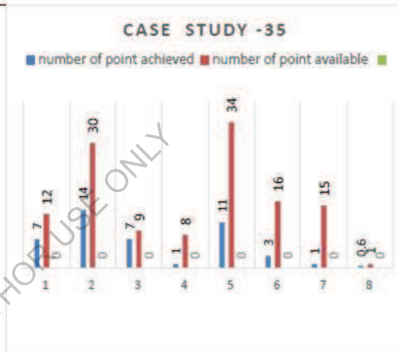
Figure 6.41: Sample 34, plot (918), block (918), Al Rouda. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 34.

Sample No. 35. Al Rouda neighbourhood, Plot No: 814, Block No: 814

This house is located in Omdurman in Al Rouda neighbourhood. It was built during the period 2005-2007. Architect Al Taieb designed this house. The architect represents a modern style in this building and windows are made of glass and aluminium. The architect used the L-shaped form and the building is oriented to the East-West directions. There are many elements that provide shades, such as balconies, in the North and terraces (mass case shades). Ventilation is through large windows, which are oriented towards the North-South direction. The outdoor environment is well designed (see Figure 6.42).

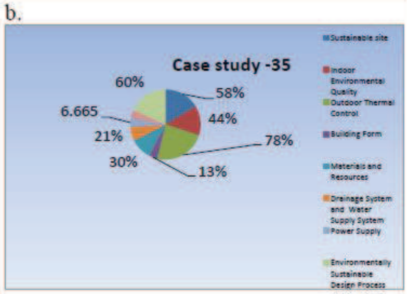
	Main categories	No. of points achieved	No. of points available	NO. of credit
1	Sustainable site	7	12	58%
2	Indoor environmental quality	14	30	44%
3	Outdoor thermal control	7	9	78%
4	Building form	1	8	13%
5	Materials and resources	11	34	32 %
6	Drainage system and water supply system	3	16	21%
7	Power supply	1	15	6.66%
8	Environmental design process	0.60	1	60%
	Total	45%	125	Good

a.



b.

Plf: The West elevation



e.

PL.c:The Large garden

PL.d:The use of L-shaped form-South elevation

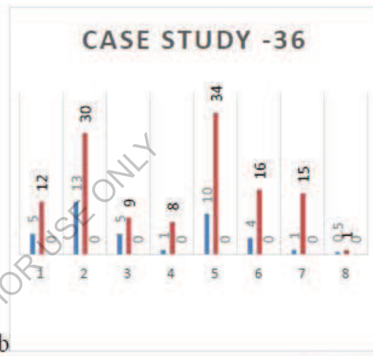
Figure 6.42: Sample 35, plot (814), block (814), Al Rouda. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 35.

Sample No. 36. **Al Rouda neighbourhood, Plot No: 228, Block No: 228**

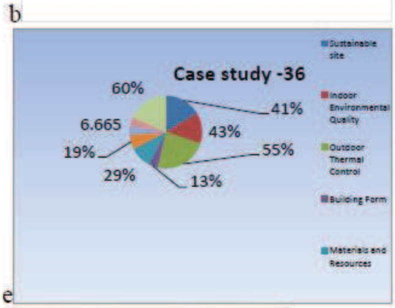
Architect Abdelhalim Khider designed this house. The architect represents a modern style in this building and windows are made of glass and aluminium. The architect used the cubic form and the building is oriented to the East-West direction. There are many elements that provide shades, such as balconies in the North and terraces (mass case shade). Ventilation is through the large windows oriented towards the North-South direction. The outdoor environment is well designed. It consists of balconies, a large garden and high fences (see Figure 6.43).

Main categories	No. of points achieved	No. of points available	NO. of credit
Sustainable site	5	12	41.6%
Indoor environmental quality	13	30	43%
Outdoor thermal control	5	9	55%
Building form	1	8	13%
Materials and resources	10	34	29 %
Drainage system and water supply system	4	16	19%
Power supply	1	15	6.66%
Environmental design process	0.50	1	60%
Total	41%	125	Pass

a



b



e

Pl f: The East elevation

PL.c:The Large front garden

PL.d:The use of L-shaped form-South elevation

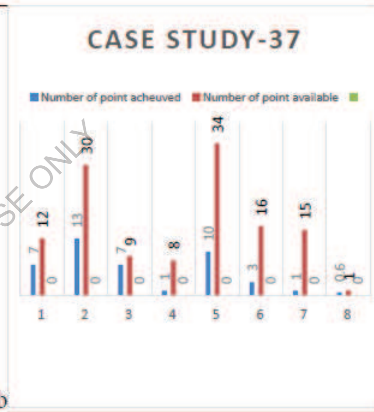
Figure 6.43: Sample 36, plot (228), block (228), Al Rouda. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 36

Sample No. 37. **Al Neil Town**, **Plot No: 238, Block No: 238**

This house is located in Omdurman- in Al Neil Town**.** It was built during the period of 2006-2008. This house is designed by architect Abdelhalim Khider as a modern house. The architect used the cubic form and the building is oriented to the East-West direction. There are many elements that provide shades, such as balconies in the North and terraces (mass case shades). Ventilation is through the large windows. The outdoor environment is well designed. It consists of a large garden, high fences, several balconies, a maximized outdoor space, terraces and a pool at the entrance (see Figure 6.44).

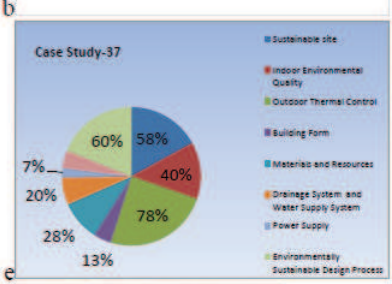
Main Categories	No. of points achieved	No. of points available	NO. of credit
Sustainable site	7	12	58%
Indoor environmental quality	13	30	40%
Outdoor thermal control	7	9	78%
Building form	1	8	13%
Materials and resources	10	34	29 %
Drainage system and water supply system	3	16	20%
Power supply	1	15	7%
Environmental design process	0.60	1	60%
Total	43%	125	Pass

a



b


Pl f : The use of balconies



e


PL.c:Soth-East Elevation

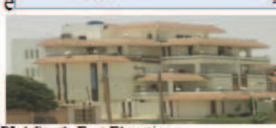

PLd:South-East Elevation

Figure 6.44: Sample 37, plot (238), block (238), Al Rouda. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 37.

6.5.2 Al Morada neighbourhood

Eight sample housing units were selected from Al Mourada in Omdurman, which is located at a central area near Khor Abu Anga. These units were covered by the survey of 2013, and consist of housing units between No. 38 and No. 45.
The following is the general description of sample housing units in Al Morada: Water is supplied from the National Grid; water efficiency is moderate there is a shortage of water supply. The drainage system consists of wells and septic tanks. Energy for the units is drawn from the National Grid. The outdoor environment is poorly designed. There are no gardens because of the limited plot area range between 200 m^2 and 300 m^2.

The architects have used leaner and cubic forms and the building are oriented in the East-West direction. Canopies have been used as the shades to the windows. There is public transport available near these samples. In these samples, load-bearing systems enhance parking control. The drainage system consists of wells and septic tanks, with some Pit Latrines.

The architects have used limited building materials such as concrete, burnt bricks, hollow blocks, thermal blocks and stabilized blocks in the building construction. Ceramic for the indoor and recycled ceramic tiles or cement tiles for the outdoor, in addition to wooden windows, have been used. The building has been constructed with brick ceilings and brick walls.

The indoor environment is enhanced by large windows in the North and South directions. Fans and water desert coolers have been used to improve air movement through the house.

The houses are simply designed; each house consists of two or three bedrooms, one or two salons and the kitchen and the bathroom are located outside the building. Figure 6.45 and Table 6.9 show the location of sample in Al Mourada neighbourhood.

Figure 6.45 and Table 6.9 show the locations of sample housing units in Al Mourada.

Figure 6.45: The locations of the sample house units in Al Mourada neighbourhood.

Table 6.9. The locations of the sample house units in Al Mourada.

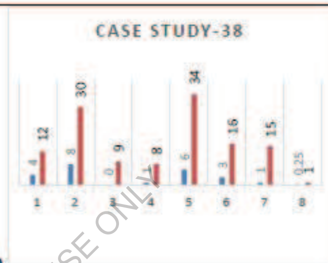
Sample No. 38., Plot No: 3241, Block No: 4/3, Al Morada	Sample No. 42. Plot No: 312, Block No: 4/3, Al Morada
Sample No. 39. Plot 2614, Block No: 4/3, Al Moradao	No.43. Plot No: 998, Block No: 4/3, Al Morada
Sample No. 40. Plot No: 1693, Block No: 4/3, Al Morada	Sample No. 44. Plot No: 249, Block No: 4/3, Al Morada
Sample No. 41. Plot No: 311, Block 4/3, Al Morada	Sample No. 45. Plot No: 293, Block No: 4/3,

Sample No. 38. Al Mourada neighbourhood, Plot No: 3241, Block No: 4/3

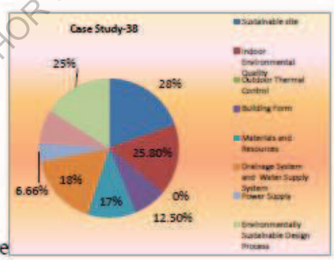
This house is located in Omdurman - Al Morada in Omdurman. It was built during the period of 1990-1905. This house is re-designed by Architect Ibrahim Atta Al Manan in 1992. In this building, the architect concentrated on the natural ventilation, which is clear from the large windows that are located in the North and South directions. The house has two floors, the ground floor and the first floor. The house consists of three bedrooms, a saloon, two family halls, a kitchen, and three bathrooms which are located outside the house (see Figure 6.46).

Main categories	No. of points achieved	No. of points available	NO. of credit
Sustainable site	4	12	28%
Indoor environmental quality	8	30	25%
Outdoor thermal control	0	9	0%
Building form	1	8	12.5%
Materials and resources	6	34	17 %
Drainage system and water supply system	3	16	18 %
Power supply	1	15	6.66%
Environmental design process	0.25	1	25%
	23 %	125	weak

a.



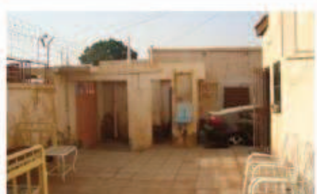
b.



e

Pl.f: The window style

PL.c:The The West elevation



PL.d:The courtyard

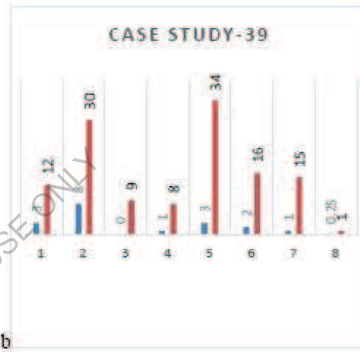
Figure 6.46: Sample 38, plot (3241), block (4/3), Al Mourada. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 38.

Sample No. 39. Al Mourada neighbourhood, Plot No: 2614 Block No: 4/3

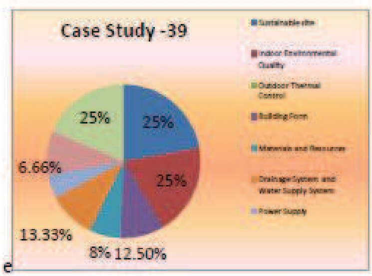
This house is located in Al Morada in Omdurman. It was built during the period of 1990-1995. This house is designed by Architect Ibrahim Atta Al manan. In this building, the architect concentrated on the natural ventilation; which is clear from the large windows that are located to the North and South directions. The house has only one ground floor. The house consists of two bedrooms, a saloon, a family hall, a kitchen and two bathrooms which are located outside the house. There is a small outdoor area with a small garden (see Figure 6.47).

Main categories	No. of Points Achieved	No. of Points Available	NO. Of Credit
Sustainable site	3	12	25 %
Indoor environmental quality	8	30	25 %.
Outdoor thermal control	0	9	0%
Building form	1	8	12.5%
Materials and resources	3	34	8 %
Drainage system and water supply system	2	16	13.33%
Power supply	1	15	6.66%
Environmental design process	0.25	1	25%
Total	18 %	125	weak

a.



b



e

PL f: The window style

PL.c:The West elevation

PL.d:The courtyard-steel windows-

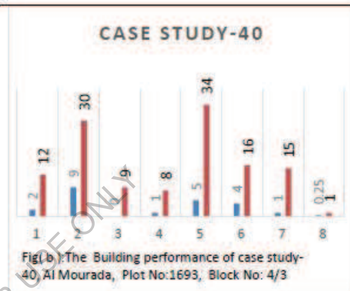
Figure 6.47: Sample 39, plot (2614), block (4/3), Al Mourada. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 39.

Sample No. (40): AL Mourada neighbourhood, Plot No: - 1693, Block

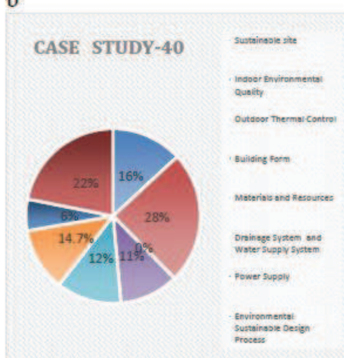
This house is located in Al Morada in Omdurman. It was built during the period of 1940-1945, and is constructed by sub-contractors. In this building, the architect concentrated on the natural ventilation; which is clear from its large windows that are located in the North and South directions. The house has one floor and consists of two bedrooms, one saloon, one family hall, one kitchen and two bathrooms, which are located outside the house. Bricks built the roof and false ceilings (see Figure 6.48).

Main categories	No. of points achieved	No. of points available	NO. Of credit
Sustainable site	2	12	16 %
Indoor environmental quality	9	30	28 %
Outdoor thermal control	0	9	0%
Building form	1	8	12.5%
Materials and resources	5	34	14.7%
Drainage system and water supply system	4	16	13.33 %
Power supply	1	15	6.66%
Environmental design process	0.25	1	25%
Total	22%	125	weak

a

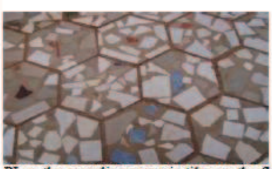


b



Pl f: Woodenroof with false ceiling

e



PL.c: the recycling ceramic tiles on the floor

PL.d:The court yard –steel doors &windows

Figure 6.48: Sample 40, plot (1693), block (4/3), Al Mourada. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 40.

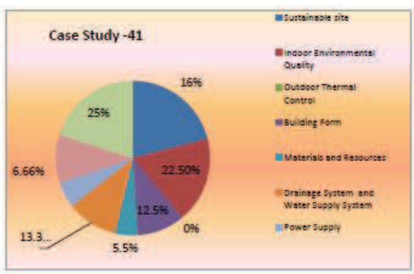
Sample No. (41): AL Morada Neighbourhood, Plot No (1693) Block No4/3: This house is located in Al Morada in Omdurman. It was built during the period of 2007-2009. Sub-contractors design this house. In this building, the architect concentrated on the natural ventilation; which is clear from its large windows that are located in the North and South directions. The house has one floor. It consists of two bedrooms, one saloon, one kitchen, and two bathrooms, which are located outside the house. The building is constructed with steel ceiling, clay on walls and steel windows (see Figure 6.49).

Main categories	No. of points achieved	No. of points available	NO. Of credit
Sustainable site	2	12	16%.
Indoor environmental quality	7	30	22 %.
Outdoor thermal control	0	9	0%
Building form	1	8	12.5%
Materials and resources	2	34	5.5 %
Drainage system and water supply system	2	16	13.33%
Power supply	1	15	6.66%
Environmental design process	0.25	1	25%
Total	15 %	125	weak

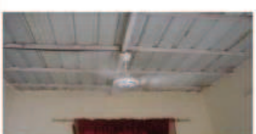
a

b

Plf: The steel windows



e



Pl.c: the ceiling from corrrecgated sheets

Pl.d: The old building near to the new one

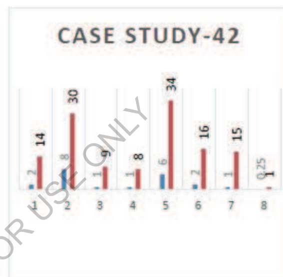
Figure 6.49: Sample 41, plot (1693), block (4/3), Al Mourada. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 41.

Sample No. 42. Al Mourda neighbourhood, Plot No: 312, Block No: 4/3

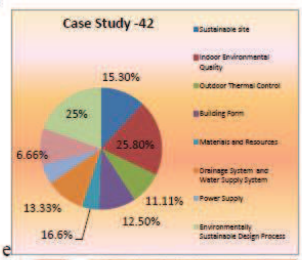
This house is located in Al Morada in Omdurman. It was built during the period of 1902-1907. Sub-contractors design this house. The architect concentrated on the natural ventilation; which is clear from its large windows that are located in the North and South directions. The house has one floor. It consists of four bedrooms, two saloons, one kitchen, and two bathrooms, which are located outside the main building. The drainage system is a Pit Latrine sewage system. In addition to steel windows, the building is constructed with coated corrugated sheets, wooden ceiling, clay on walls and wooden floors (see Figure 6.50).

Main categories	No. of Points Achieved	No. of Points Available	NO. Of Credit
Sustainable site	2	12	15 %
Indoor environmental quality	8	30	25%
Outdoor thermal control	1	9	11.11%
Building form	1	8	12.5%
Materials and resources	6	34	16.6%
Drainage system and water supply system	2	16	13.33%
Power Supply	1	15	6.66%
Environmental sustainable design process	0.25	1	25%
Total	20 %	125	weak

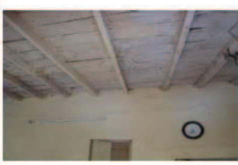
a



b



e



Pl f: The wooden ceiling

Pl.c:The steel doors & windows

Pl.d: The courtyard with trees and recycled ceramic tiles

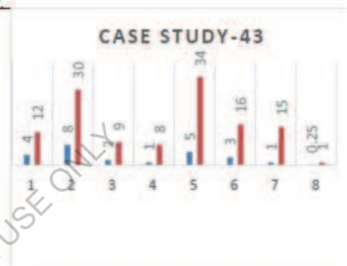
Figure 6.50: Sample 42, plot (314), block (4/3), Al Mourada. Table (a), Figure (b), Pl (c) and d and Pie (e) shows the results of sample 42.

Sample No. 43. Al Mourda neighbourhood, Plot No: 998, Block No: 4/3

This house is located in Al Morada neighbourhood in Omdurman. It was built during the period of 1970-1975. Sub-contractors designed this house. In this building, the architect concentrated on the natural ventilation; which is clear from its large windows that are located in the North and South directions. The house has one floor and it consists of two bedrooms, one saloon, one hall, one kitchen, and two bathrooms, which are located outside the house. In addition to steel windows. The building is constructed with coated corrugated sheets, wooden ceiling, clay on walls and wooden floors (see Figure 6.51).

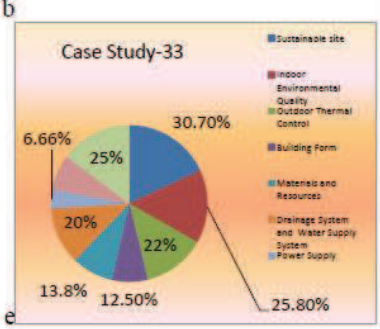
Main categories	No. of points achieved	No. of points available	NO. of credit
Sustainable site	4	12	30.7%
Indoor environmental quality	8	30	25 %
Outdoor thermal control	2	9	22%
Building form	1	8	12.5%
Materials and resources	5	34	13.8%
Drainage system and water supply system	3	16	20%
Power supply	1	15	6.66%
Environmental design process	0.25	1	25%
Total	24%	125	weak

a



b

Pl f: The East elevation



e

PL.c: The front garden in east direction.

PLd: The courtyard with baranda

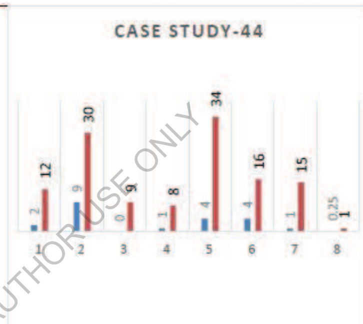
Figure 6.51: Sample 43, plot (998), block (4/3), Al Mourada. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 43.

Sample No. 44. Al Mourada neighbourhood, Plot No: 249, Block No: 4/3

This house is located in Al Morada in Omdurman. It was built during the period of 2011-2013. Sub-contractors designed this house. In this building, the architect concentrated on the natural ventilation; which is clear from its large windows that are located in the North and South directions. The house has one floor and it consist of three bedrooms, a saloon, a hall, a kitchen, and a bathroom. There is a small outdoor area. The drainage system consist of a septic tank and a well. In addition to steel windows, the building is constructed with concrete ceiling, cement blocks on walls and ceramic floors (see Figure. 6.52).

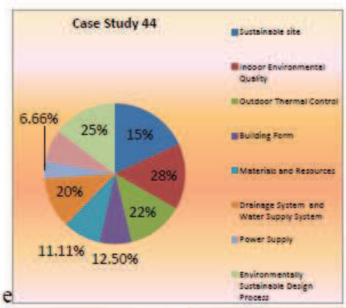
Main categories	No. of points achieved	No. of points available	NO. of credit
Sustainable site	2	12	15%
Indoor environmental quality	9	30	28%
Outdoor thermal control	0	9	22%
Building form	1	8	12.5%
Materials and resources	4	34	11.11%
Drainage system and water supply system	4	16	20%
Power supply	1	15	6.66%
Environmental design process	0.25	1	25%
Total	21 %	125	Weak

a



b

Pl f: The concrete hollow blocks walls



e

PL.c:The use of cement blocks in West

PL.d:The Resycled ceramic tiles

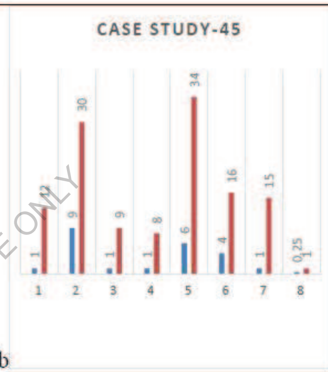
Figure 6.52: Sample 44, plot (249), block (4/3), Al Mourada. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 44.

Sample No. 45. Al Morada neighbourhood, Plot No: 293, Block No: 4/3

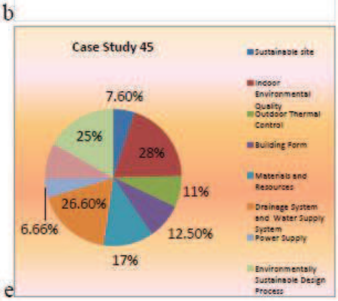
This house is located in Al Morada in Omdurman. It was built during the period of 2011-2013. This house is designed by sub-contractors. In this building, the architect concentrated on the natural ventilation; which is clear from its large windows that are located in the North and South directions. The house has two floors and it consists of three bedrooms, a saloon, a hall, a kitchen, and a bathroom. In addition to steel windows, the building is constructed with concrete ceiling, cement blocks on walls, and ceramic floors (see Figure 6.53).

Main categories	No. of points achieved	No. of points available	NO. of credit
Sustainable site	1	12	7.6%
Indoor environmental quality	9	30	28 %
Outdoor Thermal Control	1	9	11%
Building form	1	8	12.5%
Materials and resources	6	34	17%
Drainage system and water supply system	4	16	26.6%
Power supply	1	15	6.66%
Environmental design process	0.25	1	25%
Total	23 %	125	weak

a



b



e

Pl f: The cement tiles on outdoor

PL.c:The courtyard

PLd:The East Elevation-two sory –bricks wall

Figure 6.53: Sample 45, plot (293), block (4/3), Al Mourada. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 45.

6.6 House samples in the illegal residential areas of Sarya West neighbourhood

These samples were selected from the illegal house units that were built in Sarya West during 2013-2015. Sample numbers 46, 47 and 48 were adopted for these house units. Water is distributed in tanks by private vendors. The drainage system is a Pit Latrine. There is no energy supply. Building layouts are square shaped. They use mud bricks in walls, wood and animal dung on ceilings. Figure 6.54 shows the location of Sarya West illegal houses.

Figure 6.54: The locations of the illegal house units in Sarya West (2016) that are considered as samples for the research. Sample numbers 46, 47 and 48.

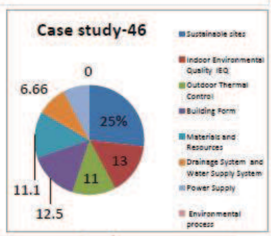
Sample No. 46. West Saria neighbourhood.

The house is located in West Saria neighbourhood. Subcontractors built it in 2000. This house is constructed by mud. The house has one floor and it contains two bedrooms, and a kitchen. There is small outdoor area without any gardens. There is veranda adjacent to the kitchen. The house has a poor outdoor environment. Limited building materials are used, such as mud bricks, animal dung plaster on mud walls, and cement sand and plaster on outside boundary walls, cloths, carton and wooden poles for walls. Ventilation is through small windows, which are oriented to the North-South direction. The outdoor environment is poorly kept. It has a wooden ground floor (see Figure 6.55).

	Main categories	No. of points achieved	No. of points available	NO. of credit
1	Sustainable site	3	12	25 %
2	Indoor Environmental quality	4	30	13 %
3	Outdoor thermal control	1	9	11 %
4	Building Form	1	8	12.5 5
5	Materials and resources	4	34	11.11 %
6	Drainage System and Water supply system	0	16	0 %
7	Power Supply	1	15	6.66 %
8	Environmental Sustainable Design Process	0	1	0 %
	total	16 points	125 points	weak

a.

b.



e.

PL. c: The outdoor environment, no garden, use of clay

PL.d: the external toilet unit , Pit latrine

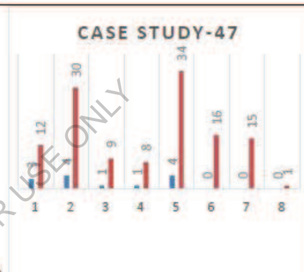
Figure 6.55: Sample 46, West Sarya, South –West Khartoum. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 46.

Sample No. 47. West Saria neighbourhood.

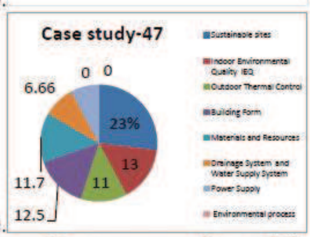
This house is located in West Saria neighbourhood. It is constructed by mud. The house has one floor and consists of two bedrooms, and a kitchen. There is a small outdoor area without any gardens and a veranda adjacent to the kitchen. The house has a poor outdoor environment. Limited building materials are used, such as mud bricks, animal dung plaster on mud walls, cement and sand plaster on outside boundary walls, cloths, carton and wooden poles for walls. Ventilation is through small windows, which are oriented towards the North-South direction. The outdoor environment is poorly kept. The house has a wooden ground floor (see Figure 6.56).

	Main categories	No. of points achieved	No. of points available	NO. of credit
1	Sustainable site	3	12	23%
2	Indoor environmental quality	4	30	13%
3	Outdoor thermal control	1	9	11%
4	Building form	1	8	12.5%
5	Materials and resources	4	34	11.7%
6	Water supply system	0	16	0%
7	Power supply	1	15	6.66 %
8	Environmental design process	0	1	0 %
	Total	17	125	WEAK

a.



b.



e.

Pl6.c:one house unit, the use of plastic, clothes and stick in walls

Pl.d: Container for water supply by vendors.

Figure 6.56: Sample 47, West Sarya, South –West Khartoum. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 47.

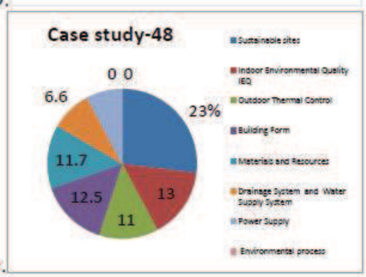
Sample No. 48. **West Sarya neighbourhood**

This house is located in West Sarya neighbourhood. Subcontractors built it in 2000. The house is constructed by mud. The house has one floor and consist of two bedrooms, and a kitchen. There is a small outdoor area without gardens, and a veranda adjacent to the kitchen. Limited building materials are used, such as mud bricks, animal dung plaster on mud walls, cement sand plaster on outside boundary cloths, carton and wooden poles for walls. Ventilation oriented to the North-South direction. The outdoor environment is poorly designed. It has a wooden ground floor (see Figure 6.57).

	Main categories	No. of points achieved	No. of points available	NO. of credit
1	Sustainable site	3	12	23 %
2	Indoor environmental quality	4	30	13 %
3	Outdoor thermal control	1	9	11 %
4	Building form	1	8	12.5 %
5	Materials and resources	4	34	11.7 %
6	Water supply system	0	16	0 %
7	Power supply	1	15	6.66 %
8	Environmental design process	0	1	0 %
	Total	15	125	WEAK

a.

b.



e.

PL.c:The use of green bricks in construction

Pl.d:The neighbourhood , no electricity

Figure 6.57: Sample 48, West Sarya, South –West Khartoum. Table (a), Figure (b), Pl (c) and (d) and Pie (e) shows the results of sample 48.

6.7 Summary

In this chapter, the fieldwork results obtained post analyses, have been presented. In the paper, first, the presentation of the results for each sample house in (El Taief, Al Rouda, and Kafoori) and Khartoum 2 neighborhoods has been done. In addition, the findings include:

- The presentation shows that the site selection has a large plot size (between 400 and 600 sq.m.), which allows the owners to maintain a good landscape with covered parking in the form of a shed.
- In addition, the analyses show good results for the category of the indoor environmental quality, which can be attributed to the factors of good ventilation and orientation, windows' size, and location.
- The majority of sample units in this group used were of cubic and linear forms.
- Also, the analyses evidenced a good quality outdoor environment due to the factors of the large plot area houses constructed by construction companies.
- The analyses also show the use of a wide range of building materials have been used like concrete, burnt bricks, sand, gravel, hollow blocks, and thermal blocks and stabilized soil blocks.

Second, the analysis for each sample unit from the third group (Sahafa in Khartoum, Al Shabia in Khartoum North and Al Mourada in Omdurman) presented the following inferences:

- Limited plot area was found for this group (250-300 sq.m.)
- The category of indoor environment has been marked a high point with good ventilation and orientation. The ventilation is good due to the large windows located in the direction of the wind.
- These areas showed poor outdoor environment, because of the limited plot area (250-300 sq.m.).

- The results from the analyses concerning water and energy were inferred to be weak for all sample units, as provided from the National Grid.
- Moreover, weak results were observed for drainage system quality. It has been found that Eltaief, Al Sahafa in Khartoum, Kafoori and Al Shabia in Khartoum North and Al Rouda, wells and septic tanks were used in the drainage system. In Al Mourada, Omdurman some houses still use a pit latrine. In addition, in the illegal areas of West Sarya people use sand and gravel, which contaminate the environment. Khartoum 2 has a drainage system. People here complained of water odor, water shortage.
- Limited choice of materials has been found such as concrete in ceiling and bricks on walls, and ceramic and marble for the floors. In these areas, people have used load-bearing systems in the construction of walls, wood and corrugated iron sheets in roofs, recycled ceramic in floors, and cement tiles in the outdoor environment. Thus, it can be inferred that the area evidenced poor roofing system.

Finally, the analysis for the fourth group for the category of indoor environment produced the following results:

- Good ventilation and orientation that could be attributed to the large windows located in the wind direction.
- These areas presented poor outdoor environment, because of limited plot area (250-300 sq.m.).
- The analysis of the results of the illegal housing areas in Khartoum West in Sarya neighborhood showed that people used mud, clay and light materials like plastic and fabric to construct their houses.
- In addition, no water or energy provided from the National Grid; and thus, in general, a poor environment has been observed.

Discussion and general conclusion of the discussion will be in the next chapter.

CHAPTER SEVEN

DISCUSSIONS AND GENERAL CONCLUSIONS FOR THE DISCUSSION

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DISCUSSIONS AND GENERAL CONCLUSIONS FOR THE DISCUSSION

7.1 INTRODUCTION

This chapter aims at discussing the fieldwork results, the analysis and states the general conclusions. As mentioned the samples were identified from different areas in Greater Khartoum, i.e., Khartoum, Khartoum North and Omdurman. The evaluation scale of study method of assessment as shown in Table 7.1 is used for the presentation and discussing the results of analysis detailed in Chapter six.

The discussion shows average results of the main categories, and average results of the sub-issues in each category in order to identify whether the results are (i) good, (ii) weak or (iii) just pass. Further, general conclusions are drawn at the end of the discussions of each part.

7.2 DISCUSSIONS OF ANALYSIS RESULTS OF NEIGHBOURHOODS AND HOUSE SAMPLES IN KHARTOUM.

7.2.1 El Taief neighbourhood

The results of the analysis are discussed by applying the sustainable-eco-building method of assessment as mentioned in Table 7.1. Table 7.2 and Table 7.3 which present the results of the sample data evaluation. Figure 7.1 summarizes the results according to the study assessment method.

Table 7.1. The evaluation scale of the study method of assessment.

Points acquired	Evaluation
< 40	Weak
(41 - 44 pts)	Pass
(45 – 59)	Good
(60 - 75 pts)	very good
(76-123 pts) or > 132	Excellent

Source: Adapted by the researcher.

Table 7.2. Presents the results and the analysis evaluation of the samples house units in El- Taief neighbourhood.

Sample No.	Result percentage	Evaluation	Reasons for results in all categories
1	47 %	Good	Good solutions in the outdoor space; maintaining the landscape; good ventilation and orientation; use of local building materials.
2	44 %	Pass	Parking cover; accessibility; roll-up shutter windows; oriented to 45˚; good landscaping; a weak result in energy.
3	37 %	Pass	Accessibility; good landscaping; large glass windows. However, poor ventilation.
4	40 %	Pass	Accessibility; good ventilation and orientation; small garden.
5	48 %	Good	Accessibility; parking cover; large garden; landscaping; ventilation and orientation are good; windows covered by wooden frame; solar water heating system; good outdoor environment; recycling grey water.
6	38 %	Pass	Good points in a sustainable site; accessibility; indoor environmental quality; good ventilation and orientation; no outdoor environment; weak result in energy, water and materials.
7	38%	Pass	Accessibility; good ventilation and orientation; no outdoor environment.
8	45%	Good	Accessibility; good orientation and ventilation; large garden; swimming pool; solar lighting, recycling grey water, marble in floors, wood in windows, L- shaped form.

Source: Adapted by the researcher.

Table 7.3. Shows and concludes the average results of the main categories in residential buildings in El Taief neighbourhood.

The category	The average result	The evaluation by the study method of assessment	Reasons for results in all categories
Sustainable Site	51 %	Good	Good accessibility, concrete skeleton, large open space, parking control.
Indoor Environmental Quality	37 %	Pass	Good practical experience in ventilation, right orientation, passive solutions with mechanical means.
Outdoor Thermal Control	64%	Very Good	Good management of the outdoor environment due to large plot sizes (400-600 m^2) and good practice and experience.
Building Form	14 %	Weak	Most samples used a linear form.
Materials and Resources	28 %	Weak	Due to the use of limited choices of ecological and local building materials.
Drainage System and Water Supply System	29 %	Weak	Most of the samples used wells and septic tanks; people claim problems in drinking water.
Power Supply	9 %	Weak	All the samples source energy from the National Grid; no natural resources such as solar or wind energy found; however one exception evident in sample No. 5 that used solar water heating.
Environmental Design Process	43 %	Good	Moderate result for environmental design process because of fewer solutions in energy, water, building form and materials.

Source: Designed by the researcher.

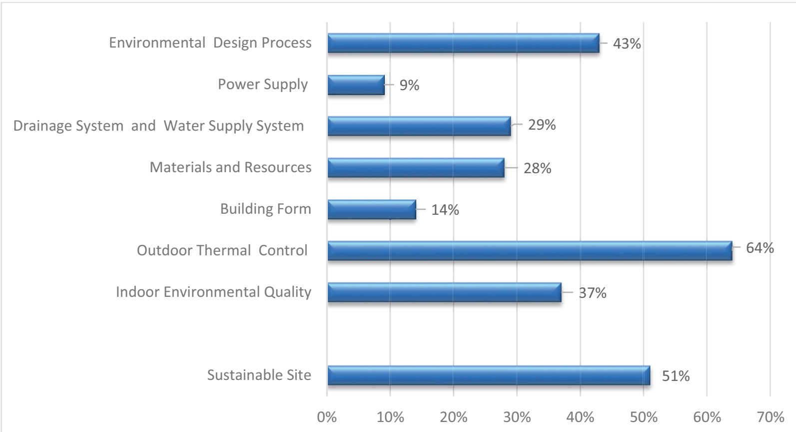

Figure 7.1: The average results of the main categories of the samples in El Taief neighbourhood. **Source:** Adapted by the researcher.

The analysis shows that sustainable site is evaluated as good, indoor environmental quality as pass, outdoor thermal control as very good, material as a weak, water supply as weak, power supply as a weak, and environmental process as good results; these results are discussed in the following paragraphs:

(a) Sustainable site

Figure 7.1 and Table 7.3 present the average result of sustainable site category for El Taief; which demonstrates a gain of 51% in accordance to the scale mentioned in Table 7.1.

Good results were found according to sustainable-eco-building assessment method of this research for the following aspects: Parking control (75%), construction activity control (87%), and public transportation axis (50%); and concrete system (90%), maximize open space (75%) and enhance landscape on site (100%).

Weak results are gained in site selection (40%) and loadbearing system (10%).

See Appendix-7 for Table 12 and Figure 12 shows the result in sustainable site.

The results are found to be inapplicable in order to control the natural water features, bicycle control, fuel control, and heat island effect (use of white paint, green trees to reflect the solar radiation away from the building). Demographically, none of the samples at this neighbourhood is placed near natural water features and demonstrated the use of bicycle in movement through the neighbourhood. None of the buildings was found to use green fuel or heat island effect solutions like green wall, green roof and white colour painting.

Most of the samples in El Taief presented good experience in using solutions such as parking control covered by shades. Most of the samples have construction activity control because they are constructed with companies. In addition, they have good public transportation axis and most of the samples sites have been well landscaped, and the open space has been maximized. Most of the buildings were constructed with concrete materials. Some of the samples were positioned away from the main road. People in Khartoum city do not use a bicycle in travelling the reason mainly heat and intense radiation climate and neither do they show the use of fuel control such as clean gas or biogas in cars. People are not aware of heat island effect solutions in their homes like the use of light colours in painting and a green roof; and the use of double roofs due to a lack of good knowledge and good experience. (See chapter five, paragraph 5.3.5).

(b) Indoor environmental quality

Figure 7.1 and Table 7.3 present the average result for indoor environmental quality for El Taief neighbourhood, and it is at (37%), which is considered a weak result, according to a scale of the research assessment method, because of poor ventilation to east-west.

Good results are gained in P.V.C layer of waterproofing in roof insulation (100%), building dimensions (75%), window size and location (100%), horizontal and vertical sunscreen (50%), wall paint and colour (50%), natural ventilation (100%), use of fans (100%), use of desert coolers (65%) and orientation to the North-South direction (50%) and courtyard system (90%). See Appendix-7 for Table 13 and Figure 13 shows the result in sustainable site.

Weak results are gained in air conditioning (25%), orientation to the East-West direction (37.5%). Other weak results are in the orientation to 45^{o} (12.50%), horizontal sunscreen (37.5 %). See Appendix-7 for Table 13 and Fig 13 shows the result in indoor environmental quality.

The results are inapplicable to the use of double roof, green roof, green wall, floor thermal control, design thermal comfort, lighting control, the use of HVAC systems and use of wind towers.

All the samples in El Taief neighbourhood have good experience in using roof insulation. Most of the buildings presented good dimensions according to Surface Volume Ratio (SVR). The houses showed good window locations and most of the samples use vertical sunscreen and light colour in painting (see sample No. 1 to No. 8). All the samples used natural ventilation and controlled the air and temperature by using fans, air conditioning systems (25%), and desert coolers (65%). The building has good orientation towards the North-South direction. People have good practical experience in orienting their houses in the direction of the wind, and use of light colours in painting to reflect sun radiations away from their houses. The research shows weak points in wind towers, use of courtyards, and double roof because people have no experience in using such solutions.

The results are inapplicable for green walls, green roofs, floor thermal control, design thermal comfort, lighting control, and the use of HVAC systems. People have no experience of using such solutions to minimize solar radiation, temperature, and humidity in their homes.

(c) Outdoor thermal control

Figure 7.1 and Table 7.3 present the average result for outdoor thermal control to be (64%), which is very good in accordance with the scale mentioned above. Analysis reveals good results for in shades to the North-South direction (75%), shades to the East-West direction (75%), balconies (100%), vegetation (75%), fences (100%) and terraces (75%); and weak results are gained in swimming pools (25%). The results are inapplicable to fountains. See Appendix-7 for Table 14 and Figure 14 showing the average result in outdoor thermal comfort.

Owners and professionals have good experience and knowledge of the importance of managing their outdoor environment to minimize the temperature in their homes by providing shades; such as shades from orienting to the North-South direction (75%), shades from the East-West direction (75%), use of balconies, vegetation cover, and terraces are good. The research shows good points in landscaping and a good balance between built-up areas and outdoor environments. Only one sample in El Taief neighbourhood presented the use of swimming pool (sample No. 8), and none of the samples used fountains.

(d) Building form

Figure 7.1 and Table 7.3 present the average result for building form to be 16%; which is weak in accordance with the evaluation scale mentioned above. A good result is gained in the use of a linear form (50%). Weak results are gained in the use of cubic forms (37%); domes (12.5%) and L- shaped form (12.5%). See Appendix-7 for Table 15 and Fig 15 shows the results in building form. The results are inapplicable to vaults and U-shaped form. Most of the samples use the linear form because owners and professionals have a good experience and use the right orientation in using linear form to improve air movement inside their buildings. Correspondingly, a few alternative solutions were found to the research method of assessment (SEBAM) in cubic forms, use of domes, and L-shaped forms. This is because of the lack of experience in people as regards using such solutions, especially L-shaped form that helps to minimize the solar radiation around the house and cool down the air, and provides shades. None of the samples used U-shaped forms or vaults in their homes.

(e) Materials and resources

Figure 7.1 and Table 7.3 present the average result for materials and resources to be 28%; which is weak in accordance with the evaluation scale mentioned. Good results are gained: in concrete (100%), sand (100%), use of gravel (100%) in base, bricks (100%), ceramic (87%), curtains (100%), and marbles (37.5%), glass and aluminium (100%). Weak results are gained in the wood on the roof (12%), wall claddings (5%), recyclable materials (25%), and carpeting (25%), steel (37.5%) and roof clay tiles (37%) and recycling content (25%). The results are inapplicable to mud; hollow blocks, suspended ceiling, and construction waste management and cement tiles. See Appendix-7 for Table 16 and Figure 16 shows the result of material and resources.

Owners and professionals have good experience in using local building material such as concrete in skeleton; walls and outdoors are built of bricks and ceramic, marbles are used on floors. There were no alternative solutions found to SEBAM in using wood because it is not available in the local market. The inhabitants refrain from using cladding because it is expensive, and do not use recyclable materials because people have no experience in using such solutions. Despite the fact that none of the samples uses recyclable building materials or wall claddings, this kind of solutions remains likeable in the field of sustainable-eco-building. None of the samples used suspended ceiling, and none has adopted construction waste management because they do not have experience and knowledge about using such solutions.

(g) Drainage and water supply systems

Table 7.3 and Figure 7.1 present the average result for drainage and water supply systems to be 29%; which is weak in accordance with the evaluation scale mentioned above. Good results are gained in the use of septic tanks and wells (100%), water supply from the National Grid (100%). The results are inferred to be inapplicable to network, reduced water usage, water recycling, and biological treatment, and rainwater container. See Appendix-7 for Table 17 and Figure 17 in the drainage system.

A few alternative solutions were evident for drainage systems other than the use of wells and septic tanks. People claimed several issues revolving around drinking water like odour, high turbidity, and plants inside water pipes. According to the analysis, 85% of samples use the septic tank and well for the drainage system with a supply of water from the local water treatment plant station. Moreover, 20% of the samples in this neighbourhood used recycled grey water for irrigation (see sample No. 1 to No. 8). None of the samples uses biological treatment or recycling of greywater systems. None of the samples uses proper technology in improving the efficiency of drinking water, minimum solutions found in use recycled grey water for irrigation and plantation, and use of the rainwater collectors. This can be attributed to a lack of experience and high cost and limited availability in the local market.

(h) Power supply

Figure 7.1 and Table 7.3 presented the average result for power supply systems to be 9%; which is weak in accordance with the evaluation scale mentioned above. Good results are gained in providing the energy from the National Grid by (100%). On the other hand, we have weak results for the use of generators (25%), the use of solar water heating systems (12.5%), and outdoor solar lighting (12.5%). The results are inferred to be inapplicable to Wind energy, energy efficiency, solar boilers, solar cooking, and photovoltaic technology, using simulations and smart energy panels. See Appendix-7 for Table 18 and Figure 18 shows the results in power supply.

Good results are gained in generating power from hydropower because of the available dams such as Marawi and Rosaris dams. Weak results are gained in using generators because it is expensive. A weak result in outdoor solar lighting can be attributed to the lack of knowledge in using such a solution. Only sample No. 12 and sample No. 7 use solar energy and solar water heating and outdoor lighting. Also, not many alternative solutions were found for SEBAM in using solar or wind energy in designing sustainable-eco-buildings. According to the analysis, 87% of the samples have used electricity from the National Grid and stand-by generator if there is no power. There were still 13% that used proper solutions, such as solar panel and heating system, refer to sample No. 12 and sample No. 7.

(i) The environmental design process

Figure 7.1 and Table 7.3 show the average result for the environmental design process to be 43%; which is good in accordance with the evaluation scaled mentioned above. The research shows good points in environmental design process in all levels including the initial stages. Refer to Appendix-7 for Table 19 and Figure 19 showing the average result for the environmental design process.

7.2.2 Khartoum 2, Arkawiet and Al Gerif West Neighbourhoods

Table 7.4 and Table 7.5 shows the results of the samples in Khartoum 2.

Table 7.4. Shows the results for accessibility of the sample house units in Khartoum 2 neighbourhoods and their evaluation by the method of assessment, (Good accessibility for all samples).

Sample No.	Results percentage	The evaluation by sustainable-eco-building assessment method	Reasons for results in all categories

9	35 %	Weak	Good ventilation and orientation; Weak solutions in outdoor environment due to the limited plot area. Energy and water from National Grid. Limited materials.
10	51 %	Good	Maximize outdoor environment, construction activity control, good ventilation and orientation, roof insulation, good shades, L- Shaped form with cantilever sheds and balconies, energy from National Grid, local water recycling, and eco- building materials.
11	47%	Good	Maximize outdoor environment, construction activity control, good ventilation and orientation, roof insulation, cubic form, energy from National Grid, local water recycling, eco building materials.
12	50%	Good	Large outdoor environment, construction activity control, and concrete structure. Good ventilation, good orientation, vaults in a roof, energy from National Grid, solar energy system as well, water recycling, and eco-building materials.
13	46%	Good	Large outdoor environment, construction activity control, concrete in structure, good ventilation and orientation, cubic form, energy from National Grid, local water recycling and eco building materials.

Source: Adapted by the researcher.

The result shows good points for samples No. 11, No. 12 and No. 13. The results show pass points for sample No. 13 and weak points for sample No. 9 according to the scale of the study method of evaluation (see Table 7.4).

Table 7.5. Shows the average results of the main categories in Khartoum 2 neighbourhoods.

The Category	The Average result	The evaluation by sustainable-eco-building assessment method	Reasons for results in all categories
Sustainable Site	64 %	Good	Good accessibility, concrete skeleton, large open spaces, parking control.
Indoor Environmental Quality	47 %	Good	Good practical experience in ventilation, right orientation, passive solutions with mechanical means.
Outdoor Thermal Control	56 %	Good	Good management of the outdoor environment due to the large plot size (400-600 m^2).
Building Form	25%	Weak	Good experience in using linear form. On the other hand, the minimum solution found in cubic, L-shaped and U- shaped forms.
Materials and Resources	29 %	Weak	Using limited choices of ecological and local building materials
Drainage and Water Supply Systems	23 %	Weak	There were few alternative solutions, for SEBAM in drainage systems, people claim water shortage.
Power Supply	11 %	Weak	No solutions such as wind energy or other natural resources energy were seen. All the samples get energy from the National Grid. Natural resources such as solar energy panels found only in sample No. 9.
Environmental Design Process	44 %	Good	Good result for the environmental design process because of good solutions in ventilation, orientation, materials, energy.

Source: Adapted by the researcher.

The analyses show that the result for a sustainable site is good, indoor environmental quality is good, outdoor thermal control is very good, materials is weak, water supply is weak, the power supply is weak and environmental process is good. This table will be discussed in the following section. Figure 7.2 shows the average result of the main categories in Khartoum 2.

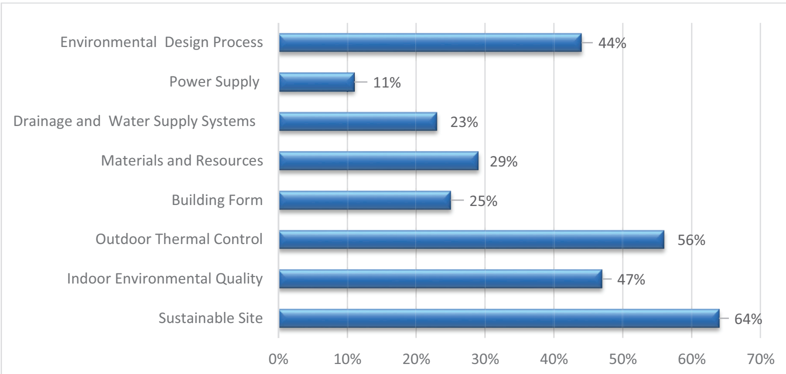

Figure 7.2: Average results of the main categories in Khartoum 2 neighbourhood. **Source:** Adapted by the researcher.

The following paragraph is discussing the results of Khartoum 2 neighbourhood.

(a) Sustainable site:

Figure 7.2 and Table 7.5 presents the average result for the sustainable site category of Khartoum 2 neighbourhood to be 64%; which is rated as very good in accordance with the scale mentioned above. Good results are gained in site selection (40%), parking control (80%), construction activity control (80%), and enhanced parking control (60%) and maximize open space (60%). Weak results are gained in load-bearing systems (40%) and steel systems (40%) and heat island effect because there is no proper solution regarding heat island effect like the use of light paint. According to the study analysis, the results are inapplicable to control natural water features, bicycle control and fuel control. See Appendix-7 for Table 12 and Figure 12 shows the average result for the sustainable site.

Most of the samples of Khartoum 2 neighbourhoods demonstrated good experience in using shades and parking control. The majority of samples have construction activity control because they are constructed with construction companies. They have public transportation routes and good site selection. Most samples have been well landscaped and their open spaces have been maximized. Most of the buildings are constructed with concrete roofs. The people in Khartoum city do not use bicycles as a means of transportation because of intense radiation; also due to fuel control, practices such as clean gas or biogas in cars are not available. People have no experience in heat island effect solutions for their houses.

b) Indoor environmental quality

Figure 7.2 and Table 7.5 present the average result for indoor environmental quality to be 47%; which is good in accordance with the sustainable-eco-building assessment method of the research. Good results gained in P.V.C waterproofing layer in roof insulation (80%), building dimensions (40%), window size and location (80%), horizontal and vertical sunscreen (40%), natural ventilation (100%), use of fans (100%), use of desert coolers (50%), use of courtyards (80%), and the orientation to the East-West direction (80%). Pass result is gained in wall paint and colour (40%). Weak results are gained in the orientation to the North-South direction (20%), vertical sunscreen (20%), horizontal sunscreen (25%), green walls (20%), and HVAC systems (20%). According to the analysis, the results are inapplicable to double roof, floor thermal control, design thermal comfort, lighting control, and occupancy based blind control and wind tower. See Appendix-7 for Table 13 and Fig 13 shows the results in indoor environmental quality.

People and designers have good experience in orienting the building to the East-West direction and in improving the indoor environment through the use of natural ventilation and mechanical systems such as fans and desert coolers, which are not expensive and available in the local market. The use of the courtyard system has also been evidenced to be good. Wall paint and colour had pass points. The research shows weak points in using vertical and horizontal sunscreen, HVAC systems, and green walls because people do not have knowledge and experience in these systems. The research shows that the results are inapplicable for using green roofs, floor thermal comfort, design thermal comfort, lighting control, and occupancy based blind control; because people do not have knowledge and experience in using such technologies (See sample No. 9 and No. 10).

(c) Outdoor thermal control

Figure 7.2 and Table 7.5 presents the average result for outdoor thermal control to be on Khartoum 2 (56%); which is good in accordance with the scale mentioned above. Good results are gained in shades to North-South direction (80%), shades to the East-West direction (40%), vegetation (80%), balconies (60%), and fences (89%). Pass result is gained for the shades to the North-South direction (40%).
A weak result is gained for terraces (30%). The results are inapplicable to swimming pools, and fountains. See Appendix-7 for Table 14 and Figure 14 showing the average result of the outdoor environment.

Owners and professionals have good experience and knowledge of the importance of managing their outdoor environment to minimize the temperature in their homes. It was observed that in 53% of the samples, shades were maximized at the North-South direction and minimized at the East-West direction; the samples also included balconies, terraces, fences, car shades, gardens, and shaded corridors. See results of samples No. 12 and No. 13 as examples. However, 47% of the samples are not in alignment; see sample No. 9. The research shows pass results in vegetation cover. Most samples have a good outdoor environment (see results of samples No. 9, 10, 12, and 13). Designers have the awareness of the importance of vegetation in reducing the heat around the house. The research shows there are few alternative solutions for SEBAM in swimming pools and fountains. This lack or limited solution availability is because of the lack of knowledge and experience in using such solutions in reducing the temperature and increasing humidity around the house.

(d) Building form

Figure 7.2 and Table 7.5 present the average result for building forms to be 25%; which is weak in accordance to the scale mentioned above. The good result is gained in 60% of the samples, which are linear in form and oriented to the North-South direction. Weak results are gained in Cubic form (20%), vaults (20%), and courtyards (20%) and L-shaped form (5%). The results are inapplicable to U–shaped forms with internal courtyard systems. See Appendix-7 for Table 15 and Figure 15 the average result in building form.

Most of the samples demonstrate the use of the linear form because people are aware of using it to improve the air movement inside their buildings. The research shows minimum solutions in cubic forms, L-shaped form, and the use of domes. People have no experience in using such solutions, especially L-shaped forms that minimize solar radiation around the house and cools the air. None of the samples used U-shaped forms or vaults; that is attributed to the lack of experience in using such solutions and because of small plot sizes (400 m^2). Expensive land prices contribute to maximizing built-up areas and results in determining building forms.

(e) Materials and resources

Figure 7.2 and Table 7.5 present the average result for materials and resources in the Khartoum 2 neighbourhood to be 29%; which is weak in accordance to the scale mentioned above. Good results are gained (80%) in the concrete sand (80%), gravel in base (80%), bricks (80%), ceramic (60%), curtains (100%), and marbles (20%). The weak result is gained in wood (30%), steel (20%) and marble (20%), roof clay tiles (5%) and recycled materials (5%). According to the analysis, the results are inapplicable to mud, hollow blocks, carpet, suspended ceiling, construction waste management, wall cladding were. See Appendix-7 for Table 16 and Figure 16 the average result in building materials.

The construction reveals that the owners and professionals have good experience in using local building materials. They use concrete in the skeleton, bricks for outdoor walls, and ceramic and marbles on floors. All these contribute to presenting a good result. The research shows a lack of many alternative solutions such as the use of wood, as wood is not available in the local market. The research shows weak results in the cladding because it is very expensive, and people do not have the relevant experience in using such solutions. Despite the fact that none of the samples used recycled building materials or efficient wall cladding, this kind of solutions remain preferred in sustainable-eco-building. In addition, none of the samples used suspended ceilings, construction waste management, and mud.

(f) Drainage and water supply systems

Figure 7.2 and Table 7.5 present the average result for drainage and water supply systems to be 23%; which is a weak result. Good results are gained in water supply from the National Grid (100%) and network drainage system (100%). Weak results are gained in reducing water usage (5%) and water efficiency (70%). The results are inapplicable to biological treatment, recycling of grey water, and rainwater containers were. See Appendix-7 for Table 17 and Figure 17 shows the results in drainage and water supply system. There were few alternative solutions for SEBAM in drainage systems such as 'drainage nets'. People claim that drinking water has problems like odour, high turbidity and plants inside the water pipes.

People use water from the local water treatment plant. It was observed in the analysis that 20% of the samples use recycled grey water for irrigation (see samples No. 12 and No. 13). None of the samples uses technologies for biological treatment, efficiency in drinking water, or recycling grey water.

(g) Power supply

Figure 7.2 and Table 7.5 present the average result for power supply systems to be 11%; which is weak according to the sustainable-eco-building assessment method.

Good results are gained in providing energy from the National Grid by (100%) and generator (50%). Weak results are gained in solar water heating systems (10%) and solar energy (10%). The results are inapplicable to wind energy, energy efficiency, solar boiling, solar cooking, photovoltaic technology, using simulations and smart energy panels were. See Appendix-7 for Table 18 and Figure 18 showing the average result in power supply.

There were few alternative solutions for SEBAM in power supply such as the use of solar or wind energy. Most of the samples have used electricity from the National Grid and standby generator for shortages of electricity. Despite that, 13% of the samples had used solar water heating system and solar generation system (refer to sample No. 12). In sustainable-eco-buildings it is recommended to use natural resources in order to provide houses with electricity and power, such as solar water heating, solar cooking, solar boiling, solar lighting, and wind energy. However, because of a lack of knowledge about the importance of using such solutions and they may expensive.

(h) The environmental design process

Figure 7.2 and Table 7.5 present the average result for the environmentally sustainable design process to be 44%; which is rated as good in accordance with the scale mentioned above. According to the study, 44% of samples used environmental design process and 34% did not. Refer to 7.2.1.i. See Appendix-7 for Table 19 and Figure 19 for the environmentally design process.

7.2.3 Al Sahafa Wasat neighbourhood

Table 7.6, Table 7.7 and Figure 7.3 show the results of the samples in Al Sahafa Wasat neighbourhood.

Table 7.6. The results and evaluation of the sample house units in Al Sahafa Wasat neighbourhood.

Sample No.	Results percentage	Evaluation	Reasons for results in all categories
AL –SAHAFA			
14	25%	Weak	There were few alternative solutions for SEBAM. The samples are away from the main road; limited outdoor environment due to small plot size (300 m^2); loadbearing system; poor roofing system; limited solutions are found in building form; energy and water from the National Grid, limited choice of materials such as bricks, recycled ceramic and coated corrugated sheets.
15	36%	Weak	There were few alternative solutions for SEBAM. The samples are away from the main road; limited outdoor environment due to small plot size (300 m^2); loadbearing system; poor roofing system; limited solutions are found in building form; energy and water from the National Grid, limited choice of materials such as bricks, recycled ceramic and coated corrugated sheets.
16	19%	Weak	There were few alternative solutions for SEBAM. The samples are away from the main road; limited outdoor environment due to small plot size (300 m^2); loadbearing system; poor roofing system; limited solutions are found in building form; energy and water from the National Grid, limited

			choice of materials such as bricks, recycled ceramic and coated corrugated sheets.
17	17%	Weak	There were few alternative solutions for SEBAM. The samples are away from the main road; limited outdoor environment due to small plot size (300 m^2); loadbearing system; poor roofing system; limited solutions are found in building form; energy and water from the National Grid, limited choice of materials such as bricks, recycled ceramic and coated corrugated sheets.
18	22%	Weak	There were few alternative solutions for SEBAM. The samples are away from the main road; limited outdoor environment due to small plot size (300 m^2); loadbearing system; poor roofing system; limited solutions are found in building form; energy and water from the National Grid, limited choice of materials such as bricks, recycled ceramic and coated corrugated sheets.
19	21%	Weak	There were few alternative solutions for SEBAM. The samples are away from the main road; limited outdoor environment due to small plot size (300 m^2); loadbearing system; poor roofing system; limited solutions are found in building form; energy and water from the National Grid, limited choice of materials such as bricks, recycled ceramic and coated corrugated sheets.
20	29%	Weak	There were few alternative solutions for SEBAM. The samples are away from the main road; limited outdoor environment due to small plot size (300 m^2); loadbearing system; poor roofing system; limited solutions are found in building form; energy and water from the National Grid, limited choice of materials such as bricks, recycled ceramic and coated corrugated sheets.

Source: Adapted by the researcher.

The following Table 7.7 shows the conclusion of the average results for the main categories in the residential buildings in Al Sahafa Wasat neighbourhood.

Table 7.7. The average results in Al Sahafa Wasat neighbourhood

The Category	The Average results -points	The evaluation by SEBAM	**Reasons for results in all categories**
Sustainable Site	27 %	Weak	There were few alternative solutions for SEBAM in accessibility and construction method.
Indoor Environmental Quality	27%	Weak	There were few alternative solutions for SEBAM such as poor roofing system, no wall and roof insulation, and limited solutions found in vertical and horizontal sunscreens.
Outdoor Thermal Control	14%	Weak	Poor landscaping due to the small plot sizes (250-300 m^2).
Building Form	16%	Weak	Most of the samples used linear form, other solutions were not found
Materials and Resources	15%	Weak	There were few alternative solutions for the SEBAM in eco materials used in the local environment.
Drainage and Water Supply Systems	25%	Weak	There were few alternative solutions for SEBAM in drainage systems such as wells and septic tanks; people said they were odour turbidity and plants in water pipes.
Power Supply	6.66%	Weak	There were few alternative solutions for research method of assessment. All the samples get energy from the National Grid; no natural resources such as solar or wind energy was found.
Environmental Design Process	25%	Weak	The environmental design process has a poor result; because there were few alternative solutions for SEBAM in energy, water form and materials.

Source: Designed by the researcher.

The analyses show that sustainable site is weak, indoor environmental quality is weak, outdoor thermal control is weak, the material is weak, water supply is weak, the power supply is weak, and the environmental process is weak. This table will be discussed in the following paragraphs.

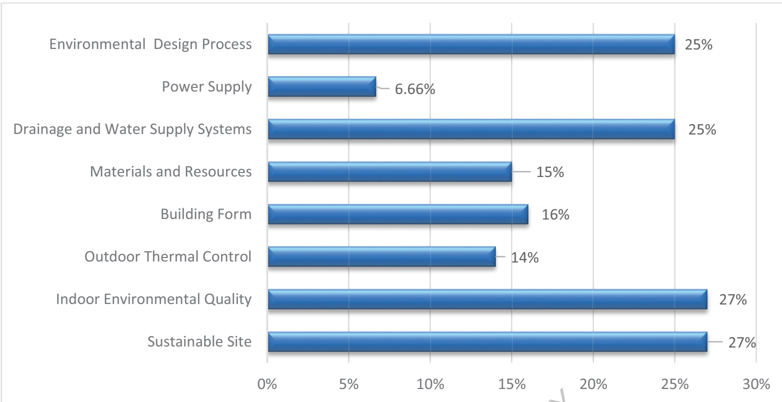

Figure 7.3: The average results of the main categories in the samples of the Al Sahafa neighbourhood in Greater Khartoum. **Source:** Designed by the researcher.

* These results show that 100% of the samples in Al Sahafa neighbourhood have weak grades in all categories according to the method of assessment used in the research.

(a) Sustainable site

Table 7.7 and Figure 7.3 shows the results of the sustainable site to be 27%; which is weak according to the method of assessment of this research. Good results are found in the loadbearing system (100%), parking control (57%), and public transportation (100%). Pass result is gained by maximizing the outdoor environment (42%). The weak result is gained in using steel (5%). See Appendix-7 for Table 12 and Figure 12 shows the results in sustainable site. Moreover, the results are inferred to be inapplicable for parking control heat island effect and bicycle control. This is due to lack of knowledge and experience in using a bicycle and managing heat island effect by using white paint and green trees to reflect solar radiation. The research shows good points in the accessibility, load bearing construction methods. Most of the samples have good access to their homes and are near to the main road. Most of the samples have good parking control, and use load-bearing systems because it is suitable for one and two storey buildings and it is more economical than the concrete system. We have pass results for maximizing the outdoor environment because of the limited plot size; all of the samples have plot sizes of 300 m^2. The results are inapplicable to site selection, natural water features' control, bicycle control, fuel control, heat island effect, construction activity control, and enhanced landscaping on site. This is because of the lack of experience and knowledge amongst the inhabitants about the importance of using such solutions in eco-buildings.

(b) Indoor environmental quality

Table 7.7 and Figure 7.3 show the result for indoor environmental quality at 27%; which is a weak result according to the method of assessment of this research. Good results are gained in orientation to the East-West direction (85%), roof insulation (42%), window size and location (85%), natural ventilation (85%), use of fans (100%), and use of desert coolers (100%), horizontal sunscreen (57%), wall painting and colour (42%) and courtyard system (70%). The weak result is gained in building dimensions (35%) and ceiling colour (28%). According to the analysis, the results are inapplicable to horizontal and vertical sunscreens, air conditioning, double roof, green roofs, green walls, floor thermal control, design thermal comfort, lighting control and the use of wind tower. See Appendix-7 for Table 13 and Figure 13 showing the average results in Indoor Environmental Quality. It was also inferred that 70% of the samples were oriented to the East-West direction, thus, improving the indoor environment by natural ventilation, and the use of mechanical systems such as desert coolers. Also, improved shading was evident through the use of vertical and horizontal sunscreen (see samples No. 15 and No. 16). People have good experience in orienting their buildings to the wind direction, and maximizing window sizes to improve air movement inside the house (see samples No. 14 to No. 20). On the other hand, buildings have illustrated poor roofing systems, no wall insulation, no light colours on the inside and outside walls, and no window management.

(c) Outdoor thermal control

Table 7.7 and Figure 7.3 shows the result of the outdoor environment at 14%; which is a weak result according to the method of assessment of this research. The good result is gained in using fences (100%). Weak results are gained in shades to the North-South direction (15%) and vegetation (15%). The results are inferred to be inapplicable to terraces, swimming pools, fountains and balconies, shades to the East-West direction. See Appendix-7 for Table 14 and Figure 14 shows the average results for the outdoor environment.

The poor outdoor environment is found because of the limited plot sizes, which range from 250 m^2 to 300 m^2. Most of the samples used fences for boundaries which protect from dust. The weak result is found in shading towards the East-West direction and from vegetation because of the limitations in plot sizes. In addition, the results are inapplicable for terraces, balconies, fountains and swimming pools because of the lack of experience and knowledge of people about the importance of such solutions in sustainable-eco-building, which provide shade and humidity to the air.

(d) Building form

Table 7.7 and Figure 7.3 show the result for building form to be 16 %; which is a weak result according to the sustainable-eco-building assessment method. Good results are gained in linear forms (85%). Weak results are gained in cubic forms (15%) and courtyard (25%). The results are inapplicable to U-shaped forms, vaults, domes and L-shaped forms. See Appendix-7 for Table 15 and Figure 15 for the average results in building form.

Most of the samples use the linear form because people and designers have good experience in using linear forms to improve air movement inside their buildings. It was also observed that 84% of the samples use a linear form that is oriented to the North-South direction. There is only one L-shaped form (sample No. 20). There are no U-shaped or cubic forms with internal courtyard systems. In chapter five, the researcher discussed building forms; Figure (5.28) shows different building forms. 14% of the samples show good results in building forms. It is recommended further that in this region, a cubic form and courtyard system should be taken into consideration. People have no experience in using L-shaped and cubic forms which are often designed by professionals.

(e) Materials and resources

Table 7.7 and Figure 7.3 show the result of the use of materials is 15% which is a weak result according to the method of assessment of this research. Good results are gained in bricks (57%), ceramic (100%), curtains (100%), and cement tiles (100%) and steel (57%). Weak results are gained in wood (15%), concrete (30%), carpet (12%), hollow block (23%), suspended ceiling (12%), and recycled content (30%), sand (25%), gravel (25%%) and wood (15%). The results are inapplicable in roof clay tiles, marble, construction waste management, wall cladding, glass and aluminium. See Appendix-7 for Table 16 and Figure 16 shows the average results for building material.

It has been observed that the owners and professionals have good experience in using local building material; such as the use of concrete in the skeleton, mud bricks, gravel, sand and stone. The result in building material is inferred at 15%, which is rated as a pass. It was also observed that 85% of samples used concrete for the skeleton slabs and columns, bricks on outdoor walls, recycling ceramic on floors, these assisted in presenting this good result because the materials are available in the local environment. The research shows weak results in wood and roof clay tiles because they are costly and limited in the local market. None of the samples uses recycled building materials or efficient wall claddings because they do not know the importance of using such solutions in eco-buildings.

(f) Drainage and water supply systems

Table 7.7 and Figure 7.3 show the result for drainage and water supply systems to be 25%; which is a weak result. Good results are gained in drainage systems using septic tanks and wells (100%), and water supply from the National Grid (100%). According to the study, results are inferred to be inapplicable to reduced water usage, use of Pit latrine system, biological treatment, recycling of grey water, and rainwater containers. See Appendix-7 for Table 17 and Figure 17 for drainage and water supply system.

In addition, the analysis revealed the availability of few other alternative solutions for the SEBAM in drainage systems such as the use of wells and septic tanks. People claim that there are problems in drinking water like odour, high turbidity and plants in water pipes. 80% of the samples use septic tanks and wells for the drainage system, and water supply from the local water treatment plant station. None of the samples used technologies for biological treatment, efficiency in drinking water, or recycling grey water, because of the lack of experience in using such solutions in eco-buildings, high cost and not available in the local market.

(g) Power supply

Table 7.7 and Figure 7.3 show the result for power supply to be 7%; which is rated as a weak result. The good result is gained in energy from the National Grid by (100%). The results are inapplicable to wind energy, energy efficiency, solar water heating, solar cooking, photovoltaic technology, using stimulation, smart energy panel, solar water heating system, and generator. See Appendix-7 for Table 18 and Figure 18 shows the results for power supply. It was also inferred that limited alternative solutions are available for the research method of assessment in using solar and wind energy for designing sustainable-eco-buildings. The study revealed that 100% of the samples use electricity from the National Grid, which uses natural resources from water falling from heights in dams. The analysis demonstrated that none of the samples in Al Sahafa neighbourhood uses solar energy, wind energy, photovoltaic energy or smart panels in heating, lighting or cooking because as they are expensive.

(h) Environmental design process

Table 7.7 and Figure 7.3 show the result of the environmentally design process to be 25%; which is a weak result according to the method of assessment of this research.

The result is rated as weak because 75% of the samples are not using the environmental design process. See Appendix-7 for Table 19 and Figure 19 shows the results in the environmentally design process.

7.3 NEIGHBOURHOOD AND HOUSE SAMPLES IN KHARTOUM NORTH

Table 7.8, Table 7.9 and Figure 7.4 show the results of the samples in Kafoori neighbourhood and their evaluation.

7.3.1 Kafoori neighbourhood

Table 7.8. The results of the sample house units in Kafoori neighbourhood and their accessibility to the plot area. This evaluation is for samples 21, 22, 23, 24 and 25.

Sample No.	results percentage	Evaluation by SEBAM	Reasons for results in all categories

Kafoori			
21	43%	Pass	This sample is away from the main street and has poor accessibility to the plot area. The outdoor environment due to the large plot size 400 m^2. There is good construction activity control, ventilation, orientation, roof insulation, cantilever, courtyard, and swimming pool.
22	44%	Pass	This sample is away from the main street and has poor accessibility to the plot area. The outdoor environment due to the large plot size 400 m^2. There is good construction activity control, ventilation, orientation, roof insulation, cantilever, courtyard, and swimming pool.
23	47 %	Good	Good outdoor environment due to the large plot size 400 m^2. There is good construction activity control, ventilation, orientation, roof insulation, cantilever, courtyard, and swimming pool.
24	47%	Good	Good outdoor environment due to the large plot size 400 m^2. There is good construction activity control, ventilation, orientation, roof insulation, cantilever, courtyard, and swimming pool.
25	47%	Good	Good outdoor environment due to the large plot size 400 m^2. There is good construction activity control, ventilation, orientation, roof insulation, cantilever, courtyard, and swimming pool.

Source: Adapted by the researcher.

Table 7.9. The average results in Kafoori neighbourhood.

The Category	The Average result	The evaluation of the main Categories by (SEBAM)	Reason for results in all categories
Sustainable Site	55%	Good	Good accessibility, concrete skeleton, large open spaces, and parking control.
Indoor Environmental Quality	41%	Pass	Good practical experience in ventilation, right orientation, passive solutions with mechanical means.
Outdoor Thermal Control	78%	Very Good	Good management of the outdoor environment due to moderate plot sizes (400-600 m^2). Good practice and experience.
Building Form	18%	Weak	Good experience in using linear form, minimum solutions in cubic, L-shaped and U-shaped forms.
Materials and Resources	36%	Weak	Using ecological and local building materials.
Drainage System and Water Supply System	23%	Weak	There were not many alternative solutions for the research method of assessment in drainage systems such as the use of wells and septic tanks. Many problems were detected in drinking water.
Power Supply	7%	Weak	There were no alternative solutions for the research method of assessment. All the samples got energy from the National Grid. No natural resources such as solar or wind energy found. Only sample No. 5 used solar water heating.
Environmental Design Process	47%	Good	Good result for the environmental design process because of fewer solutions in energy, water, building forms and materials.

Source: Adapted by the researcher.

The analysis shows that a sustainable site has good results because of the good accessibility to the plot area and moderate outdoor space. Indoor environmental quality is good in providing ventilation and the right orientation. Outdoor thermal control is very good because of its good management by owners for the landscape like plant trees, irrigation system, recycling of grey water. For example, sample 21 has swimming pool, sample 24 has a fountain, and such solutions are good in changing air from dry to humid. Building materials are weak because of the minimum use of local materials such as burnt bricks, recycled ceramic and cement. No alternative solutions are found for SEBAM for water supply and power supply and also the environmental process is moderate. These results will be discussed in the following section 7.4.1.

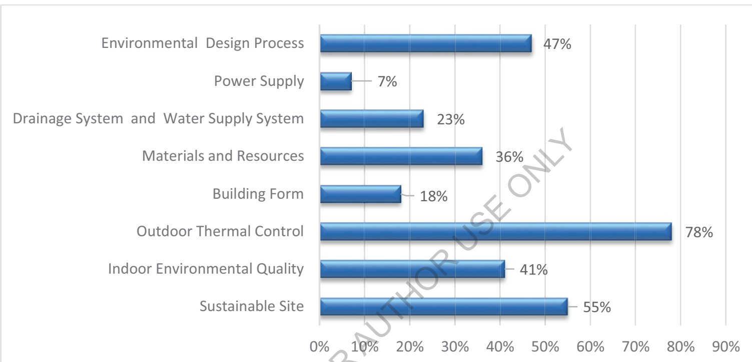

Figure 7.4: Shows and concludes of the average results in Kafoori neighbourhood. **Source:** Adapted by the researcher.

(a) Sustainable site:

Figure 7.4 and Table 7.9 present the average result for the sustainable site category in Kafoori to be 55%; which is evaluated as good in accordance with the scale mentioned above in Table 7.1. Good results are gained in parking control (66.6%), concrete systems (100%), construction activity control (87%), public transportation axis (80%), noise prevention (100%), and enhanced landscaping on site (100%).

The weak result is gained in site selection (20%). According to the analysis, the results are inapplicable to control natural water features, bicycle control, fuel control, heat island effect, and loadbearing systems. See Appendix-7 for Table 12 and Figure 12 shows the average results of a sustainable site.

Most of the samples in Kafoori have good experience in selecting the right place which has a proper public transportation axis and demonstrates freedom from any record of noise. Esteemed construction companies, which use perfect machines, construct most of the buildings. On the other hand, Kafoori is known for construction wastes as it is an incomplete city; it was designed as an industrial city. Most of the sample sites have been well landscaped and their open spaces had been maximized. None of the samples in Kafoori neighbourhood used bicycle control, fuel control or heat island effect because of the lack of knowledge in using such solutions in eco-buildings.

(b) Indoor environmental quality

Figure 7.4 and Table 7.9 present the average result for indoor environmental quality in Kafoori neighbourhood to be 41%; which is a pass result in accordance with the scale mentioned above. Good results are gained in roof insulation (100%), building dimensions (60%), window size and location (100%), horizontal and vertical sunscreen (60%), wall paint and colour (60%), natural ventilation (100%), use of fans (100%), use of desert coolers (80%), orientation to the East-West direction (60%), and use of courtyard systems (90%). Pass result is gained in air conditioning systems (40%). The weak result is gained in orientation to the North-South direction (20%). The results are inapplicable to orientation at 45^{o}, horizontal sunscreen, use of wind towers, and use of double roof, green roof, green walls, floor thermal control, design thermal comfort, lighting control and the use of HVAC systems. (See Appendix-7) for Table 13 and Figure 13 shows the results in indoor environmental quality.

All the samples in Kafoori neighbourhood have good experience in orienting their houses to the East-West direction and improving the indoor environment by natural ventilation, mechanical systems, use of vertical and horizontal sunscreens and good lighting. They use PVC on the roof, light colours on the inside and outside walls, and windows management. People use air conditioning systems to improve air movement, humidity and remove dust from inside their houses (see samples No. 21 to No. 31) because of their good practical experience with the solution. The opposite can be mentioned for the rest 66% of the samples. None of the samples in Kafoori neighbourhood used wind towers, courtyard systems, secondary roofs, green roofs, lighting control and HVAC systems due to a lack of knowledge and experience in using of such solutions.

(c) Outdoor thermal control

Figure 7.4 and Table 7.9 present the average result for outdoor thermal control to be 78%; which is very good in accordance with the scale mentioned above. Good results are gained in shades to the North-South direction (100%), shades to the East-West direction (60%), balconies (100%), vegetation (100%), and terraces (100%). The weak result is gained in swimming pools (20%) and fountains (20%).

It was also observed that the owners have good experience and knowledge of managing their outdoor environment to minimize the temperature of their houses. The study showed that 78% of the samples maximized their shades to the North-South direction with the buildings being oriented to the East-West direction. They also included balconies, terraces, fences, care shades, gardens with plants and trees, and shaded corridors (see samples No. 21 to No. 31). These are due to good experiences and practices in such solutions. Also, it was inferred that 22% of the samples are not achieving the good result. Likewise, 10% of the samples use swimming pools (see sample No. 21), and only 5% of samples use fountains (see sample No. 24).

(d) Building form

Figure 7.4 and Table 7.9 present the average result for building forms is 15%; which is weak in accordance to the scale mentioned above. The good result is gained in the use of linear forms (60%). Pass result is gained in the use of cubic forms (40%). Weak results are gained in L-shaped forms (20%). The results are inapplicable to vaults, the use of domes and U-shaped forms. See Appendix-7 for Table 15 and Figure 15 shows the results in building form.

In this analysis, the majority of the samples use a linear form because of knowledge and relevant experience of owners and professionals in using linear forms to improve air movement inside their buildings. It was also observed that 82% of the samples used a linear form that oriented to the North-South direction because people have good practice in orienting their building towards the wind direction. Only one sample has an L-shaped form (sample No. 21). Only one sample uses domes (sample No. 23). The weak result because of lack knowledge about the importance of using L-shaped, U-shaped form, vaults and domes, compared to the detailed study by (Roaf, 2001) showing the importance of using such solutions to minimize solar radiation. No sample demonstrated the use of U-shaped or cubic forms with internal courtyard systems.

(e) Materials and resources

Figure 7.4 and Table 7.9 present the average result for materials and resources to be 36%; which is weak in accordance to the scale mentioned above. Good results are gained in the use of concrete (100%), sand (100%), gravel in a base (100%), bricks (100%), ceramic (100%), curtains (100%). Pass result gained in wood (40%), marble (40%) and roof clay tiles (40%). Weak results are gained in wall claddings (40%) and steel (20%) and recycling content (15%). The results are inapplicable to recycled materials, carpets, mud, hollow blocks, and suspended ceilings, construction waste management. See Appendix-7 for Table 16 and Figure 16 shows the results for building materials.

Owners and professionals have good experience in using ecological building materials that are available in their local environment; such as the use of concrete in the skeleton, bricks for outdoor walls, ceramic and marbles for floors; these help in giving a good result. The results show a few solutions that use wood because it is available at a high price in the local market. The research shows weak points in claddings, as it is very expensive. In addition, there are weak points for recycled materials, as people have no experience in using such solutions (recycling and cladding). Despite the fact that none of the samples uses recyclable building materials or efficient wall claddings, such solutions are required in the field of sustainable-eco-buildings. None of the samples used suspended ceilings, construction waste management, it means clean the site from construction waste, because of a lack of experience in using such solutions.

(f) Drainage and water supply systems

Figure 7.4 and Table 7.9 present the average result for drainage and water supply systems to be 23%; which is weak in accordance to the scale mentioned above. The good result is gained in septic tanks and wells (100%), water supply from the main station (100%), and water efficiency (70%). The results are inapplicable to reduced water usage, recycling water, and biological treatment, recycling of grey water, and rainwater containers. See Appendix-7 for Table 17 and Figure 17 shows the results for drainage and water supply systems. According to the study, limited solutions were identified for drainage systems such as the use of soak away, wells and septic tanks. People claimed that drinking water had an odour and high turbidity. The area also presented the water shortage. Moreover, 80% of samples use septic tanks and wells for drainage systems and their supply of water is from the local water treatment plant station. Moreover, according to results, 20% of the samples use recycled grey water for irrigation (see samples No. 21 and No. 31). None of the samples used technologies for biological treatment, efficiency in drinking water, or recycling grey water, because of a lack of practice in using such solutions.

(g) Power supply

Figure 7.4 and Table 7.9 present the average result for power supply to be 7%; which is weak in accordance to the scale mentioned above. A good result is gained in providing the energy from the National Grid that is generated by hydropower (100%), and generator (100%). The study results for this region are inapplicable to solar water heating systems, outdoor solar lighting, wind energy, energy efficiency, solar boiling, solar cooking, photovoltaic technology, using stimulation, and smart energy panels. See Appendix-7 for Table 18 and Figure 18 shows the results of the power supply.

In addition, the analyses showed limited solutions are found to use solar or wind energy (only sample No. 7 used solar water heating system and sample No. 12 used solar panels). Moreover, it was inferred that 93% of samples used electricity from the National Grid and stand-by generator in case of an electricity outage. Despite that 13% use proper solutions such as solar water heating and generating systems (refer to samples No. 12 and No. 7).

(h) The environmental design process

(i) Figures 7.4 and Table 7.9 shows the average result for the environmental design process to be 47%; which is rated as pass in accordance to the scale mentioned above. While 47% of the samples used the environmental design process, 53% of the samples did not. Refer back to 7.2.1.h

7.3.2 Al Shabia neighbourhood

Table 7.10, Table 7.11 and Figure 7.5 show the results of the samples in Al Shabia neighbourhood.

Table 7.10. The results of the sample house units in Al Shabia neighbourhood and their evaluation.

Sample No.	Results percentage	Evaluation	Reason for the results in all categories
26	25%	Weak	There were few alternative solutions for SEBAM accessibility. Limited outdoor environment due to small plot size (300 m^2); loadbearing system; poor roofing system; energy and water from the National Grid; limited materials choices such as bricks, recycled ceramic and coated corrugated sheets.
27	25%	Weak	There were few alternative solutions for SEBAM accessibility. Limited outdoor environment due to small plot size (300 m^2); loadbearing system; poor roofing system; energy and water from the National Grid; limited materials choices such as bricks, and recycled ceramic.
28	22%	Weak	There were few alternative solutions for SEBAM accessibility. Limited outdoor environment due to small plot size (300 m^2); loadbearing system; poor roofing system; energy from the National Grid; water from the local plant; limited materials choices such as bricks and recycled ceramic.
29	20%	Weak	There were few alternative solutions for the SEBAM accessibility. Limited outdoor environment due to small plot size (300 m^2); loadbearing system; poor roofing system; energy from the National Grid; water from

			the local plant; limited material choices such as bricks and recycled ceramic.
30	21%	Weak	There were few alternative solutions for the research method accessibility. Limited outdoor environment due to small plot size (300 m^2); loadbearing system; poor roofing system; energy from the National Grid; water from the local plant; limited material choices such as bricks and recycled ceramic.
31	22%	Weak	There were few alternative solutions for SEBAM accessibility. Limited outdoor environment due to small plot size (300 m^2); loadbearing system; poor roofing system; energy and water from the National Grid; limited material choices such as bricks and recycled ceramic.
32	26%	Weak	There were not many alternative solutions for SEBAM accessibility. Limited outdoor environment due to small plot size (300 m^2); loadbearing system; poor roofing system; energy and water from the National Grid;; limited material choices such as bricks

Source: Adapted by the researcher.

Table 7.11. The average results of the main categories in the residential buildings of Al Shabia neighbourhood.

The Category	**The average result**	**The evaluation of the main SEBAM**	**Reason for results in all categories**

Sustainable Site	22%	Weak	There were few alternative solutions for SEBAM accessibility and construction methods.
Indoor Environmental Quality	27%	Weak	There were few alternative solutions for SEBAM. Poor roofing system; no wall and roof insulation; limited solutions found in vertical and horizontal sun-screens.
Outdoor Thermal control	25%	Weak	Weak landscaping due to small plot sizes (250-300 m^2).
Building form	13%	Weak	Most of the samples use the linear form. Other solutions were not found.
Materials and resources	15%	Weak	Minimum eco materials used from the local environment.
Water supply system	25%	Weak	There were few alternative solutions for SEBAM in drainage systems such as wells and septic-tanks.
Power supply	7%	Weak	There were few alternative solutions for SEBAM. All the samples get energy from the National Grid; no natural resources such as solar or wind energy.
Environmental Design Process	30%	Weak	Poor result for environmental design process because of the weak solutions in energy, water, building form and materials.

Source: Designed by the researcher.

The analyses showed weak results in all the main categories because of limited accessibility to plot areas, poor roofing systems and limited construction materials choices. This table will be discussed in the following paragraph.

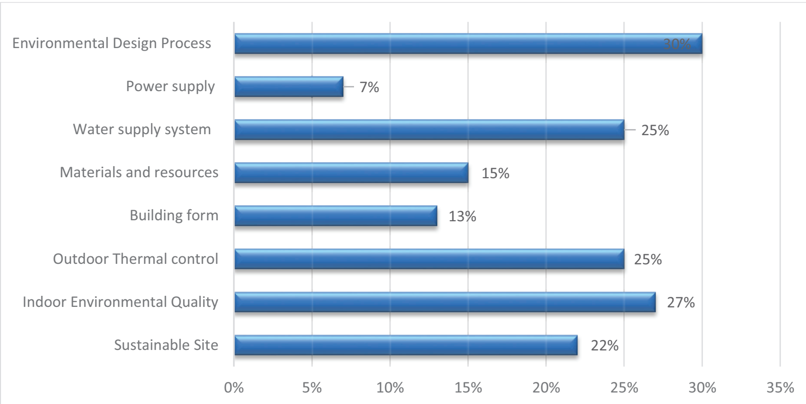

Figure 7.5: The average results of the main categories of Al Shabia neighbourhood. **Source:** Adapted by the researcher.

(a) Sustainable site

Figure 7.5 and Table 7.11 show the average results of the samples in Al Shabia neighbourhood for sustainable site to be 22%; which is weak in accordance to the scale mentioned above. Good results are gained in public transportation axis (71%), loadbearing system (71%), parking control (71%), and construction activity control (80%). Weak results are gained in site selection (20%), maximize outdoor environment (43%) and concrete system (14%). See Appendix-7 for Table 12 and Figure 12 shows the results for sustainable site. The results from the study are found to be inapplicable to enhanced parking control, using steel, control natural water features, a bicycle control, fuel control, heat island effect and enhanced landscaping on site. The common good points are the accessibility and loadbearing construction methods. Most of the samples have good access to their homes because they are near the main road, and demonstrated good parking control; and they all use loadbearing systems because it is suitable to one and two storey buildings and is more economical than concrete systems. The research found a pass result for maximizing the outdoor environment because of the limited plot area that all the samples have (300 m^2). There were inapplicable results for site selection, control natural water features, bicycle control, fuel control, heat island effect, construction activity control, enhanced landscaping on site. These were because of the lack experience and knowledge about the importance of using such solutions in eco- buildings.

(b) Indoor environmental quality

Figure 7.5 and Table 7.11 show the average results of the samples in Al Shabia neighbourhood for the Indoor Environmental Quality to be 27%; which is weak accordance to the scale mentioned above. Good results are gained in orientation to the East-West direction (86%), window size and location (100%), natural ventilation (100%), use of desert coolers (86%), and the use of fans (86%) and use of courtyard system (80%). Weak results are gained in horizontal, vertical sunscreen (14%), and roof insulations (14%). The results from the study analysis are inapplicable to air conditioning, double roof, green roof, green wall, floor thermal control, design thermal comfort, lighting control, building dimensions and wind tower. See Appendix-7 for Table 13 and Figure 13 showing the results for indoor environmental quality. It was also observed that the 71% of samples are oriented to the East-West direction and improve the indoor environment by natural ventilation, using desert coolers as mechanical system because of the good practice and experience in such solutions. On the other hand, the research shows weak results in using vertical and horizontal sunscreen. Poor roofing systems were also evident, with lacking wall insulation, absence of light colours on the inside and outside walls, and no windows management. These are because of the lack of knowledge and experience in using such solutions.

(c) Outdoor thermal control

Figure 7.5 and Table 7.11 show the average results of the samples in Al Shabia neighbourhood for outdoor thermal control to be 25%; which is weak in accordance to the scale mentioned above. Good result is gained for fences (100%).

Weak results are gained in shades to the East-west direction (14%), and vegetation cover (28%). The results from the study analysis are inapplicable to: Shades to the North-South direction, terraces, swimming pools, fountains and balconies. See Appendix-7 for Table 14 and Figure 14 shows the results for outdoor thermal control.

Moreover, in the study results, poor outdoor environment is found because of limited plot area sizes, ranging from 250 m^2 to 300 m^2. Most of the samples used fences as boundaries to their buildings and protection from dust. The research found weak results in shades to the East-West direction, and weak results in vegetation because of limited plot size (350 m^2). The results are found to be inapplicable for terraces, balconies, fountains, and swimming pools, because of the lack of knowledge about the importance of such solutions in sustainable-eco - buildings. It was evidenced that such solutions provide shades and humidity to improve the air.

(d) Building form

Figure 7.5 and Table 7.11 show the average results of the samples in Al Shabia neighbourhood for building forms to be 13%; which is weak in accordance to the scale mentioned above. Good result is gained in the use of linear forms (71%). Weak results are gained in the use of cubic forms (14%), and courtyard systems (25%). According to the analysis, results are inapplicable to U-shaped forms, vaults, domes and L-shaped forms. See appendix-7 for Table 15 and Figure 15 shows the results for building form.

It was observed that most of the samples use the linear form because owners and professionals have good experience in using linear forms to improve air movement inside the buildings. Moreover, as per the results 88% of samples used the linear forms and their house were oriented to the North-South direction. There is one usage of the L-shaped form (only sample No. 20). There is no use of the

U–shaped form or the cubic form with internal courtyard systems; as discussed in chapter five, correspondingly, Figure 5.28 shows that different plan forms can have more or less wall areas for the same plan area. In addition, 14% of the samples show good results for dealing with building forms.

It was observed that most of the samples used the linear form. It offers a good result to improving the air movement inside the buildings. The research shows that there is a minimum usage of solutions like cubic forms, domes, and L-shaped forms that minimize the solar radiation around the house, cool the air and provide shades. This is because people have no experience in using such solutions. None of the samples used the U-shaped form or vaults in their homes. That is attributed to the lack of experience in using such solutions and because of small plot sizes (400 m^2). Expensive land prices lead to maximize built-up areas and could result in determining building forms.

(e) Materials and resources

Figure 7.5 and Table 7.11 show the average results of the samples in Al Shabia for building materials is 15 %; which is rated as pass. Good results are gained in the use of bricks (71%), ceramic (43%), curtains (100%), cement tiles (28%) and hollow blocks (43%). Weak results are gained in the use of wood (15%), concrete (14%), sand (14%), gravel (14%), steel (28%), suspended ceilings (14%), roof clay tiles (14%), recycled content (28%), glass and aluminium (14%) and carpet (28%). The results are inapplicable to the use of marble, construction waste management, wall claddings. See Appendix-7 for Table 16 and Figure 16 showing the results in building materials.

The results thus show that owners and professionals have good experience in using ecological building materials available in their local environment; such as the use of concrete in building skeleton, mud bricks, gravel, sand, stones. It was observed that 84% of the samples use concrete for the skeleton, bricks on outdoor walls, ceramic and marble on floors. This can be attributed to their availability in the local environment. The research shows weak points in the use of wood because it is expensive; and weak points in the use of roof clay tiles as they are expensive and limited in the local market. It is noticed that none of the samples used recyclable building materials or efficient wall cladding, because of their lack of knowledge on the importance of using such solutions in eco- buildings.

(f) Drainage and water supply systems

Figure 7.5 and Table 7.11 show the average results of the samples in Al Shabia for drainage and water supply systems to be 25%; which is a weak result. Good results are gained in the use of septic tanks and wells (100%), and water supply from the main station (100%). Weak result is gained in water efficiency (15%). The results are inapplicable to reduced water usage, use of Pit Latrine systems, biological treatment, recycling of grey water, and rainwater containers. See Appendix-7 for Table 17 and Figure 17 showing the results for drainage and water supply systems.

There were few alternative solutions found in drainage system such as wells and septic tanks. People claimed about water supply and water quality that water pipes contain plants. 75% of samples used septic tanks and wells for drainage systems, and the water supply was from the National Grid. None of the samples used technologies for biological treatment, efficiency in drinking water, or recycling grey water, because of the limited knowledge in using such solutions in eco designs.

(g) Power supply

Figure 7.5 and Table 7.11 show the average results of the samples in Al Shabia neighbourhood for power supply to be 7%; which is rated as weak according to the scale of study of assessment.

Good result is gained in providing energy from the National Grid that is generated by hydropower (100%), and no use of generator.

The results are inapplicable to wind energy, energy efficiency, solar boiling, solar cooking, photovoltaic technology, using stimulation, smart energy panel, and solar water heating systems. See Appendix-7 for Table 18 and Figure 18 showing the results for power supply.

People get energy from the local plant. Limited solutions are found in using solar or wind energy in designing sustainable-eco-buildings. 100% of the samples use electricity from the National Grid, which is produced from natural resources of water falling from heights in dams. None of the samples in Al Shabia (see samples No. 26 to No. 31) use solar energy, wind energy, photovoltaic energy smart panels in heating, lighting and cooking because they are expensive.

(h) Environmental design process

Above the result is rated as weak. 45 % of the samples are not using environmental design process. In Al Shabia most of the buildings were built by sub-contractors, and depends on maintain of their old homes regularly. Refer to 7.2.1.i.

7.4 NEIGHBOURHOOD AND HOUSE SAMPLES IN OMDURMAN

7.4.1 Al Rouda neighbourhood

Table 7.12, Table 7.12 and Fig 7.6 show the results of the samples in Al Rouda neighbourhood.

Table 7.12. The results of the sample house units in Al Rouda neighbourhood and their accessibility to the plot area

Sample No.	results percentage	Evaluation	Reasons for results in all categories
Al Rouda			

33	46%	Good	Good accessibility, maximize outdoor environment plot size range (400-600 m^2), construction activity control, concrete structure, good ventilation, good orientation, energy from National Grid, water recycling, and eco-building materials.
34	42%	Pass	Accessibility, maximize outdoor environment plot size range (400-600 m^2), construction activity control, concrete structure, good ventilation, good orientation, energy from National Grid, water recycling, and eco - building materials.
35	45%	Good	Accessibility, maximize outdoor environment plot size range (400-600 m^2), construction activity control, concrete structure, good ventilation, good orientation, energy from National Grid, water recycling, and eco-building material.
36	41%	Pass	Accessibility, maximize outdoor environment plot size range (400-600 m^2), construction activity control, concrete structure, good ventilation, good orientation, energy from National Grid,

			water recycling, and eco-building materials.
37	43%	Pass	Accessibility, maximize outdoor environment plot size range (400-600 m^2), construction activity control, concrete structure, good ventilation, good orientation, energy from National Grid, water recycling, and eco-building materials.

Source: Adapted by the researcher.

Table 7.13. The average results of the main categories in Al Rouda neighbourhood.

The Category	The Average result	The evaluation of the main categories by SEBAM	Reason for results in all categories
Sustainable Site	52%	Good	Good accessibility; moderate outdoor environment plot size range (400-600 m^2); construction activity control; use of concrete in skeleton.
Indoor Environmental Quality	42%	Pass	Good practical experience in ventilation; right orientation; passive solutions with mechanical means.
Outdoor Thermal control	73%	Very Good	Good management of the outdoor environment due to moderate plot size (400-600 m^2); good practice and experience.
Building form	13%	Weak	Good experience in using linear forms. On the other hand, there were few alternative solutions found in cubic, L- shaped, U-shaped forms.
Materials and resources	30%	Weak	Due to using of ecological and local building materials.
Drainage System and Water Supply System	19%	Weak	There were no alternative solutions for the research method

			of assessment. The drainage system used was wells and septic tanks. People claimed drinking water had odour and high turbidity; there was also a shortage of water.
Power Supply	6.66 %	Weak	There were no alternative solutions for the research method of assessment in power supply. All the samples get energy from the National Grid. The researcher could not find solutions such as wind energy or other natural resources of energy.
Environmental Design Process	58%	Good	Good results for the environmental design process because of good orientation, ventilation and building material

Source: Adapted by the researcher.

The analysis shows good points for sustainable site because of good accessibility, pass points for indoor environmental quality because of good ventilation and orientation, very good points for outdoor thermal control because of good landscape and large plot size, limited materials are used, weak points for water supply and power supply both from National Grid and environmental process (45%). These results will be discussed in the following paragraphs. Figure 7.6 shows the average results of the main categories.

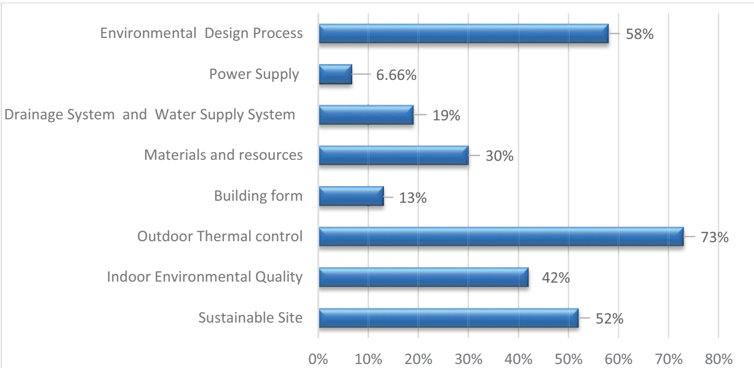

Figure 7.6: The average results of the main categories in Al Ronda neighbourhood.

Source: Adapted by the researcher.

(a) Sustainable Site

Figure 7.6 and Table 7.13 present the average result for the sustainable site category in Al Rouda neighbourhood to be 52%; which is evaluated as good in accordance to the scale mentioned above in Table 7.1.

Good results are gained in site selection (40%), parking control (60%), concrete systems (100%), construction activity control (100%), public transportation axis (89%), noise prevention (100%), and enhanced landscaping on site (80%).

Results are inapplicable to loadbearing systems, control natural water features, bicycle control, fuel control, and heat island effect. See Appendix-7 for Table 12 and Fig 12 showing the results for sustainable site.

Most of the samples in Al Rouda have good experience in using solutions such as concrete skeletons and access to public transportation axis. The sites are also free from any record of noise. Esteemed construction companies, use perfect machines and construct most of the buildings. Most of sample sites have been well landscaped and their open spaces have been maximized. None of the samples in

Al Rouda neighbourhood use bicycle control, fuel control or heat island effect because of the lack of knowledge of using such solutions in eco buildings.

(b) Indoor environmental quality

Figure 7.6 and Table 7.13 present the average result for indoor environmental quality in Al Rouda neighbourhood to be 42%; which is evaluated as a pass result according to the scale mentioned above.

Good results are gained in roof insulation (60%), building dimensions (100%), use of courtyard systems (90%), window size and location (100%), wall paint and colour (40%), natural ventilation (100%), use of fans (100%), use of desert coolers (100%), and orientation to the East-West direction (85%).

Weak results are gained in air conditioning systems (20%).

The results are inapplicable to orientation to the North-South direction, orientation to 45°, horizontal sunscreen, use of wind towers, use of double roofs, green roofs, green walls, floor thermal control, design thermal comfort, lighting control, and use of HVAC systems. See Appendix-7 for Table 13 and Figure 13 showing the results in indoor environmental quality.

Owners and professionals have good experience in orienting buildings to the East-West direction and improving the indoor environment by natural ventilation. 43% of the samples in Al Rouda neighbourhood used roof insulation. Most of the buildings have good dimensions. Window locations are good. Most of the samples used vertical sunscreen and light colour paints (see samples No. 33 to No. 37). All the samples used natural ventilation, controlling the air and temperature by using fans, air conditioning systems, and desert coolers. The buildings have good orientation to the North-South direction. House owners are aware and have practical experience in orienting the houses to the direction of the wind, and use light colour paints to reflect solar radiation away from the house.

(c) Outdoor thermal control

Figure 7.6 and Table 7.13 present the average result for outdoor thermal control to be 73%; which is very good in accordance to the scale mentioned above.
Good results are gained in shades to the North-South direction (80%), shades to the East-West direction (100%), balconies (100%), vegetation (80%), and terraces (100%).

The results are inapplicable to swimming pools and fountains. See Appendix-7 for Table 14 and Figure 14 showing the results in outdoor environment.

Owners and professionals have good experience and knowledge of the importance of managing their outdoor environment to minimize the temperature in their homes. Most of the samples used shades towards the North-South direction (75%) and shades to the East-West direction (75%). Their use of balconies are good, use vegetation cover is good, and use of terraces are good. None of the samples in Al Rouda neighbourhood used swimming pools and fountains.

(d) Building form

Figure 7.6 and Table 7.13 present the average result for building form to be 13%; which is weak according to the scale mentioned above.
Good results are gained in the use of linear forms (60%).
Pass results are gained for the use of L-shaped forms (40%).
The results are inapplicable to cubic forms, vaults, domes, and U-shaped forms. See Appendix-7 for Table 15 and Figure 15 showing the results in building form.

Most of the samples use a linear form because people and designers have good experience in using the linear form to improve air movement inside their buildings. We have minimum solutions for cubic forms and the use of domes. Only one sample uses L-shaped form (sample No. 35). People do not have experience in using such solutions, especially the L-shaped form that minimizes solar radiation around the house and cools the air and provides shades. None of the samples uses U-shaped forms or vaults due to the lack of experience in using such solutions.

(e) Materials and resources

Figure 7.6 and Table 7.13 present the average result for materials and resources to be 30%; which is weak according to the scale mentioned above.

Good results are gained in the use of concrete (100%), sand (100%), gravel in base (100%), bricks (100%), ceramic (80%), and curtains (100%).

Pass results are gained in the use of wall cladding (40%).

Weak results are found in the use of marbles (20%), wood on roof (20%), carpet (25%), and steel (20%).

Results are inapplicable to recycled materials, mud, hollow blocks, suspended ceilings, construction waste management. See Appendix-7 for Table 16 and Figure 16 showing the results for building materials.

Owners and professionals have good experience in using building materials that available in their local environment; such as the use of concrete in building skeleton, bricks on outdoor walls, ceramic and marbles on floors. These help in achieving the good result. The researcher found minimum solutions in the use of wood because it is not available in the local market; a weak result in cladding because it is very expensive; and a weak result in recycled materials because people are not experienced in using such solutions. None use suspended ceilings, construction waste management, and mud because they have limited experience in using such solutions.

(f) Drainage and water supply system

Figure 7.6 and Table 7.13 present the average results for drainage and water supply systems to be 19%; which is weak according to the scale mentioned above.

Good results are gained in septic tanks and wells (100%), water supply from the National Grid (100%).

Weak results are gained for reducing water usage and water efficiency high Results are inapplicable to water recycling, biological treatment, recycling of grey water, and rain water containers. See Appendix-7 for Table 17 and Figure 17 showing the results in drainage and water supply systems.

There were few alternative solutions to SEBAM in drainage system such as wells and septic tanks. People said they were suffering from water problems like water odour, high turbidity, and water shortage. 80% of samples used septic tanks and wells for drainage systems, and their supply of water was from the local water treatment plant station. 20% of the samples used recycled grey water for irrigation (see samples No. 34, No. 35 and No. 36). None of the samples used technologies for biological treatment, efficiency in drinking water, or recycling grey water, because they had limited experience.

(g) Power supply

Figure 7.6 and Table 7:13 present the average result for power supply systems to be 7%; which is rated as weak in accordance to the scale mentioned above.
Good results gained in power supply from the National Grid (100%), and generator (100%).

Results are inapplicable to solar water heating systems, outdoor solar lighting, wind energy, energy efficiency, solar boiling, solar cooking, photovoltaic technology, using stimulation and smart energy panels are. See Appendix-7 for Table 18 and Figure 18 showing the results in power supply.

People get energy from the National Grid and stand-by generators are used in case of electricity outage. There were not many alternative solutions to SEBAM such as the use of solar or wind energy.

(h) The environmental design process

Figures 7.6 and Table 7.13 show the average result for the environmental design process to be 58%; which is rated as good in accordance to the scale mentioned above. 58% of the samples used environmental design process and 42% did not. Refer to section 7.2.1.h.

7.4.2 Al Mourada neighbourhood

Table 7.14, Table 7.15 and Fig 7.7 show the results of samples in Al Mourada neighbourhood.

Table 7.14. The results of sample house units in Al Mourada neighbourhood.
(Energy and water supplied by National Grid; limited material choices.)

Sample No.	Results percentage	Evaluation by SEBAM	Reasons for results in all categories
AL –Mourada			
38	23%	Weak	There were few alternative solutions in this research. The samples are away from the main street; limited outdoor environment due to small plot size (300 m^2); poor roofing system; poor building form.

39	18%	Weak	There were few alternative solutions. The sample is away from the main street; limited outdoor environment due to small plot size (300 m^2); poor roofing system; poor building form.
40	22%	Weak	There were few alternative solutions SEBAM. The sample is away from the main street; limited outdoor environment due to small plot size (300 m^2); poor roofing system; poor building.
41	15%	Weak	There were few alternative solutions SEBAM. The sample is away from the main street; limited outdoor environment due to small plot size (300 m^2); poor roofing system; poor building.
42	20%	Weak	There were few alternative solutions to SEBAM. The sample is away from the main street; limited outdoor environment due to small plot size (300 m^2); poor roofing system; poor building.
43	24%	Weak	There were few alternative solutions to SEBAM. The sample is away from the main street; limited outdoor environment due to small plot size (300 m^2); poor roofing system; poor building.
44	21%	Weak	There were few alternative solutions to SEBAM. The sample is away from the main street; limited outdoor

			environment due to small plot size (300 m^2); poor roofing system; poor building.
45	23%	Weak	There were few alternative solutions to SEBAM. The sample is away from the main street; limited outdoor environment due to small plot size (300 m^2); poor roofing system; poor building.

Source: Adapted by the researcher.

Table 7.15. The average results of the main categories in the residential buildings of Al Mourada neighbourhood.

The Category	The Average result	The evaluation by SEBAM	Reasons for results in all categories
Sustainable Site	28%	Weak	There were few alternative solutions for SEBAM. The samples are away from the main street; limited outdoor environment due to small plot size (300 m^2); and loadbearing system.
Indoor Environmental Quality	26%	Weak	There were few alternative solutions for SEBAM. Poor roofing systems; no wall and roof insulation; limited solutions in vertical and horizontal sunscreen.
Outdoor Thermal Control	8%	Weak	Poor landscaping due to small plot sizes (250-300 m^2).
Building Forms	13%	Weak	Most of the samples use the linear form. Limited L-shaped form, U-shaped form and courtyard system solutions.
Materials and resources	13%	Weak	Due to minimum eco materials choices used from the local environment.
Drainage and Water Supply systems	17%	Weak	There were few alternative solutions found to SEBAM in drainage system such as wells and septic tanks. People suffering water shortage, odour, and high turbidity.

Power supply	7%	Weak	There were few alternative solutions found to SEBAM. All samples get energy from the National Grid; no natural resources such as solar or wind energy found.
Environmental Design Process	25%	Weak	Poor result for environmental design process; weak solutions in energy, water, building form and materials.

Source: Adapted by the researcher.

The analysis shows that the samples are away from the main road, good ventilation and orientation, poor landscape in outdoor because of limited plot size, limited choices for building materials and resources, drainage and water supply systems from National Grid, and the environmental process is 25% which is weak. The above table will be discussed in the following paragraphs.

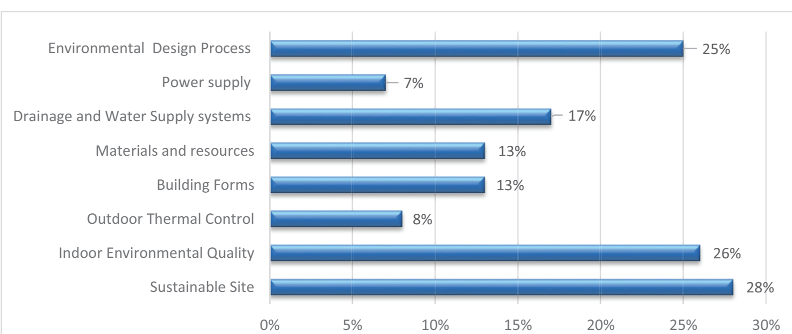

Figure 7.7: The Average results of the main categories of the samples in Al Mourada neighbourhood.
Source: Adapted by the researcher.

* This result shows that 100% of the samples on Al Mourada neighbourhood are weak in all categories according to the method of assessment of the research.

(a) Sustainable site

Figure 7.7 and Table 7.15 show the average results of the samples in Al Mourada neighbourhood for sustainable site to be 28%; which is rated as weak according to the scale mentioned above.

Good result is gained in the use of loadbearing systems (87%) and construction activity control (80%).

Weak results are gained in public transportation axis (37%), site selection (20%), enhanced parking control (37%), maximize outdoor environment (43%).

Control natural water features (37%). See Appendix-7 for Table 12 and Figure 12 showing the results in sustainable site.

Results are inapplicable to steel, bicycle control, fuel control, heat island effect, and enhanced landscaping on site.

Most of the samples have a good access to their homes; they are near to the main road. Most of the samples have a good parking control. They use load-bearing system (100%) because it is suitable for one and two storey buildings and is more economical than the concrete system.

The research shows pass points in maximizing the outdoor environment because of limited plot areas. All of the samples have a plot area of 300 m^2. Further, the results inapplicable to site selection, control natural water features, a bicycle control, fuel control, heat island effect, construction activity control and enhanced landscaping on site because of a lack of experience and knowledge about the importance of using such solutions in eco-buildings. See samples No. 38, No. 44 and No. 45.

(b) Indoor environmental quality

Figure 7.7 and Table 7.15 show the average results of the samples in Al Mourada neighbourhood for indoor environmental quality to be 26%; which is weak according to the scale mentioned above.

Good results are gained in orientation to the East-West direction (100%), natural ventilation (100%), use of desert coolers (100%), and the use of fans (100%), horizontal and vertical sunscreen (100%) and courtyard system (70%).

Weak results are gained in building dimensions (37%), window size and location (37%).

Results are inapplicable to air conditioning systems, double roof, green roof green wall, floor thermal control, design thermal comfort, lighting control, and roof insulation. See Appendix-7 for Table 13 and Figure 13 showing the results in indoor environmental quality.

71% of samples are oriented to the East-West direction; improving the indoor environment by natural ventilation. The research shows that people use desert coolers and fans as mechanical systems because of their good experience and practice in such solutions. The research shows weak points in shades by using vertical and horizontal sun- screen; poor roofing system no wall insulation; lack of light colours on the inside and outside walls; and lack of window management, because of lack of knowledge and experience.

(c) Outdoor thermal control

Figure 7.7 and Table 7.15 show the average results of samples in Al Mourada for outdoor thermal control to be 8%; which is weak according to the scale mentioned above.

Good results are gained in fences (100).

Weak results are gained for shades to the North-South direction (40%), shades to the East-West direction (80%), vegetation (37%) and terraces (12.5%).

Results are inapplicable to swimming pools, fountains and balconies. See Appendix-7 for Table 14 and Figure 14 showing the results in outdoor thermal control.

Poor outdoor environment is found because of the limited plot area size, which range from 250 m^2 to 300 m^2. Most of the samples use fences as boundaries of their buildings to keep clean from dust. In shades to East West direction. The research shows weak results in vegetation due to the limited plot size (350 m^2). The results are inapplicable result to terraces, balconies, fountains and swimming pools because they do not have enough experience and knowledge about the importance of such solutions in eco-buildings. These solutions provide shades and increase the humidity of air.

(d) Building form

Figure 7.7 and Table 7.15 show the average results of samples in Al Mourada Neighbourhood for building forms to be 13%; which is weak according to the scale mentioned above. Study shows that good result is gained in the use of linear forms (87%); weak results are gained in the use of cubic forms (12.5%). Results are inapplicable to U-shaped forms, vaults, domes and L-shaped forms See Appendix-7 for Table 15 and Figure 15 showing the results in building form.

Most of the samples use a linear form because people and designers have good experience in using the linear form it improves air movement inside their buildings. 87% of samples use the linear form and are oriented to the North-South direction. 12% of the samples show a good result in dealing with building forms. The research shows minimum solutions in cubic forms, use of domes, and L-shaped forms. People do not have experience in using such forms, especially the L-shaped form which minimizes solar radiation around the house, cools the air, and provides shades. None of the samples used U-shaped forms or vaults in their homes due to a lack of experience in using such solutions.

(e) Materials and resources

Figure 7.7 and Table 7.15 show the average results of the samples in the Al Mourada neighbourhood for building material is 13%; which is a pass result. Good results are gained in the use of bricks (75%), ceramic (75%), curtains (100%), cement tiles (75%) and sand (75%). Weak results are gained in the use of wood (40%), concrete (37%), gravel (4.7%), steel (28%), and hollow blocks (43%). Results are inapplicable to suspended ceilings, roof clay tiles, glass and aluminium, carpets, marbles, construction waste management, wall cladding. See Appendix-7 for Table 16 and Figure 16 showing the results in building material.

Owners and professionals have good experience in using building materials that are available in their local environment; such as the use of concrete in building skeleton. 82% of the samples were made of concrete skeletons, bricks on outdoor walls, and ceramic and marbles on floors; these have assisted in presenting this good result. The research shows weak result in the use of wood and roof clay tiles because they are expensive. In spite of the fact that none of the samples used recycled building materials or efficient wall cladding, these kinds of solutions remain preferred in the field of eco-building design.

(f) Drainage and water supply systems

Figure 7.7 and Table 7.15 show the average results of the samples in Al Mourada for the drainage and water supply system to be 17%; which is weak according to the scale mentioned above. Good result is gained in the use of septic tanks and wells (85%), and water supply from the main station (100%). Results are inapplicable to reduced water usage, water efficiency, and use of pit latrine systems, biological treatment, recycling of grey water, and rainwater containers. See Appendix-7 for Table 17 and Figure 17 showing the results in drainage and water supply systems.

Water supply from the National Grid. Minimum solutions were found in drainage systems such as wells and septic tanks. People complain about water odour, high turbidity and water shortage. None of the samples used technologies for biological treatment, efficiency in drinking water, or recycling grey water. This is because of the lack of knowledge and experience in using such solutions.

(g) Power supply

Figure 7.7 and Table 7.15 show the average results of the samples in Al Mourada Neighbourhood for power supply is 7%; which is a weak result. Good result is gained in energy from the National Grid generated by hydropower (100%). Results are inapplicable to generator, solar water heating systems, wind energy, energy efficiency, solar boiling, solar cooking, photovoltaic technology, using stimulation and smart energy panels. See Appendix-7 for Table 18 and Figure 18 showing the results in power supply.

People get energy from the National Grid. There were not many alternative solutions to SEBAM are found in using solar energy and wind energy in designing of the sustainable-eco-building and stand-by generator in case of electricity cut out.

(h) The environmental design process

Figures 7.6 and Table 7.13 show the average result for the environmental design process to be 25%; which is rated as weak in accordance to the scale mentioned above. 25% of the samples used environmental design process and 75% did not. Refer to section 7.2.1.i .

7.5 HOUSE SAMPLE IN THE ILLEGAL AREAS NEAR SARYA WEST NEIGHBOURHOOD

Table 7.16, Table 7.17 and Figure 7.8 show the results of the samples in the illegal areas of West Sarya.

Table 7.16. The average results of the samples in the illegal housing areas and their accessibility to the plot area.

(Good accessibility, No energy and water from the National Grid, limited material choices such as mud and bricks).

Sample No.	Results percentage	Evaluation by SEBAM	Reasons for results in all categories
46	16	Weak	Limited outdoor environment due to small plot size (250 m^2); loadbearing system; used mud, green bricks, or light materials such as cloths, plastic and sticks; poor ventilation in indoor environment; cubic form, and poor points in environmental process.

47	17	Weak	Limited outdoor environment due to small plot size (250 m^2); loadbearing systems; used mud, green bricks, or light materials such as cloths, plastic and sticks; poor ventilation in indoor environment; cubic form; and weak points in environmental process.
48	15	Weak	Limited outdoor environment due to small plot size (250 m^2); loadbearing system; used mud, green bricks, or light materials such as cloths, plastic and sticks; poor ventilation in indoor environmental; cubic form; and weak points in environmental process.

Source: Adapted by the researcher.

Table 7.17. The average results of the main categories in the illegal areas of West Sarya

The Category	The Average result	The evaluation By SEBAM	Reasons for results in all categories
Sustainable Site	23 %	Weak	Weak results in site selection; loadbearing systems are used; no bicycle control; no fuel control; and no construction waste control.
Indoor environmental quality	13 %	Weak	Poor roofing system; no wall and roof insulation; few alternative solutions in vertical and horizontal sunscreens; and poor ventilation.
Outdoor thermal control	13 %	Weak	Weak result is found in shading; limited landscaping due to small plot sizes (250-300 m^2).
Building form	12 %	Weak	There were few alternative solutions found such as linear forms. Minimum solution in cubic, L-shaped and U-shaped forms.
Materials and resources	12%	Weak	Limited choices in local building materials; they used green mud, bricks, plastic, and sticks.
Drainage and water supply system	0%	Negative impact	All samples used sand and gravel filter in drainage systems; and water supply from people who supply using

			donkey carts; no grey water recycling, rainwater containers, or water efficiency.
Power supply	6.66 %	Weak	94% of the samples have no power supply from National Grid. 6.6% of the samples used energy from neighbours. No natural resources such as solar or wind energy were found.
Environmental Design Process	0%	Not applicable	Poor result for environmental design process because of fewer solutions at site, indoor, outdoor environment, energy, water, building forms and materials.

Source: Adapted by the researcher.

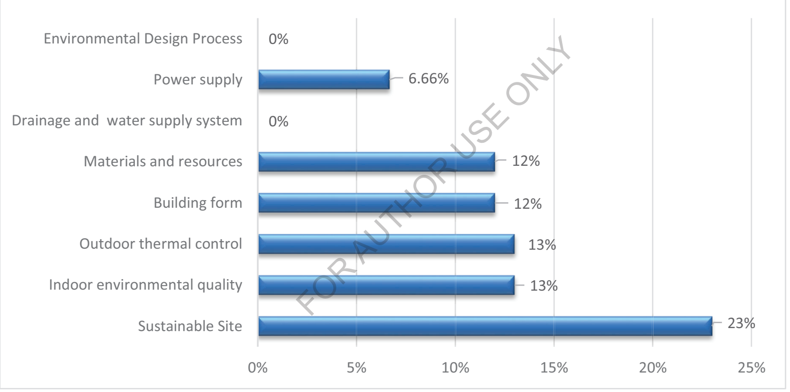

Figure 7.8: The average results of the main categories in the illegal areas of Sarya West.

Source: Adapted by the researcher.

The following paragraphs discuss the results for the illegal residential areas near Sarya West:

(a) Sustainable site

Figure 7.8 and Table 7.17 show the results of the samples in the illegal residential areas of West Sarya in Khartoum for the sustainable site to be 23%; which is a weak result.

Good results are found in loadbearing systems (60%) and large open spaces (66%).

Weak results are gained in public transportation access (30%).

Results are inapplicable to site selection, noise control, control natural water features, bicycle control, fuel control, heat island effect, construction activity control, parking control, noise prevention and enhanced parking control. See Appendix-7 for Table 12 and Figure 12 showing the results in sustainable site.

The research shows good points in loadbearing construction methods. Most of the samples have good accessibility to their homes. They are near to the main road. They use lightweight material in construction, such as wood, clothes, and sticks because they are poor people and cannot afford to build their homes. Results are inapplicable to site selection, control natural water features, bicycle control, fuel control, heat island effect, construction activity control, and enhanced landscaping on site due to a lack of experience and knowledge about the importance of using such solution in eco-buildings.

(b) Indoor environmental quality

Figure 7.8 and Table 7.17 show the results of samples in the illegal residential areas of West Sarya in Khartoum for indoor environmental quality to be 13%; which is a weak result.

Good results are gained in building dimensions (55%), window size and location (66%), natural ventilation (100%), orientation to the East-West direction (66%), roof insulation by animal waste (100%), and the use of courtyard systems (66%).

Results are inapplicable to the use of secondary roof, green roof, green wall, floor thermal control, design thermal comfort, lighting control, horizontal and vertical sunscreen, fans, air conditioning systems; desert coolers, sunscreens, wind towers, wall and ceiling colour. See Appendix-7 for Table 13 and Figure 13 showing the results in indoor environmental quality. It was also observed that 71% of the samples are oriented to the East-West direction, thus, improving the indoor environment by natural ventilation. Good results are found in using the courtyard systems. Results are inapplicable to the use of vertical and horizontal sunscreens, poor roofing system, no wall insulation, lack of light colours on the inside and outside walls, and no window management. These are because of the lack of knowledge about the importance of managing the thermal environment in eco house solutions.

(c) Outdoor thermal control

Figure 7.8 and Table 7.17 show the results of the samples in the illegal areas of West Sarya in Khartoum for outdoor thermal control to be 11%; which is a weak result. In addition, study found good results in the use of fences (66%). The results are inapplicable to the outdoor environment, swimming pools, fountains, balconies, shades to the North-South direction, shades to the East-West direction, vegetation and terraces. See Appendix-7 for Table 14 and Figure 14 showing the results in indoor environmental quality. Most of the samples use fences and walls as boundaries for privacy and to protect them from the outdoor environment. The results are inapplicable to shades to the East-West direction, and vegetation cover due to the limited plot size of 250 m^2. The results are also inapplicable for terraces, balconies, fountains and swimming pools. This is because of the lack of experience, knowledge and their limited appreciation of the importance of such solutions in eco-buildings. Moreover, these solutions could be costly.

(d) Building form

Figure 7.8 and Table 7.17 show the results of the samples in the illegal housing areas of West Sarya in Khartoum for the use of building forms to be 13%; which is evaluated to be a weak result. The study showed, good result for linear forms (66%), and weak result for cubic forms (10%), courtyards (30%). The results are inapplicable to U-shaped forms, vaults, domes and L-shaped forms. See Appendix-7 for Table 15 and Figure 15 showing the results in building form. It was also observed that 87% of the samples are cubic forms and are oriented to the East-West direction. There is no L-shaped, U-shaped or cubic forms with internal courtyard systems. The researcher discussed building forms in chapter five.

(e) Materials and resources

Figure 7.8 and Table 7.17 show the results of the samples in the illegal areas of West Sarya in Khartoum for building materials and resources to be 12%; which is evaluated as a weak result. The good results are gained in the use of mud bricks (100%), and wood (66%). The weak results were obtained for steel (33%). It was also observed that results are inapplicable to marble, carpet, construction waste management, wall cladding, glass and aluminium, ceramic and curtains. See Appendix-7 for Table 16 and Figure 16 showing the results in building material. It was also observed that 88% of the samples were constructed by mud bricks, sand, gravel and wood on floors. None of the samples use recycled building materials and efficient wall claddings because of lack of knowledge and high cost

(f) Drainage and water supply systems

Figure 7.8 and Table 7.17 show the results of the samples in the illegal housing areas of West Sarya residential complex in Khartoum for drainage and water supply systems to be 0%; which is evaluated to have a negative impact. The weak results are gained in drainage systems consisting of sand and gravel filters (100%), water supply by donkey carts (100%), and water efficiency low. In addition, according to the analysis, study results are inapplicable to water conservation, biological treatment, recycling of grey water, rainwater containers. See Appendix-7 for Table 17 and Figure 17 showing the results in drainage and water supply systems. It was also observed that 100% of the samples use sand and gravel filters in drainage systems, and their water supply is from people who supply water on donkey carts. None of the samples uses biological treatment, efficiency in drinking water, or recycling grey water.

(g) Power supply

Figure 7.8 and Table 7.17 show the results of the samples in the illegal housing areas of West of Sarya residential complex in Khartoum for power supply to be 6.66 % from the neighbours; which is evaluated as weak. The research shows weak points in energy efficiency. No power supply from the National Grid. Results are inapplicable to wind energy, energy efficiency, solar boiling, solar cooking, photovoltaic technology, using stimulation, smart energy panels, and solar water heating systems. See Appendix-7 for Table 18 and Figure 18 showing the results in power supply. According to results, 94% of the samples do not have a power supply; 6.6% of the samples use proper solutions from their neighbours and other solutions are not found, such as solar water heating, solar cooking, solar boiling, solar lighting and wind energy.

(h) Environmental process

It was observed that 100% of the samples do not present the application and use of the environmental design process. It is recommended that the environmental design process should be applied to all levels, starting from the initial stages.

7.6 GENERAL CONCLUSIONS FOR THE DISCUSSION

The general conclusions of analysis and discussion can be presented, as shown in Appendix-8, by presenting the conclusion of the results achieved by applying the scale of the study method of assessment (as shown in the methodology Section 5.2).

The conclusion of the discussions starts with Khartoum neighbourhoods. It includes the eight main categories of the study method of assessment and the justifications for evaluating the results in Eltaief, Khartoum 2 and Al Sahafa neighbourhoods. The conclusion then extends to Khartoum North samples, which includes Kafoori and Al Shabia neighbourhoods. Finally, the conclusion covers the samples of Omdurman and includes Al Rouda and Al Mourada neighbourhoods. Table 7.18 shows the general conclusion of the discussions.

Table 7.18. The general conclusion of the results with reasons.

1.Eltaief , Kafoori , Al Rouda

2.Khartoum 2

3.Al Sahafa, Al Mourada

4.Illegal areas

Applicable / Good	Applicable/ weak	Inapplicable solutions	Reasons
Sustainable Site			
1.Good accessibility; parking control; cover sheds; construction activity control; public	Site selection; loadbearing systems	Bicycle; fuel; heat island effect; outdoor lighting control;	Site selection is according to land distribution from the Ministry of Urban Planning;

Source: Adapted by the researcher.

transportation access; well landscaped; and concrete skeleton		Control natural water features.	use of construction companies; lack of knowledge and experience.
2.Good accessibility; parking control; construction activity control; public transportation access; well landscaped; concrete skeleton.	Site selection; loadbearing systems.	Bicycle; fuel; heat island effect; outdoor lighting control; control natural water features.	*Site selection is according to land distribution from the Ministry of Urban Planning; use of construction companies; *Lack of knowledge and experience.
3.Good accessibility; loadbearing construction methods	Outdoor environment	Parking control, site selection, natural water features, bicycle control, fuel control, heat island effect, construction activity control, enhanced landscaping on site	*loadbearing system is economic; *limited outdoor because of limited plot area size (205 m^2-300 m^2); *no experience and no knowledge
4.Good accessibility, loadbearing systems.	Public transportation access	Site selection, fuel control, heat island effect control, construction activity control, landscape on site	No knowledge; No experience
Indoor environmental-ly Quality			
1.Roof insulation, building dimensions, windows design, vertical sunscreen, light painting, natural ventilation, fans and desert coolers, good orientation.	Wind towers, courtyards, double roofs.	Green wall, green roof, floor thermal control, design thermal control, lighting control, use of HVAC systems, occupancy-based blind	No experience
2.Same as first class			
3.Good orientation, natural ventilation, desert coolers, vertical and horizontal sunscreen, maximize windows size	Poor roofing structure, poor insulation, Use of light colour paints.	Green wall, green roof, floor thermal control, design thermal control, lighting control, use of HVAC systems, occupancy-based blinds	No experience

4.Natural ventilation, courtyard systems, windows design, building orientation.	Roof insulation by animal waste	Green wall, green roof, floor thermal control, design thermal control, lighting control, use of HVAC systems.	No experience; *Because of their limited appreciation of the importance of such solutions. Moreover, these solutions could be costly.
Outdoor Thermal Control			
1.Good experience of managing the outdoor environment, use of shades, terraces, landscape, balconies, vegetation's.	Swimming pools	Fountains	*Good management of outdoor because of large plot size (400-600m^2).*Because of their limited appreciation of the importance of such solutions. Moreover, these solutions could be costly.
2.Good experience of managing the outdoor environment, use of shades, terraces, landscape, balconies, vegetations.	Terraces	Swimming pools, fountains	The reason that swimming pools and fountains are not used because they are costly
3.Fences	Poor outdoor environment and Shading.	Vegetation cover, balconies, fountains, swimming pools and terraces	*Poor outdoor environment because of limited plot size (250-300 m^2). The reason that swimming pools and fountains are not used because they are .costly.
4.Fence as boundaries	Poor courtyard solutions.	Shades, vegetation cover, terraces, balconies, swimming pools, canopies.	Because of their limited appreciation of such solutions. Moreover, these solutions could be costly
Building form			
All groups Used of linear forms	Weak result found for cubic forms, domes, vaults, L-shaped forms	U-shaped forms	* It is positive to use linear and cubic form because they improve air movement inside the building. *The reason of limited using of L-shaped and U-shaped forms is the high price of the plot, and the need to maximize plot area usage for the built- up area.

Materials			
1 and 2 : Concrete skeleton, sand, gravel, bricks, ceramic.	Marble, wood, wall cladding, Recycled materials, carpeting.	Mud, steel, suspended ceiling, construction waste management.	*Using materials available in the local environment. *Wood is not used because it is not available in the local market. *Cladding is not used because it is expensive. *No recycled content because of no knowledge in using such solutions
3. They used loadbearing system, recycled ceramic, bricks, ceramic, cement tiles and hollow blocks and recycled materials	Marble, wood, wall cladding, steel, concrete, suspending ceiling, glass, aluminium, and carpet	Waste management, marble, wall cladding, roof clay tiles.	No knowledge, expensive (wood, roof clay tiles, marbles)
4.Mud bricks	None	Recycled content, wall cladding, marble, carpet, construction waste, glass and aluminium, ceramic.	No knowledge. No experience. High cost.
Water and drainage system			
1. Water from the National Grid. Drainage system consist of wells and septic tanks	Recycling of grey water	Biological treatment, recycling of grey water, water containers, water metering, water efficiency.	No knowledge. No experience. Problems found in drinking water from people complains like water odour, high turbidity, water shortage and plants in water pipes
2.Water from the National Grid. Drainage to the main drainage net.	-	-	Improve water quality and standards
3. Water from the National Grid. Drainage system consist of wells and septic tanks	Recycling of grey water	Biological treatment, recycling of grey water, water container, water metering, water efficiency.	No knowledge. No experience in applying biological treatment. Problems found in drinking water from people complains like water odour, high turbidity, water

			shortage and plants in water pipes
4. Although 100% of them applied sand and gravel, it is not the proper solution because it contaminates the underground water and the environment.	Drainage system found is sand and gravel filter. Water supply by donkey carts	Biological treatment, recycling of grey water, water container, water metering water efficiency, well and septic tank.	Government should provide water supply and drainage system drainage system
Power Supply			
All the sample use energy from the National Grid; sample No. 7 use solar water heating; sample No. 9 use solar panel.	Solar energy (two sample only i.e. 4%. The use of Generator during power outage.	Wind energy, solar cooking, photovoltaic technology, *No energy for illegal areas	No knowledge and experience In using natural resources like solar or wind energy
Environmental design process			
Moderate result found for environmental design process	Maintenance	Design for durability and sustainability.	lack of knowledge and experience in applying environmental design process

These conclusions will be summarized in the following chapter in clear and concise points in order to pave the way for writing the study recommendations accordingly.

CHAPTER EIGHT

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

CHAPTER EIGHT
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

8.1 INTRODUCTION

This chapter summarizes the studies and provides conclusions and recommendations for sustainable-eco-buildings in residential areas in Greater Khartoum and recommendation for the future researches.

8.2 The Research outcomes

- The study is based on the hypothesis that some residential buildings in Greater Khartoum have serious environmental problems in the indoor environment, outdoor environment and services.
- The study concluded that good results are found in indoor environmental quality because of good ventilation, and managing building orientations, the use of vertical and horizontal sunscreen and a combination of the natural ventilation by using the mechanical means in the areas of (Eltaief, Kafoori and Al Rouda). On the other hand, the research found weak results in the indoor environment in the areas (Al Sahafa, Al Shabia and Al Mourada) because of serious problems that found in the ceiling structure; people used coated corrugated sheets and wood without insulation, which affects the thermal comfort. In addition, the limited building material used in construction and minimum uses of vertical and horizontal sunscreen.
- The research shows good results in the outdoor environment in the areas of study (Al Taief, Kafoori and Al Rouda) in managing the landscape because of large plot area size range between (400-600) m^2. People and designers have good knowledge and experience in managing the outdoor environment. On the other hand, the research detected serious problems in the outdoor environment in the areas of (Al Sahafa, Al Shabia and Al Mourada) because of limited plot area size for landscaping range between (250-300) m^2. Only the outdoor environment is used

for sleeping and sitting, the other solutions are not found like using fountains and swimming pools.

- The research shows weak results for energy efficiency for all samples; There were no alternative solutions found for energy efficiency, most of the case studies use energy from the National Grid, natural resources of energy such as wind energy, and solar energy are not found (Only case study No.9 and case study No.7).

- The research shows weak result for the water efficiency in all samples; people said there are many problems in water, such as water quality, odour, and water shortage. In addition to that there were not many alternative solutions for Sustainable-Eco-Building Assessment Method (SEBAM) such as 'well and septic tank' in the areas (Al Taief, Kafoori and Al Rouda, Al Shahafa, Al Shabia, Al Mourada), drainage network found in Khartoum two, pit latrine found in Al Mourada and sand and gravel in illegal areas in West Sarya. All these solutions caused serious environmental problems in Greater Khartoum.

- In addition; most architects do not use sustainable environmental assessment method to evaluate their projects, this system (SEBAM) could help them to compare, modify and improve their design according to sustainability main categories.

- The results show pass solutions in the sustainable site, indoor environmental quality and outdoor environment.

-The result shows weak solutions in material and resources, energy efficiency, drainage and water supply, building form and environmental design process.

8.3 CONCLUSIONS

The research made several conclusions from the analysis of the collated data and the application of evaluation method proposed, which are summarized for residential buildings in Greater Khartoum as follows

- The research concluded that the sustainable site in most residential areas in Greater Khartoum has a good accessibility level with a score of 35%, attributing to the proximity of plot to a public transportation axis. The third group, for this parameter, showed poor accessibility and revealed a score of 20%, attributing the high distance of the plot from the main road. This long distance is because of the selection of a site in accordance with the land distribution or allotment from the Ministry of Housing and Urban Planning.
- The research concluded that residential buildings have good control to parking covered by the shed, noise prevention, and waste management with a score of 65% for the first group. However, for the third group, the research inferred weak control in parking, noise and waste prevention with a score of 40%.
- In addition, large open spaces were found for the first group due to the moderate plot sizes ranging between 400 and 600 sq.m, and thus the group received a score of 60% in the data analysis. On the other hand, the research found limited plot area in the third group, size (250-300 sq.m.) with a score of 40%, according to distribution land standards for urban classes from Ministry of Urban planning.
- Heat island effect has been inferred to be significantly low in all the study samples, and thus disclosed a score of 20%. Minimum solutions found in solving the heat island effect.
- The indoor environmental quality; most of the residential buildings largely evidenced has good solutions, including roof insulation, building dimensions, windows design, vertical and horizontal sunscreens, and natural ventilation, use of fans and desert coolers, and good orientations. With a score of 33%, however, the groups also evidenced weak solutions, which seen in the use of techniques such as wind towers, courtyard systems, and double roofs. It concluded that some groups did not demonstrate the use of green walls, green

roofs, thermal comfort control, lighting control HVAC systems and occupancy based blinds or curtains.

- In the outdoor environment shows good applicable solutions such as shades, terraces, canopies, balconies and vegetation and landscape, and accordingly, received a score of 67%, attributing to the large plot sizes ranging between 400 and 600 sq.m. On the other hand, weak solutions were provided in the analysis, which revealed a score of 14.5%, because of the small plot sizes ranging between 250 and 300 sq.m.
- As regards to the environmental design process, the study revealed weak points for all areas of the study in Greater Khartoum; were found, and the corresponding score was 33% as an average result.
- The research concluded that most of the buildings in the areas of the study showed the use of linear forms with a score of (60%), then cubic forms (19%) and the courtyard systems. There were no alternative solutions to SEBAM like vaults, domes (Only case study No. 9), L-shaped forms revealed a score of (11%) (Only case studies No. 8 and No. 47) and U-shaped forms. The contributing factors to these results could be the high price of plots and the need to maximize the built-up area.
- As regards building construction; the study revealed, the use of applicable solutions, such as concrete skeleton for residential buildings in Greater Khartoum, which received a score of 57%. Similarly, load-bearing systems revealed a score of 44%, and mud bricks in illegal areas revealed a score of 100% because these solutions necessarily met the residents' needs and were economical. The research found problems in the ceiling and poor insulations in the third group.
- The use of materials in construction, it was concluded that the buildings had concrete ceilings (57%), bricks or hollow blocks in walls, and ceramic (67%) or marbles (16.4 %) on floors. Then, wood and coated corrugated sheets ceilings (32%), bricks in walls, and recycled ceramic on floors (12%). Also,

sand, gravel and clay blocks were observed in the illegal areas as owners and professionals prefer to use materials available in the local environment

- It concluded that applicable solutions such as waste management, roof clay tiles, wall cladding, glass, aluminium, and wood were not evident across the study samples. The reason for the limited or negligible use of wood, roof clay tiles and cladding could be attributed to their high costs and unavailability in the local market. Moreover, limited solutions were evident in the use of recycled materials.
- The research concluded that all case studies the water was sourced from the National Grid. The research specifically shows unsuitable solutions in the use of biological treatment, rainwater containers, water metering system, water recycling, and water efficient products because residents present limited affordability in using such solutions.
- The research concluded that all amongst the case study sample, they used septic tanks and wells, and accordingly received a score of 75% in the drainage systems. These drainage provisions, however, could contaminate the underground water. The analysis for Khartoum 2 neighbourhood revealed the use of a proper drainage network and thus received a 100% score in the sewage system. However, in Omdurman, some buildings still evidenced the use of pit latrine, and, as such received a score of 12.5%; and in illegal housing areas, sand and gravel filters were extensively used, with a score of 100%.
- The research revealed that as all case study samples in Greater Khartoum used energy from the National Grid and thus received a score of 100%. However, few alternative solutions as regards SEBAM are evident in the use of solar energy, energy heating system, outdoor lighting and solar heating. Only the case study No. 5 used solar heating and case study No. 9 used solar PV cells. The research, furthermore, shows the use of unsuitable solutions in wind energy and solar boiling because the population does not prefer employing such expensive solutions.

8.4 RECOMMENDATIONS

8.4.1 Recommendations regarding the proposed evaluation method

- The research recommends that the proposed evaluation method could be reviewed and developed by the industry academics, professionals, with their approval could be implemented by the Ministry of Housing and Urban Planning. Consequently, the advantages and benefits from the application of this research method of assessment could be apparent the application of all recommended solutions as suggested in the SEBAM studies to the 48 samples (See Appendix-1 and Appendix-5). Moreover, with the leveraging of this assessment method, as proposed in the study, the architectural field can immensely benefit and sustainable-Ecological-building, healthy, economical houses could be constructed.
- The research recommends that architects, professional could include recommendations for a larger survey on developing the building materials, energy efficiency, water efficiency, building form, site, indoor and outdoor environment.

8.4.2 Recommendations to apply sustainable-Ecological-buildings in Greater Khartoum.

- The accessibility to all plot areas should be near to a public transportation axis.
- The site should have protocols, implementation of construction activity control, noise prevention, and waste management.
- The site should have good landscape management, consequently solar lighting control.
- Heat island effect should be necessarily studied through strategic positioning of plant trees, moreover use of light colours.

- The natural ventilation through windows, the use of horizontal, consequently vertical sunscreens should be provided.
- The mechanical means such as desert coolers and fans could be used to improve the thermal comfort inside the building.
- The building should be oriented towards the East-West direction in the hot-dry climate.
- The use of wind towers, the use of courtyard systems, moreover the implementation of light colour paints on ceilings and walls could be applied.
- Solutions such as double roofs, green roofs, green walls, floor thermal control, design thermal comfort, consequently lighting control could be added to Ecological buildings.
- Open spaces at the house unit level should be provided with controlling shades, cantilever, moreover canopies.
- Fences in the outdoor environment could be built to protect the building from waste and for safety.
- Water features humidify could be built to humid the air surrounding the building.
- Trees and vegetation cover should be maintained to improve the air from dry to humid in all areas of the study.
- The building form like the linear and cubic forms, vaults, and domes is recommended.
- L-shaped and U-shaped forms could be applied in sustainable-Ecological-buildings to provide more shades to the building, accordingly cools the air through the building and improves ventilation.
- The environmental design process could be applied in the three design phases as an educational value.
- Insulation in the roof, walls should be used.
- Construction materials for the buildings should be provided from the local environment.

- Recycled materials, could be used whenever possible, especially for the outdoor area. Ecological carpets and suspended ceilings are recommended in the indoor environment.
- Water efficiency should be increased by adopting standards of The World Health Organization (WHO).
- The research is recommended adopting a distribution network for sewerage systems for all residential areas.
- The research recommended maintaining and minimizing the use of septic tanks and wells, as they are contamination threats to underground water.
- Accordingly, the application of solutions such as recycling of grey water, and rainwater collector is recommended in sustainable Ecological building.
- Natural resources for energy such as solar energy system could be applied in different applications like solar heating, solar cooking, solar photovoltaic technology.
- The research strongly recommended adding educational value to increase the knowledge of the community and teach the students, architects, designers, and people about sustainable- Ecological- building through lectures, workshops, conferences and courses corresponding to its main categories.

8.4.3 Recommendations for future research

It is suggested that further research could be conducted for different building types according to sustainable-Ecological-building issues. Examples of the same include:

- Evaluation of the local health buildings environment with a focus on thermal comfort, to identify healthcare design building standards under sustainable principles to create a healthy environment.
- Evaluation of the local educational buildings environment in order to identify educational design building standards as per sustainability principles.
- Evaluation of the local office buildings environment with a focus on thermal comfort, the study of office building design standards according to sustainability principles.
- Energy efficiency in buildings in Greater Khartoum and other similar areas in the country.
- Sustainable-Ecological-neighbourhood, with focus on case studies from Greater Khartoum.
- Sustainable-Ecological - city, with a focus on Khartoum city centre.
- The role of SEBAM, framework and some analysis of it is effectiveness.

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APPENDICES

APPENDIX-1

Record sheet

The research (sheet) method of assessment sheet was applied to 48 samples in eight neighbourhoods in Greater Khartoum. General information's are required such as, site location, name of the projects, name of architect, and name of the area, Block No., Plot No., date of start and date of end of the work.

General information:

Site location:

Case Study No.

Name of the project:

Name of the architect: Name of the client:

Name of the area: Plot No: Block No: Date of end of construction works:

Table 1. The applied sustainable-eco-building sheet.

The applied sustainable eco building sheet						
No.	**Category**	**Details of each issue**	**Justifications the scale,**	**Relevant Weight**	**Points**	**Evaluation Y/No**
	Sustainable Site 12 points					
1	**Site Selection**	**To reduce the environmental impact from studying the location, study of accessibility, plot size, plot services, plot orientation, neighbours.**	Good	0.083	1/12	
2	**Construction system**	**To study the construction system used like concrete, steel and loadbearing systems.**	Good	0.16	2/12	
	Concrete system	Prefer using of eco, durable and sustainable concrete.		0.083	1	
	Loadbearing system	Practical experience		0.083	1	
	Steel system	Used in housing in additional parts	Bad	0.083-	-1	
3	**Controlling systems**	To study controlling systems like construction activity control, controlling natural water features, enhanced parking control to minimize CO_2 emissions.	Good	0.250	3/12	
	Enhanced parking control	Covered parking, underground, or multi-storied parking.	Good	0.083	1	
	Construction activity control, pollution control	Use of mechanical systems	Good	0.083	1	
	Controlling natural water feature	Bearing wall, save the building	Good	0.083	1	
4	**Alternative Transportation**	**To study the transportation system near to the location like subways, bus stations**		0.250	3/12	

		within a walking distance of 800m.				
	Public Transport Access	Near to public transport, no need to use car, minimise CO^2	Good	0.083	1	
	Bicycle Storage & Changing Rooms	Use of bicycles, bicycle parking, minimise CO^2	Good	0.083	1	
	Low-Emitting & Fuel Efficient Vehicles	Green fuel, minimise CO^2	Good	0.083	1	
5	**Improving thermal environment**	**To improve thermal environment by landscape management on site, maximize open space**		0.16	2/12	
	Enhance landscaping on site	Landscape management, minimise heat	Good	0.083	1	
	Maximized Open space	Large garden, minimise heat	Good	0.083	1	
6	Heat island effect	**To study heat island effect by providing shades, trees, bright colour paints**	Better	0.083	1	
	Others		**Total Points**	1	12	
Indoor Environmental Quality					**30 Points**	
1	**Building orientation**	**To study building orientation; the building should be oriented to the East-West direction, other orientation needs solutions 1.1, 1.2 and 1.3**		0.133	4/30	
1.1	To the North–South direction	Sometimes the land orientations force you to such directions.			1	
1.2	To the East-West direction	The best solution	Better	0.06	2	
1.3	To 45 degree	Practice			1	
2	**Building dimensions**	**To Apply Surface Volume Ratio (SVR)**				
2.1	**Controlling building envelope**	Surface Volume Ratio between 0.12 to 0.16 to avoid excess solar radiation on the building	Good	0.033	1/30	
3	**Control building envelop**	By roof, wall, floor control		0.166	5/30	
	Roof thermal control	**To apply solutions to minimise heat gain on roof, 3.1, 3.2 ,3.3 and 3.4**				
3.1	Roof thermal insulation such as a layer of P.V.C	Use of roof thermal insulation to minimise heat gain on the roof	Good	0.03	1	
3.2	Double roof	Use double roof to reflect solar radiation	Better	0.06	2	
3.3	Ceiling colour	Use of bright colours to reflect solar radiation	Good	0.03	1	
3.4	Green oof	Minimize indoor heat by 4 to 6˚C	Good	0.03	1	

4	**Walls thermal control**	**To apply solutions on walls to control heat transfer through walls**		0.4	12/30	
	Building material	Eco building materials	Good	0.033	1	
	Windows					
	Windows dimensions	Small size windows are preferred	Good	0.033	1	
	Windows location	Windows at high-levels are preferred	Good	0.033	1	
	Window orientation	To the North-South direction of the wind	Good	0.033	1	
	Window materials	Wood, aluminium, or steel	Good	0.033	1	
	Window colour	Bright colours	Good	0.033	1	
	Sunscreen					
	Vertical sunscreen	To the East and West directions	Good	0.033	1	
	Horizontal sun screen	To the North and South directions	Good	0.033	1	
	Vertical and Horizontal screen	Practical experience	Good	0.033	1	
*	Occupancy based blinds control	Use of technology	Good	0.033	1	
	Paints and colour walls	Use of bright colours	Good	0.033	1	
	Green wall	Minimize indoor heat by 4 to 6˚C	Good	0.033	1	
5	**Floor thermal comfort**	To study floor thermal control by use of recycled flooring materials	Good	0.033	1/30	
6	**Design thermal comfort**	To study thermal comfort main components by personal, traditional or mechanical controls 6.1, 6.2, 6.3 and 6.4	Good	0.133	4/30	
6.1	**Individual thermal comfort control**	Practical experience	Good	0.033	1	
6.2	Natural ventilation through windows	Natural ventilation is a good practice.	Good	0.033	1	
6.3	The use of wind scope	Wind tower is a traditional solution	Good	0.033	1	
6.4	The use of internal courtyards	Courtyard systems are traditional solutions	Good	0.033	1	
7	**Mechanical control**			0.1	3/30	
7.1	HVAC system	Use of technology by applying HVAC system or fans or desert coolers	Good	0.033	1	
7.2	Use of fans	Fans from the practice experience by using fans	Good	0.033	1	
7.3	Use of air conditioner	AC will pollute the air	Bad	0.033 -	-1	
7.4	Use of efficient desert cooler systems	Desert cooler from practice experience	Good	0.033	1	
			Total points	1	30 points	

	Others					
Outdoor thermal control				9 points		
1	Shades to the North-South direction	To provide more shades to the building	Good	0.22	2/9	
2	Shades to the East-West direction	To provide more shades to the building	Good	0.11	1/9	
3	Balcony and canopies (cause shades)	To apply more shades to the building and protect the building from rain and solar by canopies by construction system.	Good	0.11	1/9	
4	Landscaping (vegetation)	To provide good management for the landscape by planting trees; it improves air movement and cools hot air	Good	0.11	1/9	
5	Fences (height and location) affect the air movement and dust	To protect building environment from dust and influence air movement	Good	0.11	1/9	
6	Swimming Pools	To improve air humidity	Good	0.11	1/9	
7	fountains	To improve humidity; changing hot-dry air to be more humid	Good	0.11	1/9	
8	Terraces	To encourage people to set in outdoor environment	Good	0.11	1/9	
	Total		**Total points**	1	9	
	Others					
Building Form				8 po ints		
1	Linear	Practical experience	Good	0.125	1/8	
2	U-shaped form	Literature reviewed	Better	0.141	1.13/8	
3	L-shaped form	Literature reviewed	Better	0.156	1.25/8	
4	Cubic form	Practical experience	Good	0.125	1/8	
5	Circular form	Traditional solution	Good	0.125	1/8	
6	Courtyard	Traditional solution	Better	0.25	2/8	
7	Vaults	Traditional solutions	Good	0.125	1/8	
8	Domes	**Traditional solutions**	Good	0.125	1/8	
	Others		Total points	1.016	8 points	
Materials and Resources				34 Points		
1	**Materials used in the base**	**To use eco building materials available in the local environment like concrete, stone and steel**		0.17	6/34	
	Concrete (RC) reinforcement	Professional experience	Good	0.029	1	
	Stone		Good	0.029	1	
	Sand and gravel	Practical experience	Good	0.029	1	
	Bricks	Practical experience	Good	0.029	1	
	Mud	Practical experience	Good	0.029	1	
	Steel	Practical experience	Good	-0.029	-1	
2	**Materials used on walls**	**To use eco building material in wall construction like bricks, wood and hollow blocks**		0.26	9/34	
	Mud	Practical experience	Good	0.029	1	
	Stone	Eco materials	Good	0.029	1	

	Wood	Regional priority	Good	0.029	1	
	Steel	Practical experience	Good	0.029	1	
	Cement blocks	Eco material	Good	0.029	1	
	Burnt bricks	Practical experience	Good	0.029	1	
	Compressed bricks	Eco material	Better	0.050	2	
	Hollow bricks	Eco material	Good	0.029	1	
3	**Materials used in roofing**	**To use eco building materials in roofs like construction such as concrete, bricks and wood**		0.08	3/34	
	Concrete (RC) reinforcement	Professional experience	Good	0.029	1	
	Bricks	Practical experience	Good	0.029	1	
	Wood	Regional priority	Good	0.029	1	
	Steel	Practical experience	Good	-0.029	-1	
4	**Materials used in Finishing's**	**To use high efficient eco building material in finishing's like ceramic tiles, marble.**		0.14	5/34	
	Ceramic tiles	Eco building material	Good	0.029	1	
	Marble	Regional priority	Good	0.029	1	
	Aluminium	Professional experience	Good	0.029	1	
	Wood	Regional priority	Good	0.029	1	
	Roof clay tiles	Décor materials	Good	0.029	1	
5	**Use of recycled materials**	**Using eco recycled materials in flooring like glass and ceramic.**	Better	0.05	2/34	
6	**Wall cladding**	**Using wall cladding with special specifications and allowing natural ventilation**	Good	0.029	1/34	
7	**Indoor Decorative Decor**	**Any material used for indoor decor, such as wood, gypsum boards, glass, carpet and suspending ceilings, should all be eco building materials**	0.029	0.088	3/34	
	Carpet	Décor	Good	0.029	1	
	Planked	Eco materials	Good	0.029	1	
	Suspended ceiling	Technical solutions	Good	0.029	1	
8	**Construction waste management**	**To provide an easy accessible area that serves the entire building and is dedicated to the collection and storage of hazardous materials for recycling**		0.029	1/34	
9	Calculating Embodied Energy	**To calculate the embodied energy from the factory to the site**	Good	0.029	1/34	
10	Life cycle analysis (LCA)	**To apply LCA to all building materials used.**	Good	0.029	1/34	
11	Adapting technologies	**To use technological solutions in improving the characteristics of building materials, such as clay and stones.**	Good	0.029	1/34	
12	Regional building materials	**To use regional materials such as wood and stone**	Good	0.029	1/34	
13	Low emitting building material	**To use low emitting materials in furniture, paint and carpets**	Good	0.029	1/34	
	Others					

			Total	1	34 Points	
Drainage System and Water Supply System					16 Points	
1	**Appropriate technology**	**To choose appropriate solution for drainage system like distribution net or septic tanks and wells (good practice)**		0.312	5/16	
	Distribution net	Technological and future solution	Good	0.062	1	
	Septic tank	Practical experience	Good	0.062	1	
	Well	Practical experience	Good	0.062	1	
	Biological treatment	Technological solutions	Better	0.125	2	
	Pit Latrines	Practical experience for illegal areas	Fair	0.00	0	
	Sand and gravel filter	Practical experience for illegal areas	Fair	0.00	0	
	Others					
Water supply system					16	
1	**Water Source**	**To apply water efficiency in drinking water; use water containers, and water recycling. Reduce water usage and water efficiency programs.**		0.187	3/16	
	From the river	Practical solution for illegal areas	Good	0.06	1	
	From the local station	Technical solution	Good	0.06	1	
	Well	Practical experience	Good	0.06	1	
2	**Water efficiency**			0.25	4/16	
	Water efficiency low		Good	0.06	1	
	Water efficiency moderate		Good	0.06	1	
	Water efficiency moderate		Good	0.06	1	
	Water efficiency high	Practical solution, need treatment	Good	0.06	1	
3	**Rain water collector**		Good	0.06	1	
4	**Grey water recycling**	Eco solution	Good	0.06	1	
5	**Reduced water usage**	Eco solution	Good	0.06	1	
6	**Water sense labelled products**	Eco solutions	Good	0.06	1	
	Others					
			Total Points	1	16	
Power supply					15 Points	
1	**Source**	**To apply energy efficiency by applying natural energy like wind energy, solar energy, hydropower, underground heat energy**, and other efficient **applications in energy.**		0.333	5/15	

	From the National Grid	Technical solution	Good	0.06	1	
	Generator	Use of green fuel or energy in Sudan	Fair	0.00	0 to 1	
	Wind energy	Natural resources in Sudan	Good	0.06	1	
	Solar energy	Natural resources in Sudan	Good	0.06	1	
	Hydropower energy	Natural resources in Sudan	Good	0.06	1	
	Underground heat energy	Natural resources in Sudan	Good	0.06	1	
2	**Energy Efficiency**	Eco solutions	Good	0.066	1/15	
3	**Application**			0.33	5/15	
	Solar energy heating system	Eco solutions	Good	0.06	1	
	Solar energy cooling system	Eco solutions	Good	0.06	1	
	Solar boiling	Eco solutions	Good	0.06	1	
	Solar cooking	Eco solutions	Good	0.06	1	
	Outdoor solar lighting	Eco solutions	Good	0.06	1	
	Others					
4	**Adopting technologies**			0.266	4/15	
	Photovoltaic technology	Eco technical solutions	Better	0.13	2	
	Using Simulation	Eco technological solutions	Good	0.06	1	
	Smart energy panel	Eco technological solutions	Good	0.06	1	
	others					
			Total Points	1	15	
Environmental design		**Process**			**1 Points**	
	Enhance environmental designed process	**Need it for awareness and educational priority. To apply the three steps in environmental design process in primary phase, construction phase, and durability and maintenance phase**	Good	1	1	
			Total score		**125**	

Source: Adapted by the researcher

Appendix-2

Details of the proposed sustainable-eco-building assessment method (SEBAM).

1. Sustainable site (SS)

(i) SS point 1 : site selection

Avoid development of inappropriate sites and reduce the environmental impact from the location of a building on a site. Select a suitable building location and design the building with minimal footprint to minimize site disruption of those environmentally sensitive areas. Study of transportation networks and urban infrastructures.

SS credit for site selection is one.

(ii) SS point 2: construction system, (1 to 2)

There are three types of construction systems, which are widely prevalent in Greater Khartoum: steel, load bearing or concrete system. Load bearing used for multi-storey buildings utilizing burnt bricks. In order to have a sustainable system it is advised to use stabilized earth bricks, thermal bricks, or other sustainable construction building materials available in the local environment.

Most of the buildings in first class areas were constructed with concrete. For steel construction, it will be very inappropriate if we use steel system without roof insulation and wall insulation in hot dry climate. It is mostly used in the industrial sector. The researcher do not encourage using coated corrugated sheets in roof without insulation. In third class areas, most of the buildings have lightweight roofs, wood covered by sheets or wood lined with corrugated metal panels. However, such roofing materials are most commonly found in dark colours and are not whitewashed; and hence, will be subject to solar radiation effects causing heat stress during the daytime. Thus, dwellers solved this problem by adding false ceilings of white colours.

SS POINTS for construction system is two

(iii) SS point 3: Controlling systems (1 to 2)

Construction activity control, pollution control:

Reduce pollution from construction activities by controlling soil erosion, waterway sedimentation and airborne dust generation.

Controlling natural water feature

This is a very important requisite for buildings constructed beside riverbanks. We should protect the building against river floods. Civil engineers should provide a study on the rivers' water levels during flooding seasons. Further, water level records for the last 20 years should be taken into consideration when planning housing plots, and thus, ensuring build on higher levels.

SS Point for controlling natural water feature is1

(iv) SS point 4, Alternative transportation (1 to 3)

Reduce pollution and land development impacts caused by motor vehicles emissions. 800-meter walking distance to rail, light rail or subway stations. Use of low emitting fuel, provide shaded parking, and use bicycle storage stands.

SS Point for Alternative transportation is 3, one for each.

(v) SS point 5, Improve thermal environment

Conserve existing natural areas and restore damaged areas to provide habitat and promote biodiversity.

Enhance landscaping on site (1 to 2), such as vegetation, plantation**,** adding fountains**,** sitting areas, canopies, trees, flowers and water features outside buildings. Use other potential technologies and strategies, shade constructed surfaces on the site with landscape features and utilize high-reflection materials for landscaping.

Maximized open space:

This has been adopted in order to promote biodiversity by providing a high ratio of open space to develop footprint.

SS Point for improved thermal environment is 2

(vi) **SS point 6, Heat island effect**

To reduce heat islands and minimize impacts on microclimates and human and wildlife habitats. *SS Credit for Heat Island Effect is one*

Use any combination of the following strategies for 50% of the site landscape (including roads, sidewalks, courtyards and parking lots):

1) *Provide shades from existing tree canopies or within 5 years of Landscape installation i.e. landscaping (trees).*
2) *Provide shades from structures covered by solar panels that produce energy used to offset some non-renewable resource use.*
3) *Provide shades from architectural devices or structures that have a solar reflectance index (SRI) of at least 29.*
4) *Use hardscape materials with an SRI of at least 29.*
5) *Use an open-grid pavement system.* For shrubs and trees vegetation to reduce heat absorption. (USGBC, 2009).

2. Category two: indoor environmental quality (IEQ)

(i) IEQ point 1, Building orientation

Building orientation is a very important factor affecting the indoor environmental quality. The position of the sun affects the intensity of solar radiation entering the building.

IEQ Point for Building orientation is four

1) The building is oriented to the East-West direction; the length is facing to the North-South direction; in such a case, the amount of fresh air will be 90 %; and we should design large windows to improve air movement.
2) The orientation of the building to the North-South direction is a direct cause of bad ventilation. However, if the site location dictates the architect to do so, then the architect is ought to design more canopies for provision for shades.
3) Orientating the building at 45˚, will reduce the amount of air movement by 50%. Hence, the architect should provide sunscreen to protect windows from solar radiations.

(ii) IEQ point 2, building dimensions

Experiments showed that Surface Volume Ratios range (SVR) from 1:0.16 to 1:0.12, in hot-dry climates. SVR and SFAR should be as low as possible to minimize the radiation on the building. This can be achieved through multi-storied buildings and rising the roof heights.

IEQ Point for Building Dimension is one.

(iii) IEQ point 3, roof thermal control

Design the ceiling by choosing sustainable building materials that give a large time lag; thus, storing solar radiation during the day and releasing this heat during the night. This material should have a solar reflectance index (SRI) = 0. 65 - 0.75 (Chapter two Section 2.6.2. point VI: Solar Reflectance Index and cool Roofs and heat island effect.)

IEQ Point for Roof Thermal control is five.

1. Use of waterproof membranes, two layers to protect the ceiling from rain. In addition, a thermal insulation layer will be good.
2. The researchers found that the use of double roof would be effective to minimize solar radiation from the roof in to the indoor environment by 50%.
3. The choice of the roof-painting colour is very important. Use of white colour is found to be effective in minimizing solar radiation by reflecting it away.
4. Green roof is found very effective in reducing solar radiation by 50%, effectively reflecting it away. This practice minimizes the heat island effect.

(iv) IEQ point 4, Wall thermal control

Wall is the second component of the building envelope. Architects should design walls such that thermal radiation from the indoor environment is minimized.

IEQ POINT for Wall thermal control is ten.

1. Choose the sustainable building material available in the local environment, and which has the ability to absorb and store solar radiation during the day and release this radiation during the night, i.e. the material has a large time lag.
2. In designing windows; the size, location, type of glass and window colour are the factors that affect the amount of fresh air and air movement. Refer to Chapter two, Section 2.4.6: The appropriate technology in windows design.
3. The use of sunscreening devices, vertical or horizontal or both will be effective to minimize the radiation in to the indoor environment by 50%. Applying the appropriate technology in these devices, solar energy can be acquired to be used in the buildings in different ways such as lighting and moving the shading devices. Refer to Chapter two, Section 2.6.2; point No. VI: The appropriate technology in windows design.
4. Selection of the wall colour is a very important; light colours reflect sun radiation and reduces excessive heat absorption by the building, usually white colour, beige, and light pink are preferable. EST.
5. Researchers have found that the green wall is very effective in minimizing radiations in to the indoor environment.

(v) IEQ point 5, Floor thermal control

The floor is the third building component. Designing the thermal effect of floor is very affective in minimizing the radiation from the indoor environment. It is recommended to choose the floor finishing material to be an eco-floor material, manufactured from recycled construction building materials such as concrete, stones, bricks, or ceramics that have long term of durability, easy to clean and of easy maintenance, durable to pressure, non-slippery, heat and moisture resistant. *IEQ Point for Floor thermal control is one.*

(vi) IEQ point 6, Design thermal control

Thermal comfort is defined in the British Standard BS EN ISO 7730 as:

'The condition of mind, which expresses satisfaction with the thermal environment'

Thermal comfort is based on many environmental and personal factors. Five common environmental factors are air temperature, air movement, radiant temperature, humidity, and air speed. These factors may be controlled to achieve human thermal balance (see Chapter two Environmental comfort principles point 2.5). IEQ Point for Design Thermal Comfort is four.

Natural control:

1. Provide a high level of thermal comfort system control by individual occupants or by specific groups in multiple spaces to promote productivity, comfort and well-being of the building's occupants. Provide individual comfort controls for 50% (minimum) of the building's occupants in order to enable adjustments to suit individual task needs and preferences.
2. For naturally ventilated areas, there are two main requirements:
3. There must be windows or opening (which can be opened) within 25 ft. of any area in a room, which is liable to be occupied. Note that a roof opening is also essential. ASHRAE 62.1-2004, stated that Ventilation for acceptable indoor air quality, mechanical ventilation systems should be designed using the ventilation rate procedure or the applicable local code, whichever is more stringent. Naturally, ventilated buildings shall comply with ASHRAE 62.1-2004, paragraph 5.1.
4. Traditional wind towers (Fig. 2. 17) was discussed in Chapter two.
5. Use of internal courtyards: Internal courtyard systems, if designed properly, can retain a portion of the cold night air to keep the building cool during daylight hours. Fig. 2.16 shows a courtyard in a large house. Refer to Chapter two.

(vii) IEQ point 7, Mechanical control

Mechanical ventilation systems must be designed using the ventilation rate procedure or the applicable local code, whichever is more stringent.

IEQ Point for Mechanical control is three.

1. The first requirement is that 50 % of the occupants should have control over their thermal comfort at their typical workstations or living spaces. Thermal comfort controls usually refer to some form of conditioning and are usually for both heating and cooling. This conditioning can be active (mechanical HVAC systems) or passive (natural ventilation).
2. *The use of desert cooler systems provide humid air, which is good in a hot-dry climate. It is an economical system and is widely used in Khartoum city. It needs regular maintenance to guarantee long durability. Yousif (2013) discussed the using of efficient desert cooler systems (In Direct Unit) in a green* mosque design. In dry or semi dry climates, this system minimize water consumption by 55% by using ablution (Wadu) usage water.
3. Individual adjustments may involve individual thermostat controls, local diffusers at floor, desk or overhead levels, or control of individual radiant panels, or other means integrated into the overall building's thermal comfort and energy systems design. In addition, designers should evaluate the closely

tied interactions between thermal comfort (as required by ASHRAE Standard 55-2004) and acceptable indoor air quality.

4. Other effective solutions: Installation of permanent monitoring systems to ensure that ventilation systems maintain design minimum requirements. Configure all monitoring equipment to generate an alarm when airflow values or carbon dioxide (CO_2) levels vary by 10 % or more from the design values via a building automation alarm-system to the building operator or a visual or audible alert to the building occupants.
5. The use of AC wall unit evaluated by (-1) because it has negative effect to the environment.

3. Category three, Outdoor thermal control (OTHC)

(i) OTHC point 1: For shades to the North-South direction

Provides shades to the North-South direction. This cools the air temperature, reduces solar radiation, reduces the indoor natural temperature, and gives protection from rain and sun radiation. This can be achieved by designing canopies over windows. Refer back to Chapter two, Section 2.6.2, and No. b. Designing of the walls. Shading, which shows the advantages of shading.

OTHC Point for shades to the North–South direction is two.

(ii) OTHC point 2, Shades to the East-West direction

Provides shades to the East-West direction. The plot area sometimes compels the designer to direct buildings to the North-South direction, in such a case the architect should provide canopies to cast shades over the window openings. *OTHC Point for shades to East West direction is one.*

(iii) OTHC point 3, Balconies

Provide balconies in building designs. This solution is preferred for hot dry climates. Families can site outdoors in summer. It also gives protection to the building from rain and dust as well as provisioning for shades.

OTHC Point for balconies is one.

(iv) OTHC point 4, Vegetation

Provide the outdoor environment with vegetation cover and plantations. It is preferred to plant shade trees around the house. These trees will improve the air movement around the building and cool the air temperature of the outdoor and indoor environments. Trees inspire beauty and relaxation and rather healthier as a steady source of oxygen supply.

OTHC Point for vegetation is one.

(v) OTHC point 5, Design fences (height and location)

The use of barriers and fences protect the building environment from dust and sand storms (Haboob). Fig 2.18 shows the dust movement in the case of a fence that is 6.1 m far from the building and its height equal to the building height. While, Fig 2.19 shows the dust movement in the case of a barrier lower than the building height.

OTHC .Points for fences is one.

(vi) OTHC Point 6, swimming pools

Design swimming pools in the outdoor environment to improve the air by making it more humid. An architect should apply the standards in the design and choice of the pool materials along with the design of the surrounding areas.

1. Design an eco-friendly swimming pool. This concept can be achieved by simply using green friendly products. These would be products that do not contain chemicals, which would be harmful to the earth. An eco-friendly swimming pool would also be one that would contain water and energy saving equipment.
2. Recycled content paving materials and furnishings.
3. If the swimming pool is in the ground level, the engineer should design it with plain RC, and cover with water proof and then the final finish with ceramic.
4. Above ground level by 30 cm.
5. Swimming pools, filterers, water supply systems should be considering.

OTHC Point for swimming pools is one.

(vii) OTHC point 7, Fountains

Designing fountains in the outdoor environment also improves the air temperature and the humidity in dry climates. Fountains have different shapes and makes people happier and healthier. *OTHC Point for fountains is one*.

(viii) OTHC point 8, Terraces

Providing the outdoor environment with terraces. It is very important in Sudanese occasions to have social aspects.

OTHC Point for terraces is one.

4. Category four: Building form (BF)

Total BF points are eight.

(i) Linear form provides a good solution for the building by allowing more daylight and good ventilation.

BF point for linear form is one.

(ii) U-shaped form creates a courtyard system that can be used in vegetation, plantation, sitting area or fountains that can cool the temperature and thus improving the indoor natural temperature.

BF point for U shaped form is 1.13.

(iii) L- Shaped form is the best solution for hot dry climate it provides shades in the opposite direction of sunrise; and provides a private area that can be used as a garden.

BF Point for L shaped Form is 1. 25

(iv) Cubic form is neutral; it provides medium solutions.

BF Point for Cubic form is one.

(v) Circular form is not preferred in hot dry climates because it causes the transfer of solar radiation from all directions, increasing the indoor temperature.

BF point for circular form is zero.

(vi) Courtyard system is found to be reducing to the temperature during the day, and cooling down the building temperature during the night.

BF point for Courtyard system is two.

(vii) Using vaults over corridors or bedrooms reduces the indoor temperature. The architect Jack Ishkhanes has been famous to adopt this design system in Greater Khartoum area.

BF point for vaults system is one.

(viii) Using domes over halls and saloons in Islamic designs. It was found that it reducing the vertical heat imposed on final roof.

BF point for Domes system is one

6. Category five, Building materials and resources (MR)

(i) MR point 1, Materials used in base

Materials used in base, such as concrete, stones, bricks, mud or steel should be from highly efficient building materials. Use building materials that are available locally.

MR Point for materials used in base is six

(ii) MR point 2, Materials used in walls:

Materials used in walls, such as stone, bricks, wood, steel, cement blocks, hollow blocks etc., should be of high efficiency and large time lag with the ability to store solar radiation during day time and release it during the night.

MR Point for materials used in walls is 1 to 8

(iii) MR point 3, Materials used in roofing

Examples of materials used in roofing are concrete, wood, bricks, or steel. We should improve the performance of concrete to have a SRI between 1 or 0.75 as LEED specified. We should use first class grades of burnt bricks, and should use heat insulation in steel constructions.

MR Point for materials used in roofing is 1 to 3.

(iv) MR point 4, Materials which are used in finishing's

Materials which are used in finishing are ceramic tiles, aluminium, marble, wood, and Italian baked bricks (roof clay tiles). Finishing materials should be high efficiency eco building materials, long durability, easy maintenance and available in the local markets.

MR Point for Materials that used in finishing's 1 to 3

(v) MR point 5, Use of recycled building materials

Use of recycled building materials requires the provision of an easily accessible area for servicing the entire building and to be confined for the collection and storage of hazardous wastes stored for recycling, including (as minimum) paper, corrugated cardboard, glass, plastics and metals. Coordinate the size and functionality of the recycling areas with the anticipated collection services for glass, plastic, office paper, and newspaper, cardboard and organic wastes to maximize the effectiveness of the prescribed area. Provide adequate and appropriate space for the recycling activities.

(vi) MR point 6, Wall cladding

Wall cladding should be of a special manufacture style, suitable for the hot-dry climate. This cladding should allow natural air movement and day light. Wall cladding could be used to gain solar energy that can be utilized for the building.

MR Point for Wall cladding is one.

(iv) MR point 7, Indoor décor:

Any material used for indoor decor, such as wood, gypsum, boards, or glass should all be eco building materials of long durability, high acid and fungal resistance, and nontoxic.

MR Point for Indoor decorative décor is one.

(viii) MR point 8, Waste management

Provide an easily accessible area that serves the entire building and is dedicated to the collection and storage of hazardous materials for recycling, including (at a minimum) paper, corrugated cardboard, glass, plastics and metals.

MR Point for waste management is one.

(ix) MR point 9 is Calculating embodied energy

In order to accurately calculate the embodied energy of a material, all stages of energy usage should be accounted for. An accurate figure will be derived, if we consider the energy used for extraction of raw materials, transportation of processed plants, energy used in factories, transportation to site and energy used on site to install the product.

(x) MR point 10 LCA

MR Point for LCA is one

(xi) MR point 11 is Adapting technologies

Use technologies in improving the characteristics of building materials, such as clay and stones. *MR Credit for adapting technologies is one.*

(xii) MR point 12, Regional building materials

Such as concrete, steal, and stones from surrounding areas of Khartoum. MR credit for regional building materials is one.

(viii) MR point 13, Certified wood

50% of wood-based products should be recycled wood.

Credit for certified wood is one.

(xiv) MR point 14, Low emitting materials

All interior, sealants, paints, coating, sand painting will have low volatile organic compound (VOC). Rapidly, renewable building materials and products are made from agricultural products that are typically harvested within a 10-year or shorter cycle. For example, wool, cotton insulation, agrifiber, linoleum, wheat board, strawboard and cork. During construction, ensure that the specified renewable materials are installed (Council, 2011).

7. Category six: Drainage and water supply system (DS&WS)

(i) DS&WS Point 1, Choose the appropriate technology for drainage systems.

Option 1: Network

Option 2: Septic Tank: a good practice that is being used in most of the areas in Greater Khartoum, but this system needs maintenance.

Option 3: Biological treatment

Option 2: Pit latrine system is unfortunately still used in the third class and illegal areas. It is not recommended because it is unhygienic and is considered as a source of odour pollution to the surrounding environment and provides a breeding medium for harmful insects.

(ii) DS&WS point 2, water source

Water resources in Khartoum city are from several local water treatment plants, which pump water from the White Nile, Blue Nile and River Nile, and also, from underground water. It is recommended to use treated water from the local treatment plant. Also the rain water.

DS&WS Point for water resources is three.

(iii) DS & WS Point 3, water efficiency

Water is used for cleaning, cooling and cooking food components. In each case, potable water should only be used; therefore, water treatment is necessary to treat water before use. Water supply for most of the housing areas in Khartoum comes from the local water treatment plants. We can evaluate the efficiency of this water by doing regular water analysis in specialized and official laboratories. Refer back to Chapter 2, Section 2.2.4.

DS&WS Point for water efficiency is one.

(iv) DS & WS point 4, rainwater container

An appropriate technology option such as rainwater harvesting is recommended. Khartoum region's annual rainfall level is low where occasional light shower may occur in summer, i.e. between April and May the average rainfall is expected to reach about 100 mm. In many years, there are no shower in June. The rainfall season starts in July and extends to September. The average rainfall in the Region ranges from North to South from 100 mm to 200 mm. We can provide the buildings with rainwater collectors and use this water in irrigation during this period.

DS&WS Point for rain water collector is one.

(v) DS & WS point 5, grey water recycling

Wastewater may contain substances such as human waste, food scraps, oils, soaps and chemicals. In houses, wastewater can include the water from sinks, showers, bathtubs, toilets, washing machines and dishwashers that are called grey water. Recycled grey water can be used in irrigation and plantation.

DS&WS Credit for waste water recycling is one.

(vi) DS & WS 6, reduced water usage

Technology is affecting the bathroom in different ways. First, off, products – from faucets and bathtubs to mirrors – are becoming increasingly sophisticated, a result of new and advanced manufacturing techniques, innovative materials and integrated features. Secondly, the bathroom is digitized. Electronic devices are being used to create a fully-integrated experience, where sound, light, water flow and temperature can be controlled at the touch of a button. Thirdly, technology is in the front lines of the battle to make the bathroom more energy and water efficient. *DS&WS Point for Reduce water usage is one.*

(vii) DS & WS point 7, Water sense labelled products

The use of water sense labelled products such as:

- Tank-Type Toilets labelled since 2007; over 800 labelled models.
- Lavatory Faucet 2007; over 2,800 labelled models.
- Flushing Urinals labelled since 2009; 90-labelled models.
- Showerhead labelled since 2010.

- Commercial washing machine.
- Commercial kitchen equipment.

DS&WS point for labelled products is one.

8. Category seven: Power supply (PS)

i) PS point 1, Energy source

1. Wind energy

In summer, the wind direction is from the South-East and South-West. In winter, the wind direction is from the North-East and North-West. In June during the summer season, growing instability can lead to dust storms (Haboob), producing one of the most striking weather features experienced in the area. They make this a particularly trying time of the year especially, as the annual temperature; range is less than in winter. However, tough Haboob can occur in almost any month of the year.

Point for wind energy is one.

2. Solar energy

Solar energy in Sudan is considered as satisfactory. The whole radiant energy upon smooth surfaces is 6.9 joules/m^2 in Southern Sudan, and 10.1 joules/m^2 in the year in Northern Sudan. Solar energy increasing northwards.

Point for Solar energy is one.

3. Water energy

Sudan has high potentials of electrical water energy, which could be generated from the River Nile and its various tributaries, in addition to the small electrical water energy from cataracts and canals. The available electrical water energy comes 3600 megawatt, which is equal to 22600 megawatt, represents energy in hour / year.

Points for Water energy is one.

4. Geophysical heat energy

The first land survey showed that the volcanoes area of Gabel Mara and the Red Sea area are considered as good sources for this kind of energy.

Points for Underground heat energy is one.

(ii) PS point 2, Enhanced energy efficiency

We can get energy efficiency by:

1. Establishment of energy efficiency programs, which can be applied by The Ministry of Power and Mining. People can improve their performance in dealing with energy at homes and working environment.
2. Metering the electricity in home can manage and reduce our consumptions of electricity.
3. Using smart technologies, such as smart screen to control the temperature, lighting, heating and cooling systems.

4. Controlling and providing proper HVAC systems to provide energy efficiency will minimize energy consumption by 30%.

Point for energy efficiency is one.

(iii) PS point 3: Applications

The storage of energy can be used widely in the building for heating, boiling, cooking and lighting.

Points for Applications is four.

(iv) PS Point 4: Adopting technologies

New technologies in the field of power supply are introduced every year. Therefore, it is very important to keep ourselves up to date with these new technologies, which can be achieved by attending conferences in the field of sustainable design.

1. Photovoltaic technology:

Solar Thermal (ST) Technology: In general, collectors are used to convert sunlight into heat energy. Photovoltaic (PV) technology turns sunlight directly, into electricity by means of absorbent semiconductors. National Research Centre in Khartoum is manufacturing photovoltaic cells and they are widely applied throughout Sudan. In Khartoum City, some companies import this system from abroad.

2.Using energy simulations

Dynamic system simulation tools are widely used in the planning stage for complex buildings and their energy supply and distribution system. Dynamic simulation models often contain algorithms for heating control, ventilation or cooling plants (fans and pump volume flows, valves and flaps, etc.), renewable energy systems or building components (sun shading systems, lights, etc.). These simulation models, however, have no great significance for the real operation of buildings, Examples of simulation tools are computer programs such as Energy plus 6.0 and Window Eco-tact.

3. Smart Energy panel

Environmental Protection Agency's (EPA, 2010) Energy Star Program in USA uses the most advanced amorphous silicon PV cells. The result is an integrated, flexible solar roofing panel that rolls onto flat surfaces.

Points for adapting technologies are three.

8. Category eight: Environmental design process

(i) Pre building phase: design drawings, construction drawings, and technical solutions

(ii) Post building phase: construction phase.

(iii) Maintenance phase: maintenance and use of the building, and evaluation after one year.

APPENDIX-3

Table 2. LEED V4 sheet

LEED v4 for Operations & Maintenance: Existing Buildings
Project Checklist

Project Name:
Date:

Y	?	N			
0	0	0		**Location and Transportation**	**15**
			Credit	Alternative Transportation	15
0	0	0		**Sustainable Sites**	**10**
Y			Prereq	Site Management Policy	Required
			Credit	Site Development-Protect or Restore Habitat	2
			Credit	Rainwater Management	3
			Credit	Heat Island Reduction	2
			Credit	Light Pollution Reduction	1
			Credit	Site Management	1
			Credit	Site Improvement Plan	1
0	0	0		**Water Efficiency**	**12**
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
			Credit	Outdoor Water Use Reduction	2
			Credit	Indoor Water Use Reduction	5
			Credit	Cooling Tower Water Use	3
			Credit	Water Metering	2
0	0	0		**Energy and Atmosphere**	**38**
Y			Prereq	Energy Efficiency Best Management Practices	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
			Credit	Existing Building Commissioning— Analysis	2
			Credit	Existing Building Commissioning—Implementation	2
			Credit	Ongoing Commissioning	3
			Credit	Optimize Energy Performance	20
			Credit	Advanced Energy Metering	2
			Credit	Demand Response	3
			Credit	Renewable Energy and Carbon Offsets	5
			Credit	Enhanced Refrigerant Management	1
0	0	0		**Materials and Resources**	**8**
Y			Prereq	Ongoing Purchasing and Waste Policy	Required
Y			Prereq	Facility Maintenance and Renovations Policy	Required
			Credit	Purchasing- Ongoing	1
			Credit	Purchasing- Lamps	1
			Credit	Purchasing- Facility Management and Renovation	2
			Credit	Solid Waste Management- Ongoing	2
			Credit	Solid Waste Management- Facility Management and Renovation	2
0	0	0		**Indoor Environmental Quality**	**17**
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
Y			Prereq	Green Cleaning Policy	Required
			Credit	Indoor Air Quality Management Program	2
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight and Quality Views	4
			Credit	Green Cleaning- Custodial Effectiveness Assessment	1
			Credit	Green Cleaning- Products and Materials	1
			Credit	Green Cleaning- Equipment	1
			Credit	Integrated Pest Management	2
			Credit	Occupant Comfort Survey	1
0	0	0		**Innovation**	**6**
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1
0	0	0		**Regional Priority**	**4**
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
0	0	0		**TOTALS** — Possible Points:	**110**

Certified: 40-49 points, **Silver:** 50-59 points, **Gold:** 60-79 points, **Platinum:** 80+ points

Note: The LEED V4 was applied to 48 case studies. The results were compared to the results of study method of assessment of the research.

http://www.usgbc.org

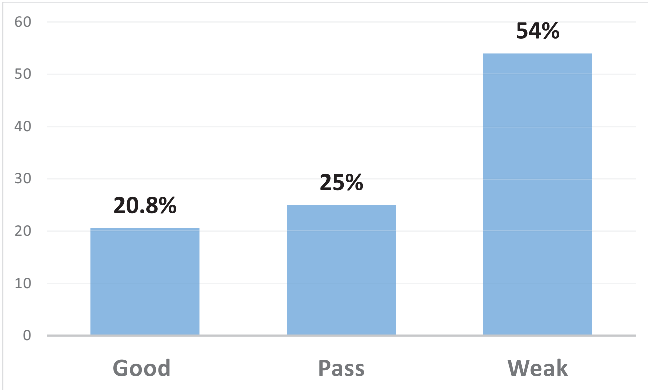


Figure 1: The evaluation of the residential buildings in Greater Khartoum by the research method of assessment (SEBAM). **Source** Adapted by the researcher.

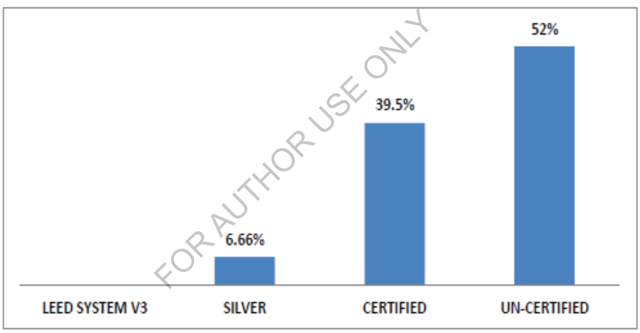


Figure 2: The evaluation of the residential buildings in Greater Khartoum by LEED V4

Source: Adapted by the researcher.

APPENDIX-3

RESULTS OF APPLYING LEED V4 ON THE SAMPLES (48 case studies)

GENERAL CONCLUSIONS FOR THE AVERAGE RESULTS BY APPLING LEED V4

Table 3. The Average result for the main categories of ecological design in Greater Khartoum; evaluated by LEED V4.

LEED V4 Principles	Applicable percentage	Evaluation
Location and transportation	41	Certified
sustainable site	10.8	Not Certified
IEQ	31	Not Certified
Materials and Resources	35.4	Not Certified
Water efficiency	31	Not Certified
Power Supply	19.2	Not Certified
Innovation in operations	22	Not Certified
Regional priority	12.5	Not Certified

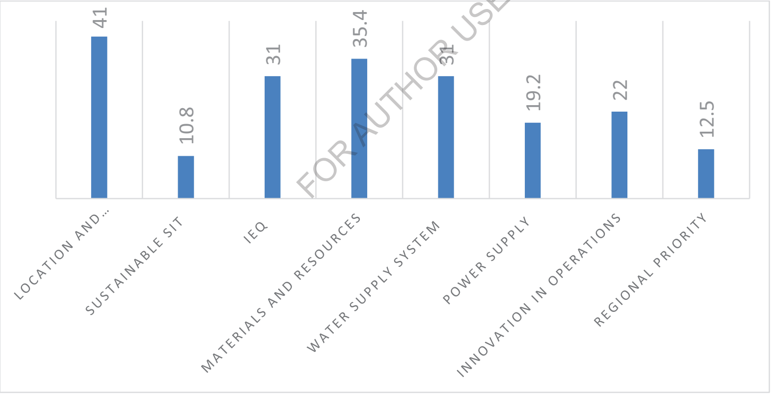


Figure 3**:** General indicator for the average results in the main categories for residential buildings in Greater Khartoum by LEED V4. **Source:** Adapted by the researcher.

Forum, S. G. B.F., 2013. *LEED Workshop.* Riyadh city, Saudi Green Building forum and United States Green Building Council.

Table 4. General indicators Location and transportation by LEED V4

Sustainable Site	Applicable percentage	Evaluation
Location and transportation Alternative Transportation	41	Certified

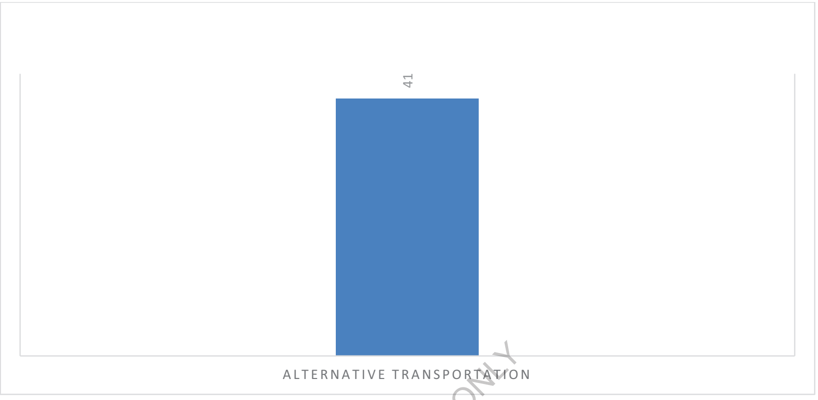


Figure 4: General indicators for location and transportation by LEED V4. **Source** Adapted by the researcher.

Table 5. General indicators for sustainable site by LEED V4

Sustainable Site	Applicable percentage	Evaluation
Site Management Policy	20	Not certified
Site Development-Protect or Restore Habitat	5	Not certified
Rainwater Management	5	Not certified
Heat Island Reduction	10	Not certified
Light Pollution Reduction	7	Not certified
Site Management	4	Not certified
Site Improvement Plan	25	Not certified

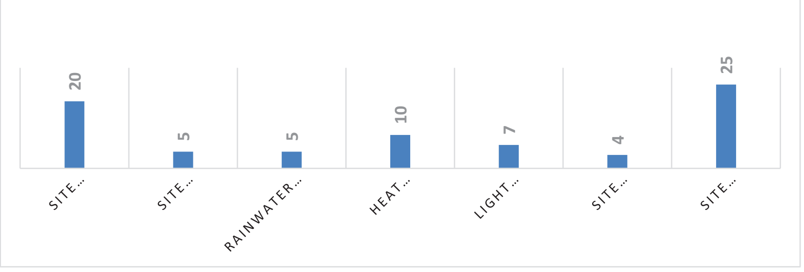


Figure 5: General indicators for Sustainable Site by LEED V4

Table 6. General indicator for water efficiency by LEED V4**.**

water efficiency	Applicable percentage	Evaluation
Building-Level Water Metering	0	Not Certified
Outdoor Water Use Reduction	30	Not Certified
Indoor Water Use Reduction	25	Not Certified
Cooling Tower Water Use	0	Not Certified
Water Metering	100	Certified

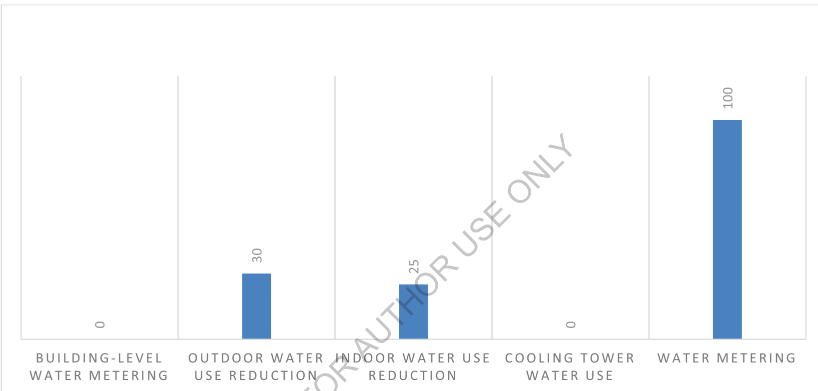


Figure 6: General indicators for water efficiency by LEED V4.

Source: Adapted by the researcher.

Table 7. General indicators for energy and atmosphere by LEED V4.

energy and atmosphere	Applicable percentage	Evaluation
Energy and Atmosphere	0	Not Certified
Existing Building Commissioning—Implementation	0	Not Certified
Existing Building Commissioning— Analysis	0	Not Certified
Ongoing Commissioning	0	Not Certified
Optimize Energy Performance	50	Certified
Advanced Energy Metering	100	Certified
Demand Response	0	Not Certified
Renewable Energy and Carbon Offsets	4	Not Certified
Enhanced Refrigerant Management	0	Not Certified

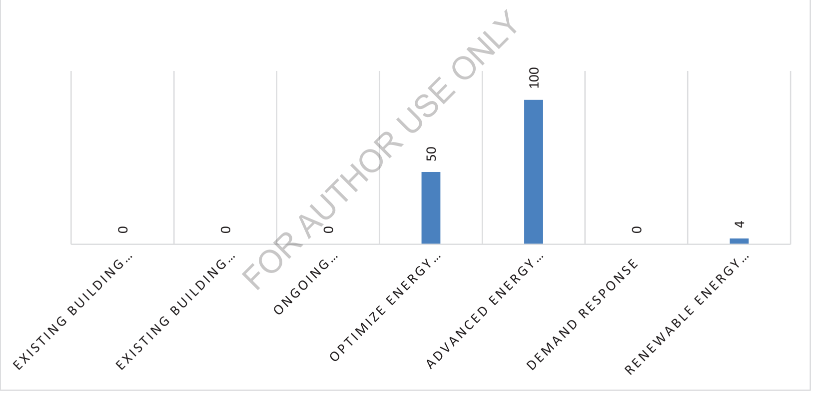


Figure 7: General indicators for Energy and Atmosphere by LEED V4. **Source:** Adapted by the researcher.

Table 8. General indicators for building materials by LEED V4.

Materials ad resources	Applicable percentage	Evaluation
Purchasing- Ongoing	92	Certified
Purchasing- Lamps	60	Certified
Purchasing- Facility Management and Renovation	0	Not Certified
Solid Waste Management- Ongoing	25	Not Certified
Solid Waste Management- Facility Management and Renovation	0	Not Certified

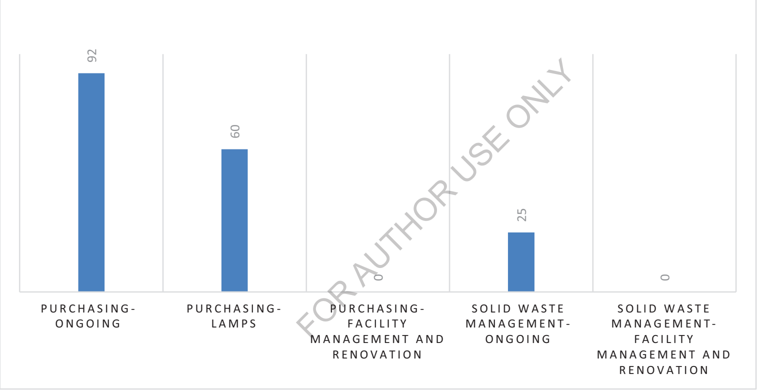


Figure 8: General indicators for Material and Resources by LEED V4. Adapted by the researcher.

Table 9. General indicators for the indoor environment by LEED V4.

Indoor Environmental Quality	Applicable percentage	Evaluation
Indoor Air Quality Management Program	0	Not Certified
Enhanced Indoor Air Quality Strategies	0	Not Certified
Thermal Comfort	50	Certified
Interior Lighting	80	Certified
Daylight and Quality Views	80	Certified
Green Cleaning- Custodial Effectiveness Assessment	0	Not Certified
Green Cleaning- Products and Materials	50	Certified
Green Cleaning- Equipment	50	Certified
Integrated Pest Management	5	Not Certified
Occupant Comfort Survey	5	Not Certified

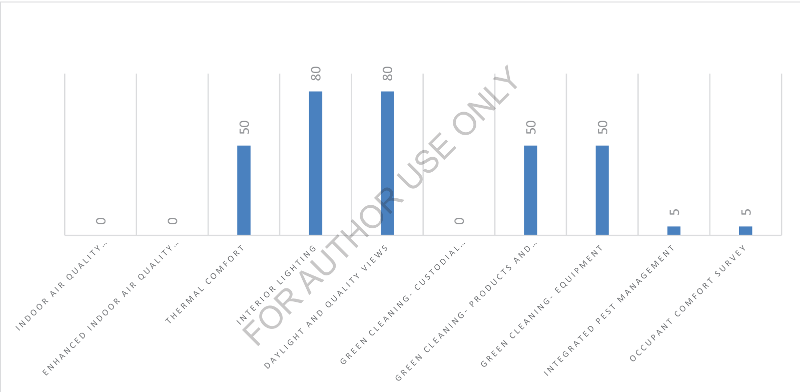


Figure 9: General indicators Indoor Environmental Quality, by LEED V4. Adapted by the researcher.

Table 10: indicator for innovation by LEED V4

Innovation	Applicable percentage	Evaluation
LEED Accredited Professional	0	Not Certified
Innovation	22	Not Certified

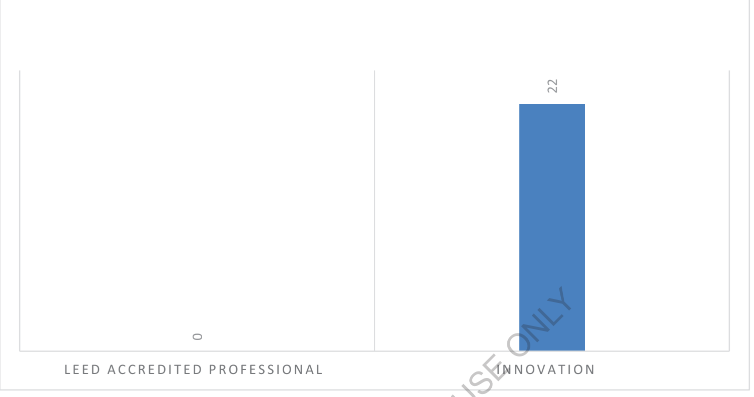


Figure 10 General indicator Innovation by LEED V4, **Source:** Adapted by the researcher.

Table 11. General indicator for regional priority by LEED V4.

Regional priority	**Percentage**	**Evaluation**
Regional priority	**12.5**	**Not Certified**

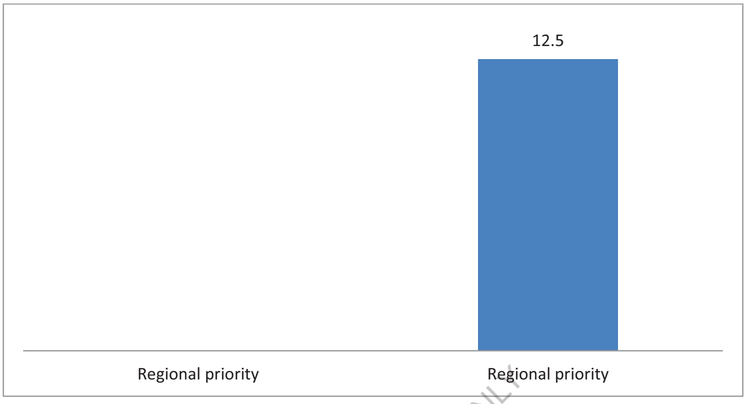


Figure 11: General indicator for regional priority by LEED V4.

Source: Adapted by the researcher.

APPENDIX-4
ABBRIVIATIONS AND DEFINNITIONS

This appendix shows some abbreviations used in the text, with Glossary.

CFCs: Chlorofluorocarbons

It is an *organic compound that contains only carbon, chlorine, and fluorine*, produced as a volatile derivative of methane, ethane, and propane. They are also commonly known by the DuPont brand name **Freon**. Many CFCs have been widely used as refrigerants.

ESD: Environmental sustainable development

It is the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (World commission on Environment and Development, 1987: 43) (Elliott, J.A., 1999).

KSP: Khartoum structure plan.

LCA: Life cycle analyses.

It is used as a way of *assessing the total impact of any building* and shows the importance of the building's lifespan. The longer a house can last, the lower the impact of the energy and pollution, resulting from the manufacture of its materials.

SEBAM: Sustainable-eco-building assessment method.

SVR: Surface volume ratio.

VOCs: Volatile organic compound

DEFINITIOŃ-4

Thermal comfort:

Thermal comfort is defined in the British Standard BS EN ISO 7730 as:

'That condition of mind which expresses satisfaction with the thermal environment'

"So, the term 'thermal comfort' describes a person's psychological state of mind and is, usually referred to in terms of whether someone is feeling too hot, or too cold. However, comfort is defined as 'the condition of mind that expresses satisfaction with the thermal environment, which requires subjective evaluation'. This clearly embraces factors beyond the physical."

Grey water

It is wastewater generated within a household consisting of sink, tub, shower and laundry wastewater, with the exclusion of toilet wastes.

Eco house

The meaning of eco-homes comes from the stem 'eco', which derives from the Greek root 'oikos', meaning 'household'. The Greek root, as with many Greek words, has two meanings: the sense of 'ecological' relationships between organisms in nature and 'economics' – relationships concerned with the use of 'resources'. Hence, 'eco' has, as its basis, two dimensions that need to operate within an 'ecological' philosophy – that is, its relation in design and use should follow a natural order, while it also has the dimension of using resources in an economical and efficient manner" (Hyde, R., 2008).

APPENDIX-5

REQUIREMENTS AND BENCHMARKS

FOR THE APPLIED METHOD

Shows the requirements and the benchmarks for the study method of assessment that was explained in chapter five.

5.1 Sustainable site

5.1.1 The requirements for sustainable site:

- Site survey
- Identify site slope
- Use of Building Information Modelling (BIM) that helps in site accessibility
- Identify the open areas from satellite images
- Identify the structural system
- Identify heat island effect requirements such as shades, trees, SRI.
- Identify outdoor lighting; provide lighting plan; control panel; and specification schedule.
- Study of noise pollution
- Study of natural water features

5.1.2 The benchmarks for sustainable site

- Master plan from the Ministry of Survey and urban planning
- Satellite images to identify open spaces
- SRI High Al-Bedo Materials
- Choose of appropriate equipment for building construction to minimize noise pollution.
- For lighting: ANSI/ASHRAE/IESNA Standard 90.1-2007.
- International energy conservation code (IECC) 2009, www.energycodes.
- Illuminating Engineers Society of North America, IESNA RP-33-99, www.iesna.org
- Illuminating Engineering Society IES RP-8, www.iesna.org.

5.2 Indoor environment

5.2.1 The requirements for indoor environment

- Identify building orientation
- Identify building dimensions
- Study roof and wall insulations
- Study thermal comfort for indoor environment
- Study of HVAC system
- Study of the appropriate dimensions of the traditional wind towers
- Study of natural ventilation

5.2.2 The benchmarks for indoor environment

- BS EN ISO 7730 for thermal comfort
- Section 4 through 7 Of ASHRAE 62.1-2004: “Acceptable indoor air quality”.
- *ASHRAE 62.2.2007 “Ventilation for Acceptable Indoor Air Quality”,* www.ashrae.org.
- ASHRAE STD 100

This standard applies to existing buildings, portions of buildings, and building complexes, including the envelope and all systems in the building.

5.3 Building form

5.3.1 The requirements for building form

- Identify the building form, L-shaped, U-shaped, or circular shaped form.
- Calculate the surface volume ratio; the suitable ratio for the hot-dry climate is between 0.12 to 0.16.
- Identify the location
- Identify the function
- Identify solar angle

5.3.2 The benchmarks for building forms

- Roaf, S., Fuentes M. and Thomas, S. (2007). *, ECOHOUSE: A Design Guide,* Architectural Press, Oxford, Great Britain.
- Saud, H. (2000). *Principles of Urban Environmental Science. Sudan University, Khartoum, Sudan.*
- The Ministry of Electricity and Water (Oct.-2012). Rationalization guide book, Ministry of Electricity and Water, Riyadh City, KSA

5.4 The outdoor environment

5.4.1 The requirements for outdoor environment

- Identify the cause of shades on the outdoor environment, such as the building, the balconies and the trees.
- The balconies
- The vegetation
- The fence, fence height, and the distance from the building.
- The fountains
- The terraces

5.4.2 The benchmarks for outdoor environment

- Saud, H. (2000). *Principles of Urban Environmental Science. Sudan University, Khartoum, Sudan.*

5.5 The materials

5.5.1 The requirements for building materials

- Identify the materials used in the base, walls, ceilings and décor.
- Classify these materials according to their time lag and impeded energy.
- Testing the materials if there is any toxic materials.
- If there are recycling building materials
- If there is any regional building material
- If there is any material waste management system
- If there is any space for material recycling.

5.5.2 The benchmarks for building materials

-Construction waste program

EU directive on dangerous substances 67/548/EEC

http://ec.europa.eu/environment/chemicals/dansub/consolidated_en.htm

EU Directive 67/548/EEC Annex III

-Palestine Engineers Association (2013). Green buildings Guidelines. Palestine Engineers Association, Palestine Higher Green Building Council, State of Palestine.

5. 6 Drainage and water supply system

5.6.1 The requirements for drainage and water system

- Identify the system used for sewage
- Identify water source
- Test the water, take water sample and test it in an official laboratory and compare the results with WHO standards for potable water.
- Identify if there is grey water recycling
- Identify if there is rain water collector
- Check the equipment in kitchen and baths

5.6.2 The benchmarks for drainage and water system

- United State water sense programme
- WHO standards for potable water
- ASHREA STANDARDS, SSPC 191, standards for efficient use of water in building, site and mechanical systems
- **ASHRAE STD 13256-1**
- ISO 13256 establishes performance testing and rating criteria for factory-made residential, commercial and industrial, electrically-driven, mechanical-compression type, water-to-air and brine-to-air heat pumps. The requirements for testing and rating are based on the use of matched assemblies.
- Guides from Ministry of Water in Sudan.

5.7 The Energy

5.7.1 The requirements for energy

- Identify the source of energy. Identify whether there are any natural resources for energy supply.
- Identify if there is energy efficiency programmes
- Identify if there is sustainable supplications
- Use of energy simulations
- Use of photovoltaic technology

5.7.2 The benchmarks for energy

- Guide of Ministry of Power in Sudan
- Energy Star Programme
- *ANSI/ASHRAE/IESNA standard 90.1 2007: Energy Standard for Buildings except Low-Rise Residential.*
- *Department Of Energy (DOE)*
- *Commercial Building Energy Consumption Survey (CBECS).*

APENDEX -6

INTERVIEWS WITH SPECIALISTS

This appendix presents some of the interviews carried with the professionals during the fieldwork, and this helped in developing the study method of assessment as follows:

(i) Eng. Nouralla Yassin Ahmed, the Manager of Technology Department and Dissemination Department, *the Energy Research Institute (ERI);* mentioned that "*The Ministry of Science and Technology (MOST) established the Energy Research Institute (ERI) in 1972 and since then the Institute had established the wind power unit, bio mass unit, the solar energy unit and started many projects all over the country*".

(ii) The previous Minister of Energy and Mining. Eng. Abdel Moneim Khogali confirmed that: "*the solar energy system is suitable to provide isolated rural areas with solar energy, where the main electricity supply line from the main station did not reach. Although the initial cost of establishing solar energy system is high, the running cost is low. The government established Sustainable projects, such as lighting of 100 villages at rural areas and supplying energy for a solar water-pump system*"

(iii) Eng. Ali Siddig Ali the manager of solar and eclectic projects at the International Company for Electrical and Mechanical Works mentioned that: "*his company is working in providing solar energy systems to different projects, solar street lighting, solar heating and cooling systems. He mentioned that providing houses with solar energy systems in Greater Khartoum has a lot of problems*".

The initial cost of providing a house with a solar energy system depends on the household electrical equipment such as T.V. sets, coolers, air conditioners, refrigerators, fans etc. He added that, these raised the initial cost because two or three storage batteries are required to meet such energy consumptions. However, the running cost could be reduced by $20,000 if the solar energy system is incorporated within the building's plot, which will be more attractive and cost-effective. He also mentioned that, it is viable to provide the system as a neighbourhood's overall project, which is more economical. The system needs to be cleaned regularly, from dust and rain, and requires maintenance every five years.

IV). The Ministry of Power and Mining mentioned that the government built Meroe dam in North Sudan, which started on 2007 and adds 1250 Mega Watts. The dam generates hydro-electric power, which is a source of clean energy. Study of alternative, renewable sources of energy (e.g. solar, biomass and wind) becomes important. They should be utilized for energy production in Greater Khartoum, thus, reducing consumption of scarce conventional fuels.

All these opinions from the specialist are very important and helped in developing the study method of assessment. The researcher added solar energy, wind energy, biomass energy and hydro-electric energy as basic natural resources.

APPENDIX -7

PROPOSED EVALUATION METHOD RESULTS

Table 12 Conclusions of the discussions of the average results for all categories on the selected areas of the study in Greater Khartoum.

Thae Main Category	El Taief	Khartoum 2	Al Sahafa	Ilegal Areas	Kafoori	Al Shabia	Al Rouda	Al Mouradfa	Average for Greater Khartoum	Evaluation
Sustainable site	51	64.6	27	23	55	22	52	28	40	Pass
Indoor Environmental Quality	38	47.8	27	13	41	27	42	26	33	Pass
Outdoor Thermal Control	64	55.6	14	11	78	25	73	8	41	Pass
Building Form	14	24.8	16	13	18	13	13	13	15	Weak
Materials and Resources	28	29.6	15	12	36	15	30	13	22	Weak
Drainage System and Water Supply System	29	23.14	25	0	23	25	19	17	20	Weak
Power Supply	9	10.584	7	7	7	7	6	7	7	Weak
Environmental Sustainable Design Process	32	36	19	11	35	19	33	16	25	Weak

Source: Adapted by the researcher.

Table 12 shows Conclusions of the discussions of the average results for all categories on the selected areas of the study in Greater Khartoum.

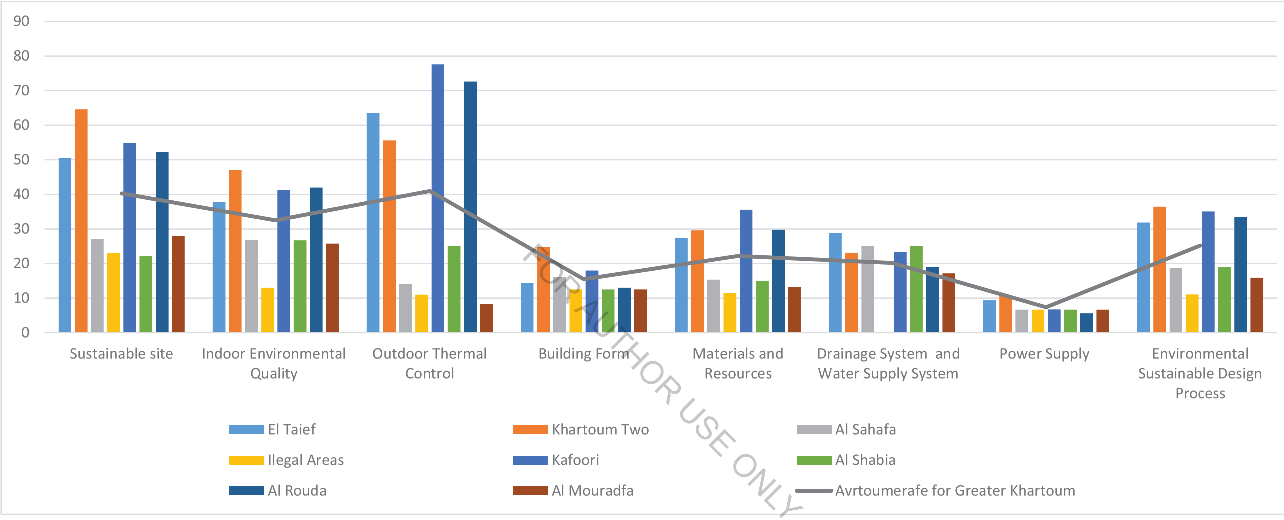


Figure 12: The average results for all categories on the selected areas of the study in Greater Khartoum.

Source: Adapted by the researcher.

Figure 12 shows the average results for all categories on selected areas of the study in Greater Khartoum.

Table 13. The average result in Sustainable Site for the areas of study in Greater Khartoum.

Sustainable Site	El Taief	Khartoum 2	Al Sahafa	Illegal	Kafoori	Al Shabia	Al Rouda	Al Mourada	Greater Khartoum	Evaluation of the category by the study method of assessment
Site selection	40 Pass	40 Pass	20 -Weak	0 N/A	20 Weak	20 Weak	40 Weak	20 Weak	23	Weak
Loadbearing	10-Weak	40- Pass	100-(excellent)	100- excellent	0 N/A	71 Excellent	0 N/A	87	50	Good
Steel structure	0 N/A	40 pass	0 N/A	5-(Weak)	0 N/A	0 N/A	0 N/A	20 Weak	7.5	Weak
Concrete system	90-Excellent	80-(v. Good)	0 N/A	0 N/A	100	14	100	12.5	51	Good
Parking control	75-V.Good	80-(v .Good)	57-Good	0 N/A	66.6 Good	71 Good	60 Good	37 Good	49 Good	Good
Construction activity control	87- (v.Good)	80-(V.Good)	85-(V. Good)	0 N/A	100 Excellent	80 Good	100 Good	0 N/a	56.5 Good	Good
Noise prevention	75-(V.Good)	60-(V.Good)	0 N/A	0 n/a	100	0 NA/	100 Excellent	0 N/A	42 Good	Pass
Control natural water features	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	37 Pass	5 Weak	Weak
Public transportation axis	50 Good	80 V.Good	100 excellent	30 Weak	80 Good	57 Good	89 Good	37 Pass	65 Good	Good
Bicycle control	0N/A	0 N/A	0-	0	0	0	0	0	0	Not applicable
Fuel control	0-(not-applicable	0-(not-applicable)	0-(not-applicable)	0	0	0	0	0	0	Not applicable
Enhanced landscaping on site	100-(Excellent	60-(V.Good)	0-(not-applicable)	0	100	0	80	0	42.5	Good
Maximize open space	75-(V.Good)	60-(V.Good)	42-(good)	66	100	43	100	37	65	Good
Heat island effect	0-(not-applicable	20-(Weak)	0-(not-applicable)	0	0	0	0	0	2.5	Weak

Table 13 shows the average result in sustainable site category for all areas of the study areas. For El Taief neighbourhood the analysis shows good results in site selection, parking control, and enhanced landscaping on site due to large plot area size ranging between 400-600 m^2. Use of concrete. The not applicable results were in fuel control, bicycle control and heat island effect. For other neighbourhoods see Chapter seven.

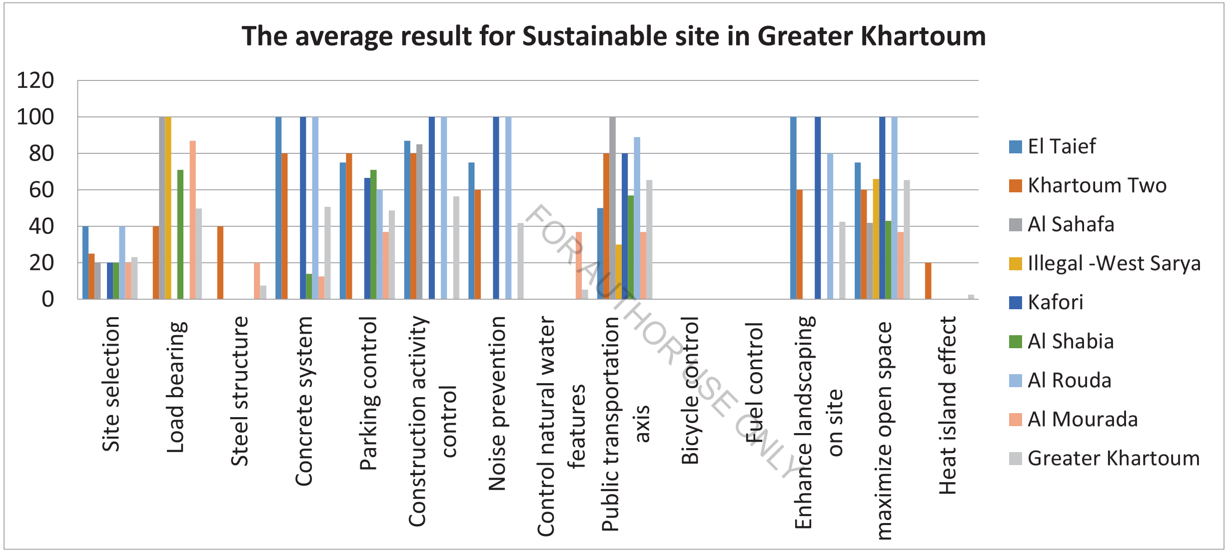


Figure 13: The average results for the sustainable site category in the selected areas of the study in Greater Khartoum.

Source: Adapted by the researcher.

Figure 13 shows the average results in sustainable site category in all the areas of the study. Source: Designed by the researcher

Table 14. The average results for indoor environmental quality category for the areas of the study in Greater Khartoum.

Indoor environmental quality issues	El Taief	Khartoum 2	Al Sahafa	illegal	Kafoori	Al Shabia	Al Rouda	Al Mourada	Evaluation of the category by the study method of assessment
Orientation to the North-South direction	50-good	20-weak	0-N/A	0-N/A	20-Weak	0-N/A	40-GOOD	0-N/A	18.5 WEAK
Orientation to the East-West direction	37.5 Good	80 Good	85 Good	66 Good	60 Good	86 Good	100- Good	100 Good	76.8 Good
To 45º	12.5- Weak	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	1.5 Weak
Building dimension	75 Good	0 N/A	0 N/A	55 Good	60 Good	0 N/A	100 Good	0 N/A	36.25 Good
Roof Insulation	100- Good	80- Good	42 Good	33 Weak	100 Good	14 Weak	60 Good	0 N/A	53.62 Good
Double roof	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
Ceiling colour	0 N/A	0 N/A	28 Weak	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	3.5 Weak
Green Roof	0 N/A	0N/A	0-N/A	0	0 N/A	0-N/A	0-N/A	0-N/A	0 N/A
Windows size and location	100 excellent	80 Good	85 Good	66 Good	100 Good	100 Good	100 Good	37 Good	83.5 Good
Vertical sunscreen	0 N/a	20 Weak	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	2.85 Weak
Horizontal sunscreen	37.5- Good	25 Weak	57 Good	0 N/A	60 N/A	0 N/A	0 N/A	0 N/A	22.43 Weak
Horizontal and vertical sunscreen	37.5 Good	40 Good	0 N/A	0 N/A	40 Good	14 Weak	100 Good	100 Good	41.43 Good
Wall paint and colour	50 good	40 Good	42 Good	0 N/A	60 N/A	0 N/A	100 Good	0 N/A	36.5 Good
Green wall	0-not applicable	20 Weak	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	2.5 Weak
Floor thermal control	0-not applicable	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
Design thermal control	0-not applicable	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
Natural ventilation	100 good	100 Good	85 Good	100 Good	100 Good	100 Good	100 Good	100 Good	98.12 Good
The use of wind tower	0-not applicable	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
Courtyard system	90 Good	80 Good	70 Good	30 Weak	90 Good	0 N/A	100 Good	70 Good	66.25-Good
Lighting control	0-not applicable	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N//A	0 N/A	0 N/A
Use of fans	100 Good	100 Good	100 Good	0 N/A	100 Good	86 Good	100 Good	100 Good	85.75 Good
Use of desert coolers	62.5 Good	60 Good	100 Good	0 N/A	80 Good	86 Good	100 Good	100 Good	73.562 Good
Use of air conditioning systems	25 Weak	30 Weak	0 N/A	0 N/A	40 N/A	0 N/A	0 N/A	0 N/A	11.87 Weak
HVAC systems	0 N/A	20 Weak	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	2.5-WEAK

Table 14 shows the average result for all the areas of the study in indoor environment; for El Taief neighbourhood the analysis shows good results in ori entation and ventilation, roof and wall insulation; weak results in vertical and horizontal sunscreens; not applicable solutions in use of lighting control, floor thermal control, green walls, and green roofs because people in El Taief neighbourhood have no experience in using such solutions. For the other neighbourhoods see Chapter seven and its general conclusions.

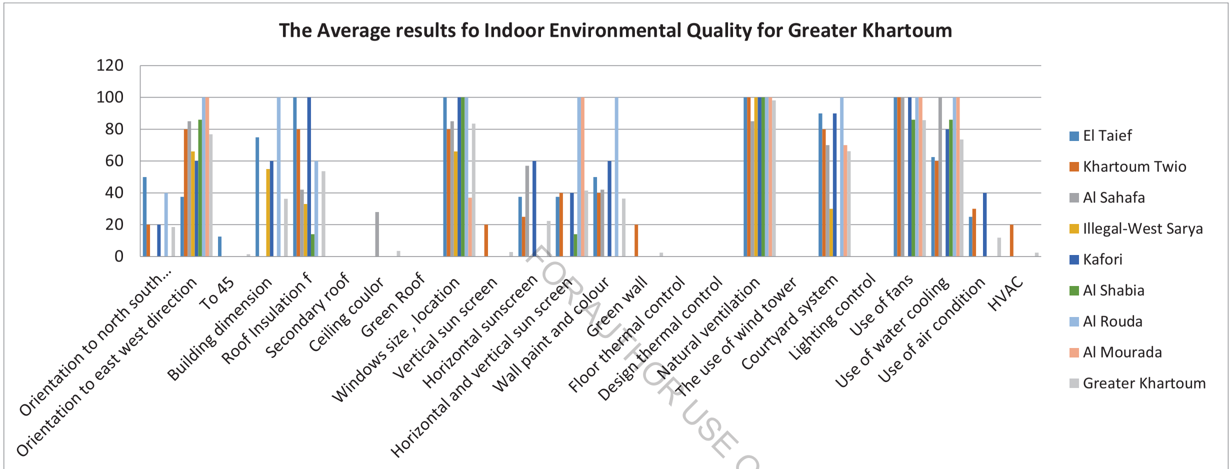


Figure 14: The average results for the indoor environmental quality category in the selected areas of Greater Khartoum.

Source: Adapted by the researcher.

Figure 14 shows the average results for the indoor environmental quality category for all areas of the study in Greater Khartoum

Table 15. The average results for the outdoor environment category in the areas of study in Greater Khartoum

The outdoor environment issues	El Taief	Khartoum 2	Al Sahafa	Illegal	Kafoori	Al Shabia	Al Rouda	Al Mourada	Evaluation of the category by the study method of assessment
Shades to the North-South direction	75 GOOD	80 GOOD	15 WEAK	0 N/A	60 GOOD	0 N/A	80 GOOD	40 GOOD	43.75 GOOD
Shades to the East-West Direction	75 GOOD	40 GOOD	0 N/A	0 N/A	100 GOOD	14 WEAK	100 GOOD	80 GOOD	51.12 GOOD
Balcony	100 GOOD	60 GOOD	0 N/A	0 N/A	100 GOOD	0 N/A	100 GOOD	12.5 WEAK	53.21 GOOD
Vegetation	75 GOOD	80 GOOD	15 WEAK	0- N/A	100- GOOD	28 WEAK	80 GOOD	37 GOOD	51.87 GOOD
Fences	100 GOOD	89 GOOD	100 Good	66 GOOD	100 GOOD	100 GOOD	0 N/A	100- GOOD	69.37 GOOD
Swimming pool	25 Weak	0 N/A	0 N/A	0 N/A	20 GOOD	0 N/A	0 N/A	0-N/A	15.62 WEAK
Fountain	0 N/A	0 N/A	0 N/A	0 N/A	20 GOOD	0 N/A	0 N/A	0 N/A	2.5 WEAK
Terraces	75 GOOD	30 WEAK	0 N/A	0 N/A	100 GOOD	0 N/A	100 GOOD	12.5 WEAK	39.68 GOOD

Table 15 shows good results for the shades to the North-South direction, shades to the East-West direction, balconies, vegetation, fences, swimming pools and terraces in El Taief neighbourhood. People have good experience and knowledge of the importance of managing their outdoor environment to minimize the temperatures within their homes. For the other neighbourhoods see Chapter seven and its general conclusions.

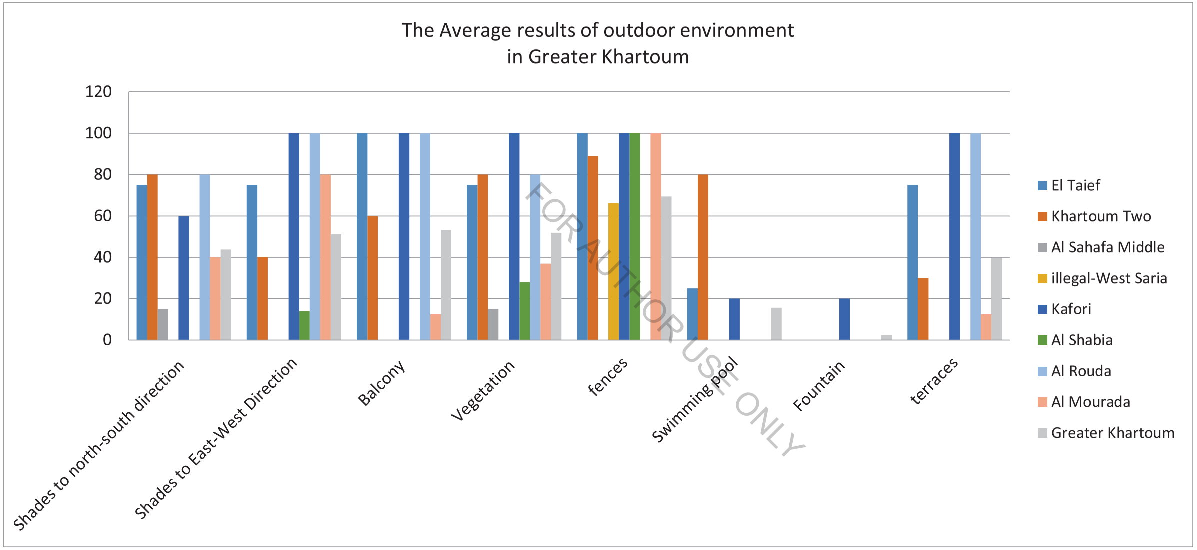


Figure 15: The average results for the outdoor environmental quality category in the areas of the study in Greater Khartoum.

Source: Adapted by the researcher.

Figure 15 shows the results for the outdoor environmental quality category for all areas of the study in Greater Khartoum.

Table 16 The average results for the building form category in the areas of the study in Greater Khartoum.

Building form Issues	**El Taief**	**Khartoum 2**	**Al Sahafa**	**illegal**	**Kafoori**	**Al Shabia**	**Al Rouda**	**Al Mourada**	Evaluation of the category by the study method of assessment
Linier form	50 GOOD	60 GOOD	85 GOOD	33 GOOD	60 GOOD	71 GOOD	60 GOOD	87 GOOD	60.75 GOOD
U-shaped form	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
L-shaped form	12.5 WEAK	5 WEAK	0 N/A	0 N/A	20 WEAK	0 N/A	40 GOOD	0 N/A	10 WEAK
Cubic form	37 GOOD	20 WEAK	15 WEAK	10 WEAK	40 GOOD	14 WEAK	0 N/A	12.5 WEAK	19 WEAK
Vaults	0 N/A	20 WEAK	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	2.5 WEAK
Domes	12.5 WEAK	0 WEAK	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	2 WEAK

Table 16. Shows the average results for the building forms category. It shows good results in linear and cubic forms, weak results in L-shaped form, no applicable result in U-shaped form, vaults and domes for all neighbourhoods. This is because people have good experience in using linear forms to improve air movement inside their buildings. For the other neighbourhoods see Chapter seven and its general conclusions.

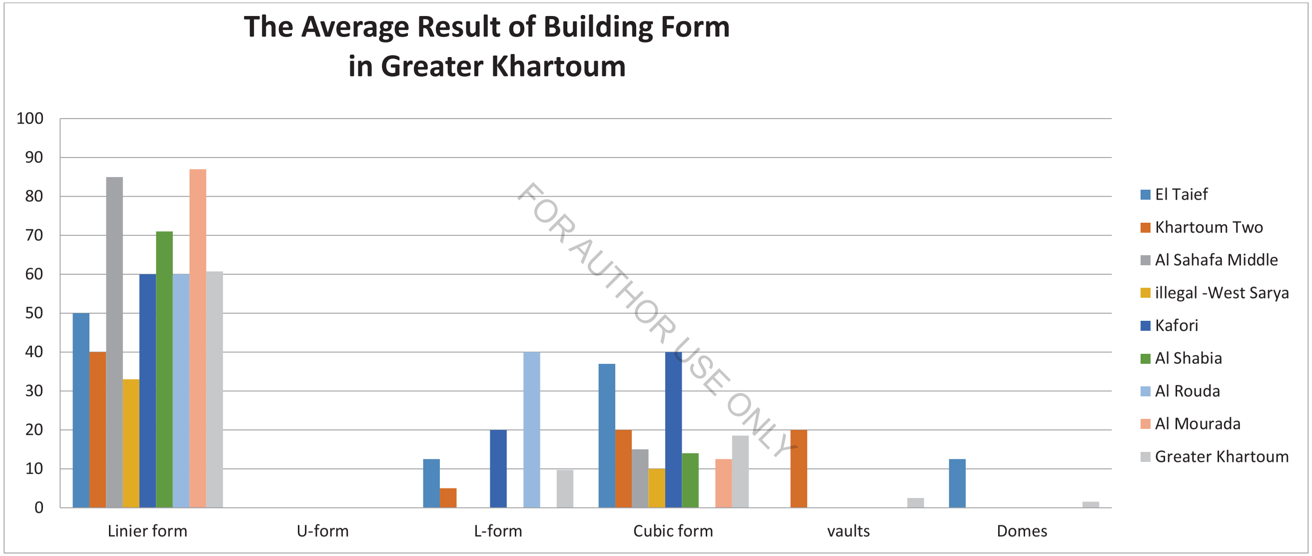


Figure 16: The average results for the building forms category in the selected areas of Greater Khartoum.

Source: Adapted by the researcher.

Figure 16 shows the results for the building forms category in all areas of the study in Greater Khartoum.

Table 17. The average result for the building materials category in the selected areas of the study in Greater Khartoum.

Building materials	El Taief	Khartoum 2	Al Sahafa	illegal	Kafoori	Al Shabia	Al Rouda	Al Mourada	Evaluation of the category by the study method of assessment
Concrete	100-Good	80-Good	30-weak	0-N/A	100-good	14-weak	100-good	37 Good	57-Good
Sand on base	100-Good	80-Good	25-weak	0-N/A	100-good	14-weak	100-good	75- good	67-Good
Bricks	100-Good	80 Good	57 Good	0 N/A	100 Good	71 Good	100 Good	75 Good	73-Good
Mud	0 N/A	0 N/A	0 N/A	100 Good	0 N/A	0 -N/A	0 N/A	0 N/A	12.5-Weak
Steel	37.5 Weak	20 Weak	57 Good	33 Weak	20 Weak	28 Weak	0 N/A	30 Weak	28-Weak
Hollow blocks	0-N/A	0-N/A	0-N/A	0-N/A	0-N/A	43-good	0-N/A	12.5-Weak	7-Weak
Wood	12-Weak	30 -Good	15- Weak	66-Good	40- Pass	15 N/A	100-Good	40- Pass	40-Pass
Ceramic tiles	87-Good	60-Good	100-Good	0 N/A	100-Good	28 Good	80- Good	75- Good	68-Good
Marble	37.5 Weak	20 Weak	0 N/A	0 N/A	40 Pass	14 Weak	20 Weak	0 N/A	16.4 Weak
Cement tiles	0 N/A	0 N/A	100 Good	0 N/A	100 Good	28 Weak	20 Weak	37 Good	36 Weak
Glass and aluminium	100-Good	40- Pass	0 N/A	0 N/A	100 Good	14 Weak	100 Good	0 N/A	45 Good
	12 Weak	20 Weak	0 N/A	0 N/A	80- Good	14-Weak	20- Weak	37 Weak	32.25 Weak
Wood on roof	0 N/A	10 Weak	30 Weak	0 N/A	0 N/A	14 Weak	0 N/A	0 N/A	7.71 Weak
Roof clay tiles	37-Weak	5-Weak	0-N/A	0-N/A	40-Pass	14-weak	60-good	0-N/A	19.5 weak
Recycled material	25 Weak	5 Weak	15 Weak	0 N/A	0 N/A	28 Weak	0 N/A	25 Weak	12.25 Weak
Wall cladding	0 N/A	0 N/A	0- N/A	0- N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
Carpets	0 N/A	20 Weak	12 Weak	0 N/A	0 N/A	28-Weak	25-Weak	0 N/A	10.625wWeak
Curtains	100-N/A	100-Good	100-Good	0 N/A	100-Good	100-Good	100-Good	100 Good	87.5-Good
Suspended ceiling	0 N/A	0 N/A	28-Weak	0 N/A	0 N/A	14-Weak	0 N/A	0 N/A	5.25-Weak
Construction waste management	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A

le 17 shows the average results for the building materials category for all neighbourhoods in Greater Khartoum; l Taief the analysis shows good results in concrete, bricks, wood, wall cladding, and ceramic tiles; weak results ecycled content; not applicable results in construction waste management. This is because people have good erience in using building materials that are available in their local environment. For the other neighbourhoods see pter seven and its general conclusions.

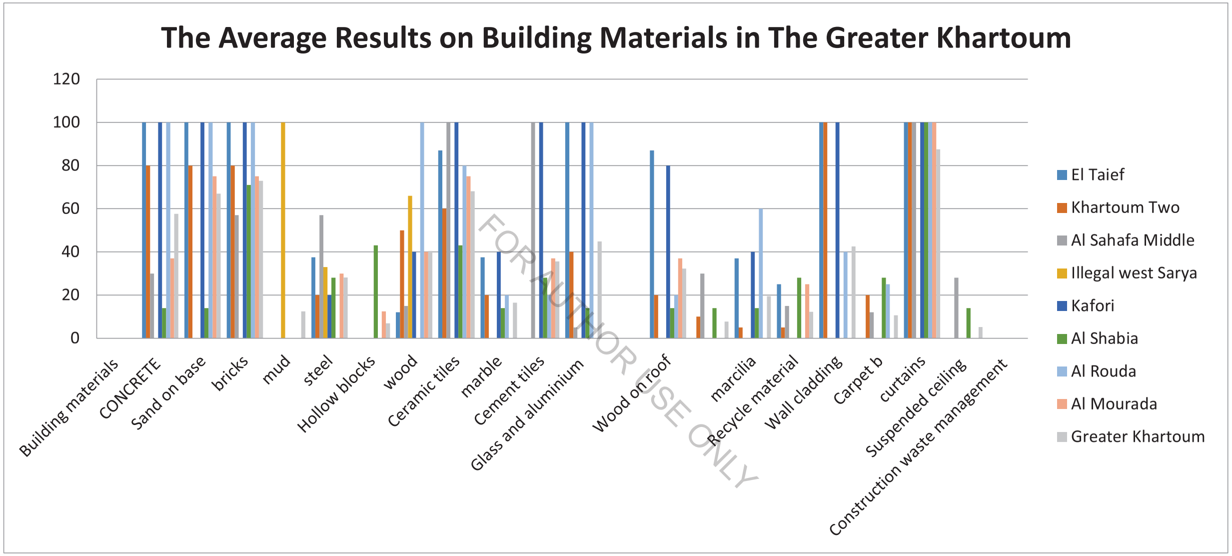


Figure 17: The average results for the building materials category in the areas of the study in Greater Khartoum.

Source: Adapted by the researcher.

Figure 17 shows the average results for the building materials category in all the areas of the study in Greater Khartoum.

Table 18. The average results for the drainage and water supply systems category for the areas of the study in Greater Khartoum.

Water supply and drain system issues	El Taief	Khartoum 2	Al Sahafa	Illegal	Kafoori	Al Shabia	Al Rouda	Al Mourada	Evaluation of the category by the study method of assessment
Network	0-N/A	100- Good	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	16.66- weak
Septic tank	100- Good	0-N/A	100- Good	0 N/A	100- Good	100- Good	100- Good	100-Good	75-good practice
Well	100- Good	0 N/A	100- Good	0 N/A	100- Good	100- Good	100- Good	100-Good	75-good practice
Biological treatment	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
Pit latrine	0 N/A	0 N/A	0 N/A	100 Fair	0 N/A	0 A/A	0 A/A	30%- Weak	12.5 Weak
VIP	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
Reduce Water source	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
From the river	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
From the National Grid	100- Good	100- Good	100- Good	0 NA	100- Good	100- Good	100- Good	100-Good	87.5- Good
Water efficiency	70 Good	50-Good	15- Weak	30- Weak	60- Good	15 Weak	15 Weak	15 Weak	33.75- Weak
Rain water container	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
Water recycling	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
Reduced water usage	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A

Table 18 shows the average results for the drainage and water supply systems category in all areas of the study in Greater Khartoum. The analysis shows that all neighbourhoods are taking water from the local station, and water efficiency is 70%; not applicable results in rainwater container, water recycling, and reduced water usage. All neighbourhoods used wells and septic tanks for drainage. Except Khartoum 2, they used the drainage network. Illegal areas used sand and gravel. For the other neighbourhoods see Chapter 7 and its general conclusions.

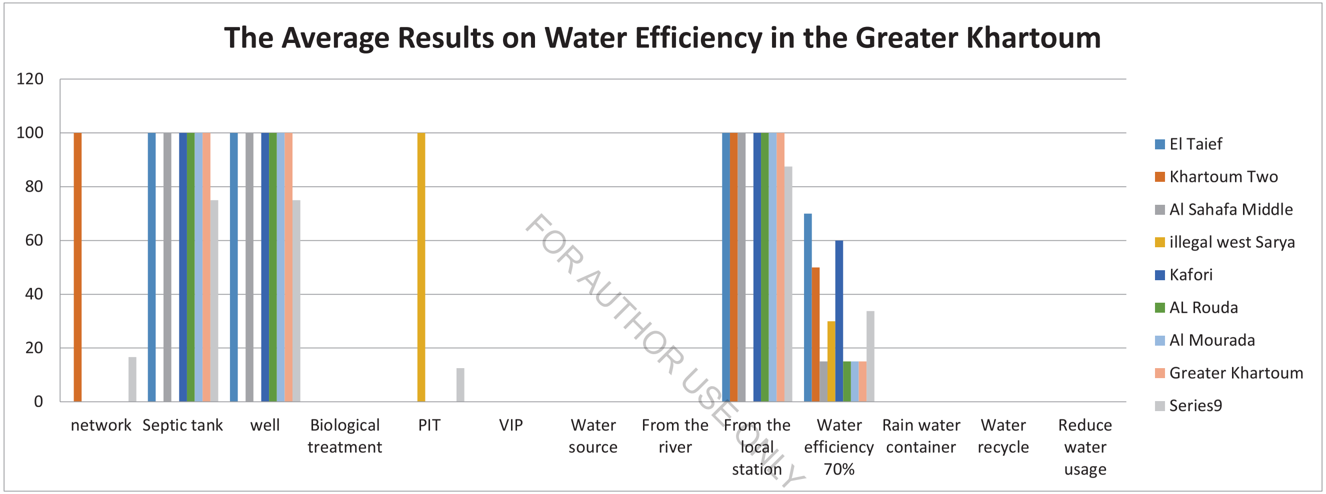


Figure 18: The average results for the drainage and water supply systems category for areas of the study in Greater Khartoum.

Source: Adapted by the researcher.

Figure 18 shows the average results for the drainage and water supply systems in all areas of the study in Greater Khartoum.

Table 19. The average results for the power supply category in the areas of the study in Greater Khartoum.

Power supply issues	El Taief	Khartoum 2	Al Sahafa	Illegal	Kafoori	Al Shabia	Al Rouda	Al Mourada	Evaluation
From the National Grid	100 Good	100 Good	100 Good	0 N/A	100 GOOD	100 GOOD	100 GOOD	100 GOOD	100 Good
Generator	25 Weak	50 Good	0 N/A	0 N/A	100- GOOD	100- GOOD	100- GOOD	12.5- WEAK	46.875- Good
Wind energy	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
Solar energy	12.5- Weak	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	4 N/A
Water falling energy	100 Good	100 Good	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	37.5 Good
Underground heat energy	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
Energy efficiency	25 Weak	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	3 N/A
Solar energy heating system	12.5 Weak	10 Weak	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	1.5 Weak
Solar boiling	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
Solar cooking	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
Outdoor solar lighting	12.5- Weak	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	1.5 Weak
Photovoltaic technology	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A
Using Simulations	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0 N/A	0-N/A

Table 19 shows the average results for the power supply category in all areas of the study in Greater Khartoum. The analysis shows that all neighbourhoods are taking energy from the local station; limited solutions are found in using solar and wind energy.

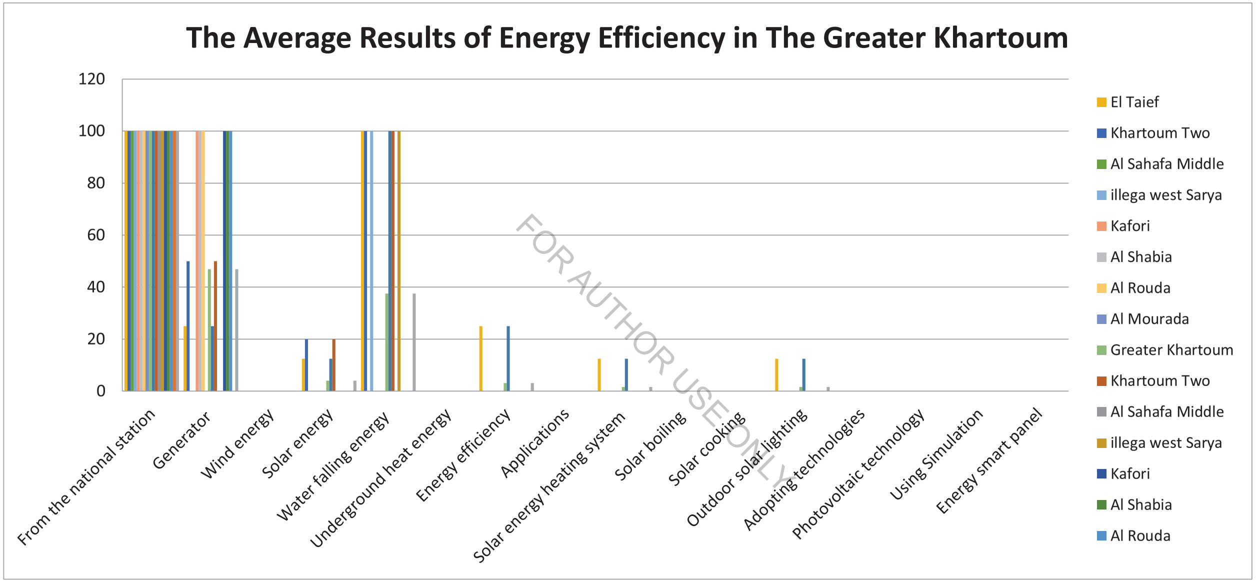


Figure 19: The average results for the power supply category in the areas of the study in Greater Khartoum.

Source: Adapted by the researcher.

Figure 19 shows the average results for the power supply category. All neighbourhoods were taking energy from the local plant; minimum solutions are found in solar energy, case study No. 10 in Al Gerif West and case study No. 7 in El Taief.

Table 20. The general conclusions of the average result for the environmental design process category in the areas of the study in Greater Khartoum.

	El Taief	Khartoum 2	Al Sahafa	Illegal	Kafoori	Al Shabia	Al Rouda	Al Mourada	Evaluation	El Taief
Environmental Sustainable Design Process	32	36	19	11	35	19	33	16	25	Weak

Estimated for the following table:

-On the first class construction and design is depends on construction companies and consultant companies, so the percentage on pre building phase and pre-building phase are equal and near to above percentage 40%, then the maintenance phase has lower percentage 20%.

-Then for the third class the building constructed by sub-contractors, the dependence on the consultant companies are less than dependence on sub-contractors, that's why pre -building phase is 20%, and construction phase is 60%, and people (owner) maintain their houses in this long period of time from (1965 to 2017) according to the survey.

EDP issues	El Taief	Khartoum 2	Al Sahafa	Illegal	Kafoori	Al Shabia	Al Rouda	Al Mourada	Evaluation
Pre building phase	40	40	20	10	40	20	40	20	25
Building phase	40	40	60	40	40	60	40	60	47.5
Post building phase	20	20	30	50	20	50	20	50	32.5

Table 20 shows the average results for the environmental design category. In Al Taief, pre building phase is applicable by 40%, building phase is applicable by 40% and post building phase by 20%.

Source: Adapted by the researcher.

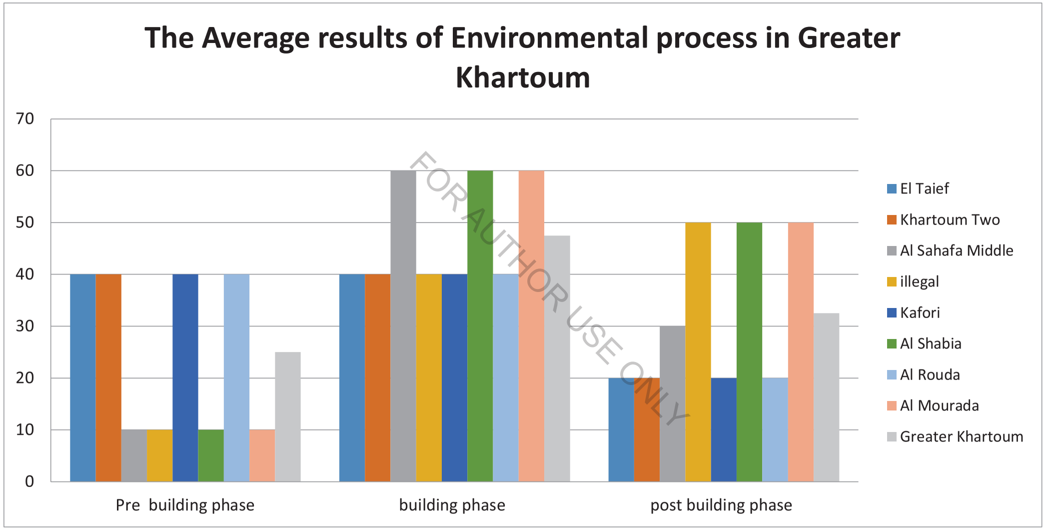


Figure 20: The general conclusions of the average results for the environmental design process category in the areas of the study in Greater Khartoum.

Source: Adapted by the researcher.

Appendix-8

Applying of five global assessment methods in one case study in Khartoum

Sample No. (9): plot No: 365/1, Block No: 5.

This sample because it has got the higher points with all the other samples studied in this research, is chosen for global assessment approach an excellent solutions for the sustainable-eco-building assessment method (SEBAM).

1. Introduction

House of Dr. Othman El Kheir, This house was built in Geraif West Neighbourhood in Khartoum city; in late nineties. It attempted to demonstrate several features significance to the designer. In this case, the keywords were environment, traditions and modernity. Great consideration was hence given to orientation and shading. Natural ventilation was made easier by the intrinsically narrow plan and the open multi-level interior. A wind catcher further accentuated this and underground brick ducts for supplying cool filtered air. Small high-level openings siphoned the hot air and enhanced convectional currents. The incorporation of plants in the interior was combined with a water sprinkling system for irrigation and climate modification. Solar energy provided the back-up supply for lighting and low-demand appliances as well as Water: It is from the National Grid, water efficiency is 70%; which indicates a shortage of water supply. Drainage system: septic tank + well. Energy: supplied from the National Grid, energy is generated through hydropower. The structure is a composite RC frame and brick load-bearing walls system. The frame constitutes a stiff core holding brick vaults and combating the resulting lateral forces. The area framed by the RC skeleton receded upwards from the ground level to the first level, leaving the third level for load bearing walls. Perpendicular vaults acting as buttresses framing openings and casting shadows further assist this. The interior is softly rendered and made very simple and open. It accommodates artwork, feature panels and sometimes purposely designed furniture.

2. Objectives

2.1 The main objective of this analysis is to compare global solutions for sustainable eco buildings (SEBAM) in Greater Khartoum

2.2 To find out the applicable solutions from the global systems

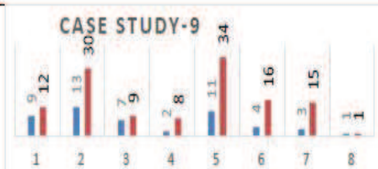
2.3 To find out un applicable solutions from the global system and the reasons

3. Results and findings

1. The research method of assessment: Sustainable-Eco-Building (SEBAM)

Main Categories	No. of Points Achieved	No. of Points Available	No Of Credit
Sustainable site	9	12	75 %
Indoor Environmental Quality	13	30	40 %
Outdoor Thermal Control	7	9	42%
Building Form	2	8	25%
Materials and Resources	11	34	32 %
Water Supply System	4	16	12.5%
Power Supply	3	15	20%
Environmental Sustainable Design Process	1	1	100%
	50%	125	Good

Table (6.9):The results of case study-9, Gerif West, Plot No:365/1, Block No:5,



Fig(6.9):The Building Performance Of case study 9, Gerif West, Plot No:365/1, Block No:5,

PL.6.9: East Elevation

PL..6.9 :The use of Solar Energy

Fig. 6.12: Sample 9, plot (365/1), block (5), Geraif West

2.Green Star Rating System IN AUTRALIA

Table 21. The result by Green Star Rating System.

Credit	Number of points Achieved	Number of points available	%
Management	7	14	50%
Indoor environment quality	17	17	100%
Energy	7	22	31%
Transport	8	10	80%
Water	8	12	66.66%
Materials	4	14	28.5%
Land use and ecology	3	6	50%
Emissions	1	5	20%
Innovation	3	10	30%
Total	50 points 4 star	110	

Source: Designed by the researcher.

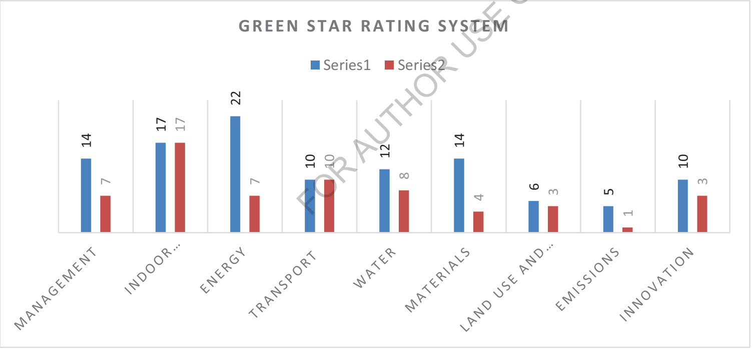


Fig.21: Shows Green Star Rating System results for one case study, source: Adapted by the researcher.

2. BREEAM rating system in the UK

Table 22. The result by BREEAM rating system in UK

Issue name	Achieved	Credit available	%
Land use and land ecology	2	10	20%
Energy	19	31	61%
Water	4	9	44.4%
Material	6	14	42.8%
Health and wellbeing	4	22	18.1%
Transport	2	12	16.6%
Materials	8	14	57.1%
Waste	6	9	66.66%
pollution	2	13	15.3%
Innovation	3	10	30%
Total	56 (very good)	144	

Source: Adapted by the researcher.

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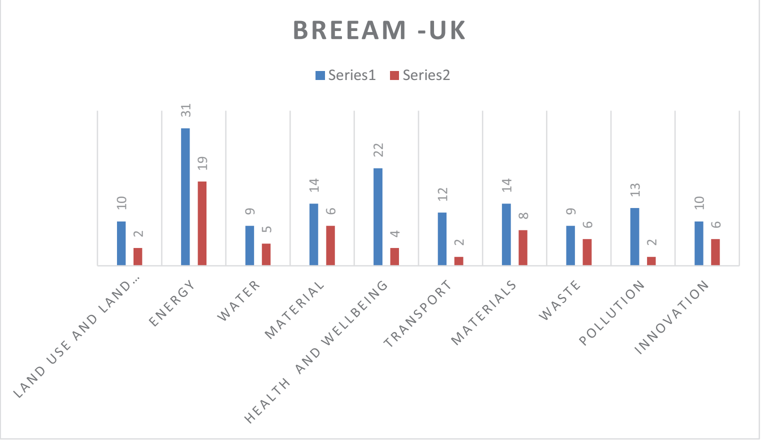

Fig.22: Shows the results of BREEAM applied for one case study, source: Adapted by the researcher.

4. LEADER IN ENERGY AND ENVIRONMENT DEVELOPMENT (LEED)

Table 23. The result by LEED V4 rating system

Category	Point available	Point achieved	%
Location and Transportation	15	10	66%
Sustainable site	10	6	62%
Water efficiency	12	10	83%
Energy & atmosphere	38	12	31.3%
Material & resources	8	3	37%
Indoor environment	17	4	23%
innovation	6	4	66%
Regional priority	4	2	50%
	110	51 % (silver)	

Source: Adapted by the researcher.

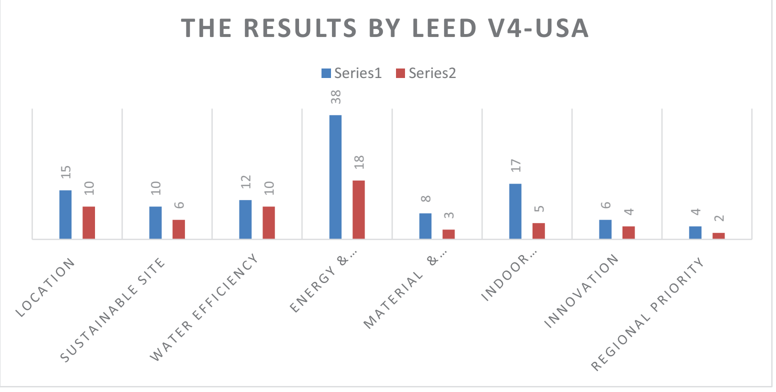

Fig.23: Shows the results LEED V4 applied for one case study, source: Adapted by the researcher.

5. ESTIDAMA BUILDING RATING SYSTEM

Table 24. The result by ESTIDAMA building rating system

Credit	Achieved points	Maximum credit points available	%
Integrated development process	5	13	38%
Natural system	2	12	16.6%
Livable building: outdoors	8	14	57.14%
Livable Building: indoor	17	23	73.9%
Precious water	8	43	18.6%
Resourceful energy	9	44	20.4%
material	14	28	50%
Innovation practice	2	3	66.6%
Total	65 (2 pearl)	180	

Source: Adapted by the researcher.

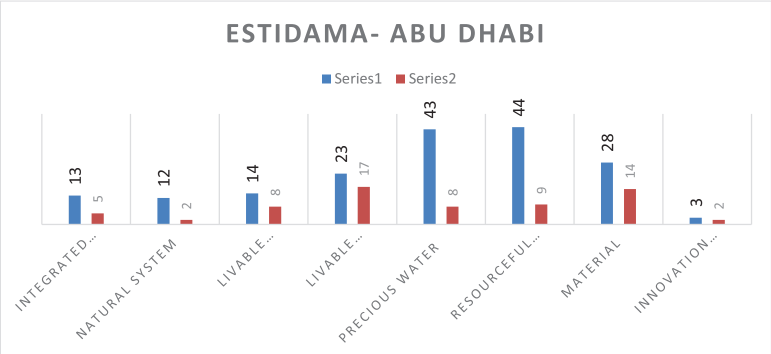

Fig.24: Shows the results of ESTIDAMA applied for one case study, source: Adapted by the researcher.

6. GLOBAL SUSTAINABILITY ASSESSMENT SYSTEM (GSAS)

Table 25. The result by GSAS

	Category	Achieved weight	Weighing available	%
UC	Urban connectivity	7	7	100%
S	Site	2.74	15	18%
E	Energy	6.87	24	28.6
W	Water	6	16	37.5
M	Materials	5.7	12	47.5
IE	Outdoor environment	4.03	16	25%
CE	Culture & economic value	3.12	7	44.5%
MO	Management and operation	1.2	8	15%
	Total	36.66 2 star	105	

Source: Adapted by the researcher.

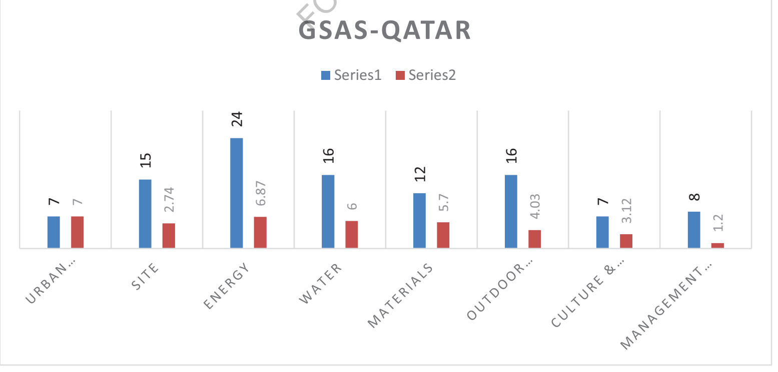

Fig. 25: Shows the results of GSAS applied for one case study, source: Adapted by the researcher.

4. Discussion of the results

The case study number 9 was analyzed first by the research method of assessment, the applied solutions found are the good accessibility, parking with cover shed, concrete structure, bricks, glass and aluminum. Vaults over the bed rooms, double height with green plant. Large garden with shrubs and trees. Solar panel. Recycled grey water. A wind catcher further accentuated this and underground brick ducts for supplying cool filtered air. Small high-level openings siphoned the hot air and enhanced convectional currents.

In addition this sample was analysed by the five global assessment methods, which are: GBCA, BREEAM, LEED, ESTIDAMA AND GSAS sustainable building assessment method in chapter six to find out the global challenges in applying the sustainable assessment methods in Greater Khartoum.

1. The site and management

Applied solutions:

GBCA: building information committed to performance, metering and monitoring, construction environmental management, BREEAM: Site selection, ecological value in addition, LEED added building exterior and hard cape management plan, erosion control, alternative transportation, heat island effect and lighting control. In addition ESTIDAMA added improved outdoor thermal comfort, private outdoor space, public transportation, parking space, lighting control, in addition to that, GSAS added transportation load, proximity to existing district, solid waste management.

Not applied solutions:

AGBC: green star certified professional, commissioning and tuning, adaptation and resilience, but BREEAM not applied minimizing impact on existing site ecology, enhancing site ecology, and long term has impact on biodiversity. However LEED is not applied to LEED certified design, management plan, site development, storm water control despite, ESTIDAMA not applied urban system assessment outdoor thermal strategy, rated communities, accessible community facilities, active urban environment, bicycle facilities and travel plan. GSAS: None.

2.Water Facilities

***Applied solutions*:**

GBCA: Portable water and BREEAM added water consumption, water monitoring, and water efficient equipment, also LEED applied plumbing factor, water efficient landscape, in addition, ESTIDAMA added water use reduction, and GSAS applied water consumption.

Not applied solutions:

GBCA: partial, but BREEAM not applied water leak detection, however LEED not applied indoor plumping efficiency, water performance measurement and cooling tower on the other hand, ESTIDAMA not applied Minimum interior water use reduction, exterior water monitoring, improve interior water reduction, exterior water use reduction, and water monitoring and storm water.

GSAS: partial

3. Energy

Applied Solutions

GBCA: Greenhouse Gas Emissions, peak electricity reduction, and BREEAM: reduction of energy use, energy monitoring, external lighting, low carbon design, energy efficient transportation system, also LEED: energy efficiency, energy metering in addition to that, ESTEDAMA: renewable energy, and GSAS: energy delivery performance

Not Applied Solutions

GBCA: all solution , but BREEAM: energy efficient cold storage, energy efficient transportation system however, LEED: energy efficient best practice, energy performance, fundamental refrigerant, exiting building commissioning, building automation system emission reduction reporting in spite of the fact that

ESTIDAMA: minimum energy performance, energy monitoring, And ozone impact, improve energy performance, cool building strategies, vertical transportation, peak load reduction but, GSAS: fossil fuel conservation, CO_2 emissions, NO_x, So_x matter.

4. Material

Applied Solutions

GBCA applied responsible building materials, construction and demolition waste and, BREEAM applied responsible sourcing of materials, insulation, design for durability, material efficiency, hard landscaping and boundary protection in addition, LEED added sustainable purchasing, sustainable furniture, sustainable food. In addition ESTIDAMA added non-polluting material, design for flexibility, modular flooring system, design for durability, recycling materials, waste management, and GSAS added regional material, responsible sourcing materials, recycled materials.

Not applied solution

GBCA: life cycle impact, sustainable products, but BREAM not added Life cycle impact on the other hand LEED not added sustainable policy, solid waste policy, reduction mercury lamps, ESTIDAMA not added design material reduction, design for disassembly, building reuse, material reuse, regional material, rapidly renewable material, reused certified timber, and improve operation waste management, organic waste management. GSAS not applied material reuse and LCA.

5. Indoor environment

Applied solutions

GBCA applied indoor air quality, acoustic comfort, lighting comfort, visual comfort, indoor pollutants, and thermal comfort. BREEAM applied None, LEED: Best management practice, control lighting, daylight and view, sustainable cleaning equipment, chemical control in addition to that, ESTIDAMA applied ventilation quality, materials emissions, indoor air quality, thermal zone, views, day light, noise control, secure environment. GSAS: has no indoor environment category.

Not applied solutions

GBCA: None

BREEAM: applied all, LEED not applied environmental tobacco control, green cleaning, occupant comfort, ESTIDAMA not applied thermal comfort control, thermal comfort modeling and, GSAS: applied all.

Addition of New categories

GBCA: emissions, innovations, but BREEAM added health wellbeing, transportation, waste, pollution, innovation on the other hand, LEED added Innovation, regional priority, but ESTIDAMA added integrated design process, natural system, innovation. On the other hand, GSAS added urban connectivity, culture value, management and operation.

There are fixed 5 main categories between these global assessment methods which are: sustainable site, indoor environment quality, building material, water efficiency, energy efficiency, on the other hand each system added additional categories like GBCA added management and ecological category and emission. ESTIDAMA added integrated development process, livable community and innovation. LEED added innovation and regional priority. BREEAM added health wellbeing, transport, waste, pollution and innovation. GSAS added urban connectivity, culture value and management. Because of these additional categories and different sub issues, the result was vary from system to another: The conclusion from the analysis of "one case study" by the global systems are different variation in the result: GBCA (63, five STAR), BREEAM (68, very good), LEED (60, gold). GSAS (5 star), ESTIDAMA (3 pearl). For all not applied solutions, the reasons are educational and economic reasons. Solutions need to be educated like: green star certified professional, LEED certified design, by having workshops or continuous educations courses in specific assessment methods. Solutions not applied for its high expensive solutions like energy efficient transportation system. It is very important to study their local environmental, special, technological conditions in the local environment in Greater Khartoum and apply economical solutions suitable to local environmental, social and economic value. The research method of assessment studied the conditions of Greater Khartoum in chapter three and added three categories suitable to local environmental social and economic conditions, detailed by the passive solutions can be applied in our houses, which are, building form, outdoor environment and sustainable design process to add educational value.

5. CONCLUSIONS

The conclusion from the analysis of "one case study" by the global systems are different variation in the result: The proposed research method of assessment SEBAM (50 points) , GBCA (63, 5 STAR), BREEAM (66, very good), LEED (58, silver). GSAS (2 star), ESTIDAMA (2pearl) because of the different in the main categories and sub issues to achieve their local goals in environment, culture, social and economic value. On the followings, the researcher discusses the result to find out the applicable solutions to Greater Khartoum and not applicable solutions to highlight them as global challenges.

1. Site and management

Applied solutions: GBCA: building information, commitment to performance, metering and monitoring, construction environmental management.

BREEAM: site selection, ecological value. LEED: building exterior and hard cape management plan, erosion control, alternative transportation, heat island effect and lighting control. ESTIDAMA: improved outdoor thermal comfort, private outdoor space, public transportation, parking space, lighting control. GSAS: transportation load, proximity to existing district, solid waste management.

3. Water Facilities

Applied solutions:

GBCA: Portable water. BREEAM: water consumption, monitoring and efficient equipment. LEED: Plumbing factor, water efficient landscape. ESTIDAMA: water use reduction. GSAS: water consumption.

3. Energy

Applied Solutions

GBCA: Greenhouse gas emissions, peak electricity reduction. BREEAM: Reduction of energy use, energy monitoring, external lighting, low carbon design, energy efficient transportation system. LEED: energy efficiency, energy metering. ESTEDAMA: renewable energy. GSAS: energy delivery performance.

4. Material

Applied Solutions

GBCA: Responsible building materials, construction and demolition waste. BREEAM: Responsible sourcing of materials, insulation, design for durability, material efficiency, hard landscaping and boundary protection. LEED: sustainable purchasing, sustainable furniture, sustainable food. ESTIDAMA: Non-polluting material, design for flexibility, modular flooring system, design for durability, recycling materials, waste management. GSAS: regional material, responsible sourcing materials, recycled materials

5. Indoor environment

Applied solutions

GBCA: indoor air quality, acoustic comfort, lighting comfort, visual comfort, indoor pollutants, thermal comfort. BREEAM: None. LEED: Best management practice, control lighting, daylight and view, sustainable cleaning equipment, chemical control. ESTIDAMA: ventilation quality, materials emissions, indoor air quality, thermal zone, views, day light, noise control, secure environment. GSAS: None

New categories added by the global systems.

GBCA: emissions, innovations. BREEAM: health wellbeing, transportation, waste, pollution, innovation. LEED: Innovation, regional priority. ESTIDAMA**:** integrated design process, natural system, innovation. **GSAS:** urban connectivity, culture value, management and operation

There are fixed 5 main categories between these global assessment methods which are: sustainable site, indoor environment quality, building material, water efficiency, energy efficiency, on the other hand each system added additional categories like GBCA added management and ecological category and emission. ESTIDAMA added integrated development process, livable community and innovation. LEED added innovation and regional priority. BREEAM added health wellbeing, transport, waste, pollution and innovation. GSAS added urban connectivity, culture value and management because of these additional categories and different sub issues. The result was varying from system to another: The conclusion from the analysis of "one the case study" by the global systems are different variation in the result: GBCA (63, five STAR), BREEAM (68, very good), LEED (60, gold). GSAS (5 star), ESTIDAMA (3 pearl).

For all not applied solutions, the reasons are educational and economic reasons. Solutions need to be carefully selected; like green star certified professional, LEED certified design, by having workshops or continuous educational courses in specific assessment methods. Solutions are not applied for its high expensive solutions; like energy efficient transportation system. It is very important to study our local environmental, special, technological conditions in the local environment in Greater Khartoum and apply economical solutions that are suitable to the local environmental, social and economic value. The research method of assessment studied the conditions of Greater Khartoum in chapter three and added three categories suitable to local environmental social and economic conditions, detailed by the passive solutions can be applied in their houses, which are, building forms, outdoor environment and sustainable design process to add educational value.

6 RECOMMENDATIONS OF ANALYSIS "ONE CASE STUDY" BY THE GLOBAL SUSTAINABLE ASSESSMENT METHODS TO MEET GLOBAL CHALLENGES

Case study number 9 was analyzed by the proposed research method of assessment (SEBAM) and by the five global assessment methods, which are GBCA, BREEAM, LEED, ESTIDAMA, GSAS to find out the global challenges in applying the sustainable assessment methods in Greater Khartoum.

1. Site and management

The research recommends keeping and increasing their applied solutions in sustainable site like:
Building information, committed performance, metering and monitoring, construction environmental management, site selection, ecological value, building exterior and hard cape management plan, erosion control, alternative transportation, heat island effect and lighting control., improved outdoor thermal comfort, private outdoor space, public transportation, parking space, lighting control, transportation load, proximity to existing district, solid waste management.
The research recommends adopting such solutions as:
green star certified professional, commissioning and tuning, adaptation and resilience, minimizing impact on existing site ecology, enhancing site ecology, long term impact on biodiversity, LEED certified design, management plan, site development, storm water control, urban system assessment outdoor thermal strategy, rated communities, accessible community facilities, active urban environment, bicycle facilities and travel plan.

1. Water Facilities
The research recommends keeping and increasing our applied solutions in water efficiency like:
Portable water, water consumption, water monitoring, water efficient equipment, plumbing factor, water efficient landscape, water use reduction and water consumption.
The research recommends adopting such solutions as:
Water leaking detection, indoor plumping efficiency, water performance measurement and cooling tower, Minimum interior water use reduction, exterior water monitoring, improve interior water reduction, exterior water use reduction, and water monitoring and storm water.

3. Energy
The research recommends keeping and increasing the applied solutions in energy such as: Greenhouse Gas Emissions, peak electricity reduction, reduction of energy use, energy monitoring, external lighting, low carbon design, energy efficient transportation system, energy efficiency, energy metering, renewable energy and energy delivery performance
The research recommends adopting solutions such as:
Energy efficient cold storage, energy efficient transportation system,
energy efficient best practice, energy performance, fundamental refrigerant, exiting building commissioning, building automation system emission reduction reporting, minimum energy performance, energy monitoring, ozone impact, improve energy performance, cool building strategies, vertical transportation, peak load reduction., fossil fuel conservation, CO_2 emissions, NO_x, So_x matter.

4. Material

The research recommends keeping and increasing their applied solutions in material such as: Responsible building materials, construction, demolition of waste, responsible sourcing of materials, insulation, design for durability, material efficiency, hard landscaping and boundary protection. sustainable purchasing, sustainable furniture, sustainable food, non-polluting material, design for flexibility, modular flooring system, design for durability, recycling materials , waste management, regional material, responsible sourcing materials, recycled materials.

The research recommends adopting such solutions as:

Life cycle impact, sustainable products, Life cycle impact, sustainable policy, solid waste policy, reduction mercury lamps, design material reduction, design for disassembly, building reuse, material reuse, regional material, rapidly renewable material, reused certified timber, and improve operation waste management, organic waste management, material reuse, LCA.

5. Indoor environment

The research recommends keeping and increasing their applied solutions in material: Indoor air quality, acoustic comfort, lighting comfort, visual comfort, indoor pollutants, and thermal comfort, best management practice, control lighting, daylight view, sustainable cleaning equipment, chemical control, ventilation quality, materials emissions, indoor air quality, thermal zone, views, day light, noise control, and secure environment.

The research recommends adopting solutions such as:

Environmental tobacco control, green cleaning, occupant comfort, thermal comfort control, and thermal comfort modeling.

1. The research strongly recommends applying the common categories shared by the five global systems in the research method of assessment, which are sustainable site, indoor environment quality, energy efficiency, water efficiency and building material.
2. The research recommends adding additional categories like educational value in learning green star certified professional, LEED certified design, by having workshops or continuous educational courses in specific assessment methods.
3. The research recommends adding suitable categories to their local environment. Solutions are not applied for its high expensive solutions like energy efficient transportation system. It is very important to study their local environmental, special, technological conditions in the local environment in Greater Khartoum and apply economical solutions suitable to local environmental, social and economic value.

The research method of assessment studied the conditions of Greater Khartoum in chapter three and added three categories suitable to local environmental, social and economic conditions, detailed by the passive solutions can be applied in their houses, which are; building form, outdoor environment and sustainable design process to add educational value.

Appendix-9

Human thermal comfort and Building thermal comfort

Figure 26.6shows the six factors affecting thermal comfort are both environmental and personal. These factors may be independent of each other but together they contribute to human thermal comfort.

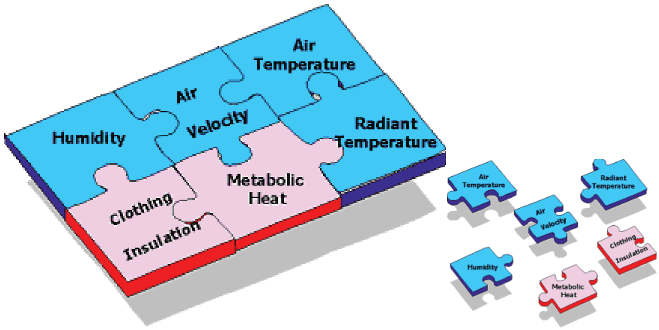

Figure 26: The six basic factors of thermal comfort (Comfort, 2005).

9.1 Air temperature

"Air temperature is a measurement of the warmth or coldness of an object or substance with reference to some standard value. The temperature of two systems is the same when the systems are in thermal equilibrium" (Szokolay, 2004). Air temperature that is surrounding the body is usually given in degrees Celsius (°C) or degrees Fahrenheit (°F).

(°C) = (°F-32) x 5/9

(˚F)= (˚C x 9/5) + 32 (Chemicprograms, 2016).

9.2 Radiant temperature

"Radiation heat transfer is proportional to the difference of the 4th power of absolute temperatures of the emitting and receiving surfaces and depends on their surface qualities" (Szokolay, 2004).

Our skin absorbs almost as much radiant energy as a matt black object, although this may be reduced by wearing reflective clothing. Examples of radiant heat sources include the sun, fires, electric fires, furnaces, steamrollers, ovens, walls of kilns, cookers, dryers, hot surfaces and machineries.

9.3 Air velocity

"*Volume flow rate through an opening of area A, velocity v, mass flow rate mt, and volume flow V,*

Air flow=*V* x *A* m^3/s *or L/s"* (Szokolay, 2004).

Natural air flow is caused by pressure difference: it will flow from a higher pressure zone to a lower pressure zone. Air velocity is an important factor in thermal comfort because people are sensitive to still or stagnant air. Opening windows for cross ventilation increase air to penetrate inside buildings.

9.4 Humidity

Comfort (2005) defined relative humidity as *''the ratio between the actual amount of water vapour in the air and the maximum amount of water vapour that the air can hold'*.

In Greater Khartoum's hot-dry climate, the humidity in autumn is about 30% and in summer it is about 15%.

9.4.1 Personal factors

9..4.2 Clothing

The nature of a person's clothes affect thermal comfort; heavy clothes make the person feel too hot in hot climates such as Sudan. Therefore, in Greater Khartoum where the weather is dry and hot most of the year and especially so in summer, people wear cotton clothes of light colours. The clothes are mainly white in colour to reflect sun's radiation, and cotton to absorb sweat.

9.5 Metabolic heat

A change in stored heat within a human can be caused by metabolic heat production, net radiation exchange, convection, conduction to the surface or surrounding air. Metabolic heat production is calculated from the body's oxygen consumption. The body temperature rhythm (1.6 kJ), corresponds to less than 1 % of the total daily energy budget (172 kJ) in a human. It is likely that the daily oscillation in heat balance has a very slow effect on body temperature (Labratory, 2003).

9.6 Human thermal balance and comfort

Szokolay (2004) stated that the human body continuously produces heat by its metabolic processes. The heat output of an average body often recorded could vary from about 70W (during sleep) to over 700W during heavy work or vigorous activity (e.g. playing squash). This heat is dissipated to the environment. The deep-body temperature is normally about 37˚C, whilst the skin temperature can vary between 31˚C and 34˚C. Fig. 27 shows heat exchanges of the human body; the body's thermal balance could be expressed as,

$M \pm Rd \pm CV \pm Cd - Ev = S$ (1)

Where, M = metabolic heat production, Rd = net radiation exchange, CV = convection (incl. respiration), Cd = conduction, Ev = evaporation (including respiration), and S = change in stored heat for human.

A condition of equilibrium is reached when the sum (S) is zero, and such equilibrium is a precondition for thermal comfort.

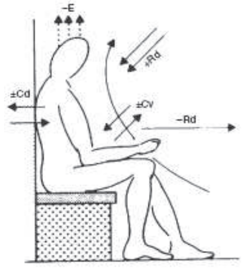

Figure 27: Heat exchanges of the human body (Szokolay, 2004).

This equation is important when studing the building thermal balance with human thermal balance to provide a comfort zone.

9.7 Thermal behaviour of buildings

In addition, Szokolay (2004) mentioned that a building could be considered as a thermal system, with a series of heat inputs and outputs (analogous to Eq. (1) for the human body). The system could be depicted by the following equation:

Qi + QC + Qs + Qv + Qe = S (2),

Where,

Qi – internal heat gain, QC – conduction heat gain or loss, Qs – Solar heat gain. Qv – ventilation heat gain or loss, Qe – evaporative heat loss, and S – the change in heat stored in the building.

Thermal balance exists, when the sum of all heat flow terms, S is zero**.** If the sum is greater than zero, the temperature inside the building is increasing; and if it is less than zero, the building is cooling down. The system could be analysed assuming steady-state conditions.

9.8 Olgyay's building bioclimatic chart

Olgyay's bioclimatic chart, as shown in Fig. 28, was one of the first attempts at an environmentally conscious building design. It had been developed in the 1950s to incorporate the outdoor climate into building designs. The chart indicates the zones of human comfort in relation to ambient temperature and humidity, mean radiant temperature (MRT), wind velocity, solar radiation and evaporative cooling. On the chart, dry bulb temperature is the ordinate and relative humidity in the abscissa. The comfort zone is in the centre, with winter and summer ranges indicated separately (taking seasonal adaptation into account).

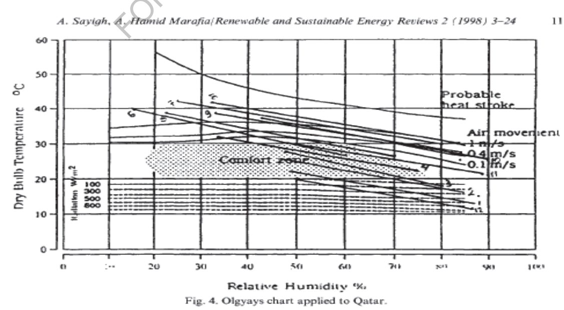

Figure 28: Olgyay chart applied to Qatar (Gallo, 1998)

Appendix-10

10.1 RESIDENTIAL ASPECTS

10.1.1 Historical background on housing conditions

Nagieb (2004) gave a historical background of the Sudanese cities and villages; and found them to be characterized by homogeneous and big residential plots due to the nature of the family sizes, the strong family ties and the extended family characteristics of the Sudanese society.

I. In 1906, through the division of housing lands, preference was given to government officials and high-income people to live in Khartoum town. In 1924, the concept of 'Native Lodging Areas' was introduced to urban workers. This happened as a result of the expansion of Khartoum. The towns and lands scheme act was also introduced.

II. In 1947, the housing areas were enforced to be divided into three classes, differentiated by plot size, building material and lease duration: first (800 m^2), second (400 m^2) and third class (300 m^2). Nagieb (2004)

III. In 1960s, the need for more urban areas and the desire to use modern building materials (concrete, bricks and cement) resulted in a reduction of the plot sizes by an average of 25% for all classes. The plot sizes were 400, 300, 200 and 400 m^2 for the first, second, third and fourth classes respectively until 1997. See table 25

IV. From 1997 to 2015, names of some areas in Greater Khartoum are El Taief, Kafuri, Al Rouda, Al Sahafa Middle, Al Shabia and Omdurman, then illegal scattered around Khartoum, Omdurman and Khartoum North. The distribution land plot sizes are 500 m^2, 400 m^2, 300 m^2 in 2016 see table 26

Table 26. Building standards and areas for different land classes.

Land Class	Min. Plot Area m^2	Minimum standards of building materials	Maximum built area	Width of roads
First	400	Red bricks Stone, cement mortar.	Two third of plot	10-40
Second	300		Two third of plot	10-40
Third	200		Two third of plot	10-40
Fourth	400			10-20

Source: Hassan (1995), page 84 and Doxiadis-Mustafa (1991), page 78.

The last distribution of land was in Al Khogalab area in North Khartoum, according to level of income, the area location, planning vision and theory of planning, as shown in Table 27.

Table 27. Areas of different land classes.

Land class	Min. plot area m^2	According to:
First	500 m^2 and above	Level of income
Second	400 m^2 and above, up to 500m^2	Area location
Third	300 m^2 to 350 m^2	Urban vision and planning theory.

Source: The Ministry of Housing and Urban Planning (2016).

The following paragraphs show the problems, which face the residential buildings in Greater Khartoum.

10.1.2 Growth of housing demand

The rate of acceleration of the demographic growth is directly proportional to the housing demand.

(i) In 1931, the population of the capital increased to more than 200,000 from a bit less than 80,000 inhabitants in 1906. In addition, by the time of independence; 1956, the total population of the three towns was about a quarter of a million. Mazari (1966) indicated that this Figure rose within one year to more than 400,000 (Mazari, 1966, Table a, p. 8).
(Osman, A., 1996)

(ii) In the next seven years, the population's growth went at an annual rate of 3.7%. It became 610,000 inhabitants in 1972. Demand for housing rose to 34,000 units, whereas only 17,378 plots were distributed (Abdul Rahim, 1987, p. 9).

(iii) In addition to that, colonial control on the population's movement led to the increase of its population at a rate of 6% annually, whereby it reached 784,300 in 1973/74 (Abdul Rahim, 1987, p. 6).

(iv) This trend accelerated in the next decade due to increased disparities, environmental and political problems in the West and South. The population growth rate of the capital reached 7.8% in 1973.

(v) In 1975/76, the population was 877,030 people. Provisional results of 1983 census estimated a figure of 1,547,200 with an increase of 76% in one decade.

(vi) Later, estimations as announced by the Governor of Khartoum in Al Ayam daily on 25/05/1988 had been 4 to 4.5 million in 1988. Whether that was a true fact or not, the population explosion could be recognized

(vii) In 2008 the population of Khartoum city was nearly 6.5 million, and the distribution plots 24.8%.

It could be seen that the recent increase in demand for housing in Greater Khartoum has led the Ministry of Housing and Urban Planning to offer many new areas and distribute plots for people in different sectors. It is essential to consider ecological buildings for a sustainable future.

10.1.3 Increasing migration towards Khartoum City

Migration contributed mostly to this increase in the capital's population. For example, in 1973 migration contributed 5.6%; however, ten years later it contributed 60% to 70% of the increase (El Sarnmni, 1986). The origins of migration were changing; the Northern Province according to 1955/56 census contributed 17.2%, Khartoum Province 9.97%, the Blue Nile Province 6% and Kordofan 5.4 %. Later, there were indications that Kordofan and Darfur became the main sources of migration starting from the mid-sixties and following the October 1964 popular up rise and the fall of the first military dictatorship. Abdul Rahim (1987, p.7), Osman, A., (1996) and El Kheir, O., (1990) wrote about migration towards Khartoum city. In my opinion, migration continued to increase from South, West and East towards Khartoum city for work and settlement. The migration towards Khartoum city is expected to be minimize by 50% after the referendum that splited the North from the South on 9 July 2011.

10.1.4 Lack of Services

Associated with the concentration of population - such needs for social, cultural and commercial facilities grew. In many cases, these were met by directly converting existing houses into office buildings, private clinics, sport and social clubs, and so on. This problem still prevails all over the big cities, and my personal experience may stand as a living example in Khogalab neighbourhood, north of Khartoum, a location lacking all services. Modern urban planners should follow certain procedures in planning and providing services, when allotting housing plots to the public.

Hamid (2010) presented a seminar about the incremental housing in Khartoum. A paradigm shift showed that the site and services started in post-colonial period (1956-1960) with the development of 98.7% of the 11,807 distributed plots, and ended in 2007 with the development of 34.3% of the 197,375 distributed plots. These figures clearly prove the poor availability or rather lack of services.

10.1.5 The current urban masterplan

The Ministry of Urban Planning started implementing the Khartoum Structure plan (KPP5, 2006). The core objectives of KPP5 are derived from the concurrence of current, inherited and accumulated spatial issues, as well as the vision for the future. The urban and regional logic of development are not necessarily incompatible. Expressed in a clear statement this would mean the alleviation of shortages at present, and the satisfaction of the needs for the future in close coordination to sectoral developments and spatial location allocations. A timeline of 25 years is set for KPP5, divided into five year phases with 2008 as the base year of the plan. The plan considers national level influences on Khartoum, adjacent state interactions, the regional setting of the Khartoum state, its rural territory and the agglomeration of Khartoum's urban area; and for all levels a set of action areas pre-requisite for the future development of Khartoum, national and regional levels are two components expressed in planning information systems. Methods, regional definitions, land use and settlements, population, economic activities, basic services, environment, roads, transports, housing, governance and finance. The KPP5 action plan will continue until 2033 with the main aims to achieve. In addressing current issues and expected future developments of Khartoum, KPP5 acquired a number of characteristic features:

(i) *"Wider territorial levels which affect and are affected by Khartoum are considered in the formulation of the plan.*

(ii) *A comprehensive structure of the development sectors and the territorial settings.*
(iii) *A clean environmental orientation.*
(iv) *A coordinated set of interventions covering mainly rehabilitation, relocation, re-use and restructuring.*
(v) *A set of extensive scenarios of spatial nature.*
A set of projects for each phase of the plan for all components including budgetary costs, potential financing sources and executing agencies" (Planning, 2014).

Figure 24 shows the historical background of the growth of Greater Khartoum from 1920 to 1981.

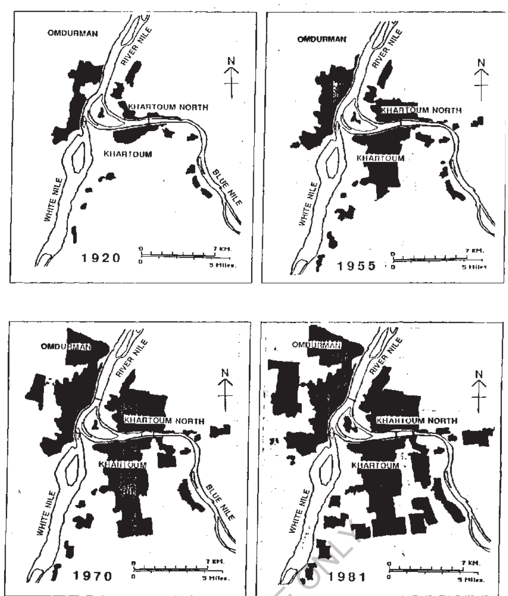

Figure 29: Historical background showing the growth of Greater Khartoum from 1920 to 1981(El Kheir, 1990).

Figure 29 shows the expansion of the three towns, Khartoum, Khartoum North and Omdurman, until 2014 because of the improvements implemented by KPP (Planning, 2014).

Figure 30: Greater Khartoum image showing the expansion of the three towns, Khartoum, Khartoum North and Omdurman until 2014 the improvement in KPP (Planning, 2014).

A satellite image (Fig. 30) shows an updated extension of Greater Khartoum in the three towns Khartoum, Khartoum North and Omdurman.

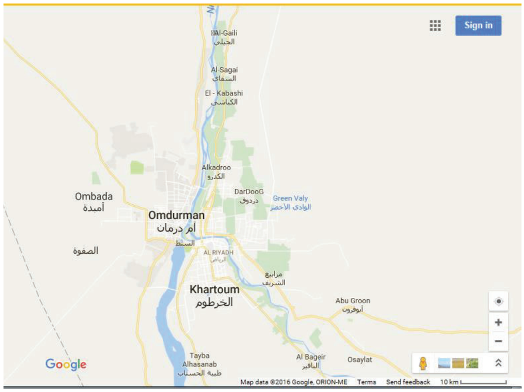

Figure 31: Greater Khartoum Satellite image showing the extent of the three towns, Khartoum, Khartoum North and Omdurman until 2016 (Map, 2016).

10.2 ARCHITECTURAL AND BUILDING ASPECTS

10.2.1 Orientation

Most Khartoum buildings are oriented towards the East-West direction to facilitate natural ventilation into the building. The direction of the wind is North- West in winter and South -East in summer (Hassan, 1995).

10.2.2 Ventilation

Most Greater Khartoum buildings have good ventilation through large windows as designed and installed in the North direction as well as the South direction, and this provides cross ventilation through the building spatial voids and spaces like bedrooms and living areas.

10.2.3 Residential aspect

The residential areas are spread over the three towns in varying densities; that is in Khartoum the capital of Sudan, Khartoum North and Omdurman cities, where most of the residential development process has become a characterizing phenomenon. It also prevails in illegal settlement areas.

10.2.4 Building form

It is noted that most of the buildings in Greater Khartoum use the cubical forms and the rectangular plan shapes, very few use other forms. Researcher survey and practice experience.

10.2.5 Structure methods

The residential buildings in Greater Khartoum were built from different types of building materials and constructions; some of them use concrete skeletons, while others use load-bearing systems.

10.2.6 The outdoor Environment

In my opinion, the Sudanese people have a great tendency towards the outdoor environment. In the first and second classes, most of the plot area is specified for gardens, for providing space for events celebrations and for sitting in the afternoons and evenings. The researcher found that the third-class residential areas that have limited plot areas of about 300 m^2 to 350 m^2 utilize most of the land for building, in spite of the fact that people still have a tendency towards the outdoor environment. They have also fenced a part of the street pavement and converted it into small gardens.

10.3 TECHNOLOGICAL ASPECTS

10.3.1 Building material

Mud is a good example for ecological building material; it is cool, has a good time lag, low cost, and with little embodied energy. However, it has low life cycle; Therefore, the construction techniques should be improved. Sidiq (1996) and Ali (2010) have discussed this issue.

Elhaj (2012) stated that a perceived urgency to use modern construction techniques are estimated to have increased by eight times over a period of 5 years, and the imports of heavy construction equipment increased by 7% over the same period. Moreover, the local construction product sector has expanded, with more cement, concrete and steel/metal fabrication businesses established over the last 10 years.

All this can have a considerable effect on the environmental impacts associated with the Sudanese construction sector. Table 28 shows some of the available building materials in Greater Khartoum. Additionally, UN-HABITAT (2009) discussed the experiment of using interlocking stabilized soil block in Africa, which are prepared through the United Nation’s settlement programme.

In Greater Khartoum, people use ecological building materials; they use concrete, burnt bricks, cement hollow blocks and thermal hollow blocks. We also found clay and bricks in suburb areas. Al Goni (2007) presented a seminar at the Future University in Khartoum about the use of Stabilized Earth bricks in new smart house buildings in Sudan. In addition, blocks are produced from a sandy soil with clay (www.Hydraform.com, 2014). Hansen (2011) discussed the importance of using ecological building materials that are available in the local environment.

Table 28. Shows the eco building materials at Greater Khartoum and their time lags.

Building material	Thickness (cm)	Time Lag (Hours)
Natural stone	20	5.5
	30	8
	40	10.5
	60	15.5
	30	7.8
	40	10.2
Burnt Brick	10	2.3
	20	5.5
	30	8.5
	40	12.0
Wood	1.25	0.17
	2.5	0.45
	5	1.3
Thermal Isolated panel	1.25	0.08
	2.5	0.23
	10	0.77

	15	2.7
Concrete	5	1.1
	10	2.5
	15	3.8
	20	5.1

Source: Mohamed (2003).

10.3.2 The use of smart applications

ABB (2010) presented a paper about smart homes and intelligent building controls. This system encourages people to improve their attitudes and behaviour in using energy at home by using new technologies that use a central unit to control energy. The control unit controls each space in blinds, light heating, security, energy and consumption management and scene. Aoun (2011) discussed how we can increase the comfort for users by smart light controls for each room. Tahadronics (2014) mentioned that proper control of HVAC systems provide energy efficiency and keeps energy consumptions low. In addition, Al Rashood (2012) discussed the Eco Structure programme in Saudi Green Building Forum in 2012; it is efficient, reliable, safe, green and widely used in buildings to provide energy efficiency in controlling: HVAC systems, lighting control, access control, video control, electrical distribution systems, energy monitoring, motor control, critical power and IT data. Additionally, Nazal (2012) discussed the importance of energy efficiency in green building and construction, and stated measures to increase energy efficiency. Crawley (2011) mentioned the application of energy plus systems in housing sectors. Eicker (2009) discussed the use of simulations on energy efficiency programmes.

All the above smart solutions are suggested to improve the indoor thermal comfort. They are applied to eco buildings according to client requests and implementation possibility. From the author’s practical experience and survey, in Greater Khartoum, some of these solutions are found in Araak city residential villas and apartments, presidential villas, and some residential villas in first class areas. An example is the use of split units with smart applications that minimize the electricity consumption, are those units having filters that clean the air from dust and use smart screens that ease controlling the air temperature, air humidity, lighting and curtains in indoor environment.

Appendix-11

Global sustainable assessment methods

11.1 Leadership in Energy and Environmental Design (LEED)

LEED is an internationally recognized green building certification system. Developed by the U.S. Green Building Council (USGBC) in March 2000, LEED provides building owners and operators with a framework for identifying and implementing practical and measurable green building designs, constructions, operations and maintenance solutions (Council, 2014). Table 28 shows the main categories of LEED V4 system.

Table 29. The LEED V4

Main categories	Points	Range of points	Certificate
Sustainable Site	26	40-49 points	Certified
Indoor Environmental Quality	15	50-59 points,	Silver:
Water efficiency	14	60-79 points,	Gold
Energy and atmosphere	35	80-110 Points and above	Platinum
Material	10		
Innovation	6		
Regional priority	4		
Total points	110		

Source: usgbc.org (LEED).

The positive point of LEED is that it has been developed since 2000 through to 2013 and has been reviewed four times, where we now find LEED 2009, LEED V3 and LEED V4. The LEED process is developed from time to time with announcements made on the USGBC.org for members who are interested to share their experience. The development process takes about six months from review 1, review 2 through to review 3. They listen to experts, professionals and users views towards improvement of the negative notes into possible positive issues. In LEED v3 the sustainable site increased from 14 points to 26 points, more challenges were added, like development density and community connectivity (5 points), alternative transportation (12 points max), storm water design (2 points max) and site development (up to 2 points). In water efficiency, they increased water use reduction from 5 points to 10 points; they added water efficient landscaping (5 points max), innovation wastewater technologies up to 2 points. In energy the total points increased from 17 points to 35 points; the main focus was on optimizing energy performance (19 points max), on site renewable energy (7 points max), enhance refrigerant management (2 points), measurement and verification (3 points max) and green power (2 points). In materials the total points increased from 13 points to 14 points; they increased the points on material reuse from 1 point to 2 points. The total points on indoor environmental quality remained the same at 15 points. Innovation increased from 5 points to 6 points.

Haselbach (2008) presented an introduction to sustainable construction and discussed the LEED system and its principles. Council (1996) discussed the main issues of environmentally sustainable development.

In addition, LEED released V4 in July 2013

. Malin (2013) discussed in their report the new concepts in LEED V4 and stated that LEED V4 added integrative design processes. LEED V4 added rainwater management in sustainable site category and provided reduction in light pollution. In addition, it added building envelop commissioning, green power and carbon offsets. They also

added building life assessment, biomass raw materials, response to Mining, Health product, Measuring of VOCs. In the indoor environment, special day light autonomy and acoustic performance were added. LEED V4 was finalized after the fifth public comments through the period from fall 2012 to fall 2013.
From the above analysis, we can conclude that the rating system is a developing system. LEED was developed from 2000 to 2017 and they announced four versions during that period. These improvements depend on the best practices from users and experts. In each version, we have more challenges, and the total points are increased to achieve a higher certification standard. It also contains sub issues that help in managing a certain local and global problem; an example of local problems is the design of storm water within the sustainable site category; and examples for global problems that have an effect on the local environment are heat island effect, smoke control, and energy performance optimization.

11.2 The environmental assessment methods (BREEAM)

BREEAM is the world's foremost environmental assessment method and the rating system for buildings in UK. BREEAM was one of the 10 global building rating systems published in a paper by Science (2009), was created in 1990 for the UK building market and is administered by the BRE Global Sustainability Board, which oversees BRE Global guides, publications, standards and certification programs (BREEAM, 2014). BREEAM has the following goals: understanding and mitigating the impacts of buildings on the environment; enable buildings to be recognized according to their environmental benefits; provide a credible, environmental label for buildings; stimulate demand for sustainable buildings (BREEAM, 2014).
In addition, BREEAM has four assessment tools that can be used at different stages of a building's life cycle. BREEAM Design and Procurement (D&P) can be used during the designing stage of a building renovation or for a new building or extension project. The Post Construction Review (PCR) is carried out once the construction is complete to verify the D&P assessment. The Fit Out assessment is employed during major renovations of existing buildings and a Management and Operation (M&O) assessment evaluates the performance of a building during its operation (Saunders 2008).

BREEAM method of assessment: BREEAM schemes award credits for each section, which are then summed and weighted according to the section weight. Credits are awarded in 10 categories for meeting a series of performance criteria that, if complied with, would reduce the building's negative environmental impact and increase its environmental benefits. The total number of credits awarded is 114 points in each category is multiplied by an environmental weighting factor The category scores are then added together to produce a single overall score on a scale of Pass, Good, Very Good, Excellent and Outstanding. A star rating from 1 to 5 also is provided (Saunders, 2008).

Energy, Management, site management and procurement, health and well-being: indoor, transport, Water, Materials, Waste, Land Use, Pollution and Ecology. Table 30 shows BREEAM weight system and certificate levels.

Table 30. BREEAM Weight system and certificate level

Main categories	Weighing	points	Points range	Certificate
Management	12%	10	<30	Unclassified
Health and wellbeing	15%	16	25-<40	Pass
Energy	15%	18	40-55	Good
transportation	9 %	12	55-75	V. Good
water	7%	9	>70	Excellent
Material	13.5%	14	>85	Outstanding
Land ecology	10%	10		
pollution	15%	13		
Waste	8.5%	9		
Pollution	10%	16		
Innovation	10%	10		
Total		144		

Source: (Fower, 2006)

The positive for BREEAM is providing a program to address the environmental impact of buildings lies in better management and improvement of the existing building stock. BREEAM In-Use is a scheme to help building managers reduce the running costs and improve the environmental performance of existing buildings. The main goals of this program are as follows; reduce operational costs; enhance the value and marketability of property assets; give a transparent platform for negotiating building improvements with landlords and owners; provide a route to comply compliance with environmental legislation and standards; give greater concern and engage with staff in implementing sustainable business practices; provide opportunities to improve staff satisfaction with the working environment and increase the potential for significant improvements in productivity. BREEAM is developed by clients, planners, development agencies, funders and developers (BREEAM, 2014).

11.3 Green Star Rating System of the Green Building Council of Australia.

Green Star is a comprehensive, national, voluntary environmental rating scheme that evaluates the environmental design and achievements of buildings. It started in 2002 and is developed by the Green Building Council of Australia. Their aims are: to establish a common understanding; to set a standard for measuring sustainability of green buildings; promote integrated whole-building design; recognize environmental leadership; identify building life-cycle impacts; and raise awareness of green building benefits. Green Star covers a number of categories that assess the environmental impact as a direct consequence of a project's site selection, design, construction and maintenance. The Green Star Rating System of Australia announced the following schemes: Green Star Multi Unit Residential V1, Green Star Healthcare V1, Green Star Retail Centre V1, Green Star Education V1, and Green Star Office Design V2 and V3. The nine categories included within all Green Star rating tools are: management, indoor environment (BREEAM, 2014) energy, transport, water, materials, land use, ecology, emissions and innovation (Australia, 2013). Table 31 shows the Australian Green Star rating system and points for each category.

Table 31. Green Star rating system points for each category

The main categories	No. of points	Star system	Range of points

Management	**10**	**One star**	**10 - 19 pts**
Indoor Environment	**20**	**Two star**	**20 - 29 pts**
Energy	**30**	**Three star**	**30 - 44 pts**
Transport	**10**	**Four star**	**45 - 59 pts Best Practice**
Water	**10**	**Five star**	**60 - 74 pts Australian Excellence**
Materials	**15**	**Six star**	**75+ pts World Leader,**
Land Ecology	**8**		
Innovation	**10**		

Source: Green Star (2008).

Green Star rating system assessment method: A GBCA case manager is assigned to support the project team through the assessment process. Once the applicant signs the necessary agreements, the project team submits appropriate documentation for the first round. If unsuccessful, the submission is returned with guidance on what needs to be done before resubmission. If the review is successful, an assessment panel will be convened. Projects that are awarded one to three stars may not be certified, but those awarded with four or more stars may be certified and are recognized as follows :

(i) 4 Star Green Star Certified Rating (score of 54 to 59) - Best Practice

(ii) 5 Star Green Star Certified Rating (score of 60 to 74) - Australian Excellence

(iii) 6 Star Green Star Certified Rating (score of 75 to 100) - World Leadership (GBCA. 2009)

Each rating tool includes a number of credits in nine categories. Within the credits, points may be awarded for each credit criteria. The nine categories include management, energy, indoor environmental quality, transport, water, materials, land use and ecology, emissions and innovation. Each rating tool also applies environmental weightings for each of these categories as may be appropriate for that tool or a particular geographic area(s) (GBCA, 2009; Australia, 2013).

11.4 REGIONALLY

11.4.1 Qatar Global Sustainability Assessment System (GSAS)

The Global Sustainability Assessment System (GSAS) is the first of its kind, performance-based sustainability rating system in the MENA region that started in 2007. It is developed by the Gulf Organization for R&D in collaboration with T.C. Chan Centre at the University of Pennsylvania – USA. The assessment system aims at creating a sustainable urban environment to reduce environmental impacts while satisfying local community needs. *The aims of GSAS rating system*: First, the environmental benefits, which include the enhancement and conservation of flora/fauna, biodiversity and ecosystems; conservation and restoration of natural and non-renewable resources; improvement of air, land and water quality; increase of energy efficiency while reducing greenhouse gas emissions; and reduction of waste production. Second, the economic benefits, which consist of reductions in operating and maintenance costs; creation of new opportunities and markets for green products and services; and improvement in occupant productivity, faster occupancy rates and lower turnover rates. Third, the social benefits, which include enhancement of human comfort and health; reduction in strain on local infrastructure; improvement of life quality; and preservation of cultural identity.

GSAS method of assessment: The criteria of GSAS are divided into eight categories (different weights), each with a direct impact on environmental stress mitigation and measures a different aspect of the project's environmental impact. The main categories are: Urban community, site, energy, water, materials, indoor environmental quality, culture and economic value and management operation. At present, there are thousands of buildings which are designed in accordance with this system. Table 32 shows GSAS main categories and the total weight for each category.

Table 32. GSAS main categories, the total weight for each category and the score system.

The main categories	GSAS total weight:	Cumulative Score (X)	GSAS Star Rating (★)
Urban community	0.24	0.00≤X≤0.50	★
Site	0.27	0.50<X≤1.00	★★
Energy	0.72	1.00<X≤1.50	★★★
Water	0.48	1.50<X≤2.00	★★★★
Material	0.24	2.00<X≤2.50	★★★★★
Indoor Environmental Quality	0.42	2.50<X≤3.00	★★★★★★
Culture and economic value	0.39		
Management and operation	0.24		

Source: Alhor (2009).

Diar (2010) noted that the vital role played by the NGOs is to encourage organizations to act sustainably and raise awareness of green issues in Qater. The positive for GSAS is that it allows complete flexibility in future

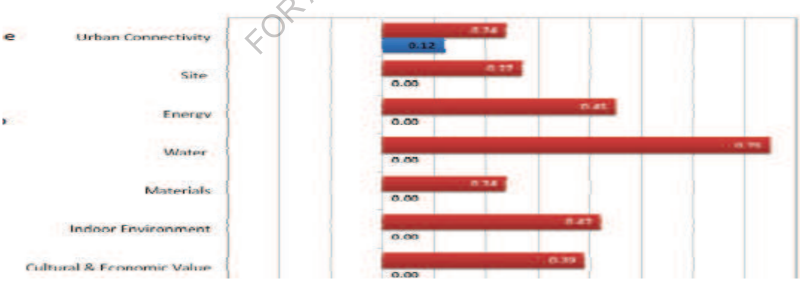

Fig. 32: Shows GSAS main categories and its weighing system

expansions and modifications, as well as for the seamless integration between Qatar specific requirements and sustainable goals. The system takes advantage of the best features of the rating systems available worldwide with a focus on the needs and impacts on Qatar and the surrounding regions. The GSAS rating system is applicable to all building types and projects. Alhorr (2014) presented a workshop about the deployment of GSAS in GCC construction; industry challenges and opportunities to apply GSAS regionally. He stated that GSAS started by studying 40 global rating systems and focused on the basic study of six systems, which helped in developing their own local system.

11.4.2 ESTIDAMA Environmental Assessment System

ESTIDAMA, which is the Arabic term for sustainability, was established in 2008 by The Abu Dhabi Urban Planning Council (UPC); announcing ESTIDAMA V1 in 2010. It is recognized internationally for large-scale sustainable urban planning and rapid growth. promoting thoughtful and responsible development while creating a balanced society on four equal pillars of sustainability: environmental, economic, social, and cultural. 4

The goal of ESTIDAMA is to preserve and enrich Abu Dhabi's physical and cultural identity, while creating an always improving quality of life for its residents focusing on the rapidly changing built environment. All new projects must achieve a minimum 1 Pearl rating to receive approval from the planning and permitting authorities. Government funded buildings must achieve a minimum 2 Pearl rating.

ESTIDAMA *Method of assessment:* ESTIDAMA has the Pearl Rating system that is also a point-based system, awarding project points for different credits that are grouped under a number of general categories. Points are added up to a final rating which ranges from one pearl to five pearls system. The pearl process passes through four stages: pearl design, pearl construction and the pearls operational system. Table 33 shows ESTIDAMA's main categories and the total points of each main category.

Table 33. ESTIDAMA main categories and the total points of each main category

ESTIDAMA	Points	Points range	certificate
Integrated Development Process	13	All mandatory credits	1 Pearl
Natural Systems	12	All mandatory credits + 60 credit points	2 Pearl
Livable Communities	37	All mandatory credits + 85credit points	3 Pearl
Precious Water	43	All mandatory credits + 115 credit points	4 Pearl
Resourceful Energy	44	All mandatory credits + 140 credit points	5 Pearl
Stewarding Materials	28		
Innovating Practice	3		
Total	**177**		

Source: Abu Dhabi Urban Planning Council (2010).

The positive point is ESTIDAMA itself is a part plan of Abu Dhabi 2030 that encourages sustainable growth, protection of the natural environment of the sensitive coastal and desert ecologies (Council, 2010).

11.4.3 Saudi Green Building Forum (SGBF)

Saudi Green Buildings forum (SGBF) started on 05/10/2010. The Saudi Green forum's workshops, conferences and exhibitions emerged from the initiative lead by Faisal Al Fadal. Partners and the private sector were permitted to hold conferences, in accordance with the royal instruction given to the high commissioner and the approval of the Ministry of Commerce and Industry (SGBF, 2010).

The aims of SGBF are to facilitate the exchange of ideas, scientific production technologies and professional interests in the field of the forum between institutions and relevant bodies within and outside the Kingdom; to contribute to the development of standards of practice and professional projects in relevant disciplines; to participate in monitoring their performance and maintenance; to contribute to raising the level of among the public.

The method of SGBF main categories of SGBF are: development site, transportations, atmosphere, indoor environmental quality, living environmental quality, water, energy, material, innovation and culture. SGBF uses points for evaluation (King Fahad Universit)