Chapter

Green Building Rating Systems as Sustainability Assessment Tools: Case Study Analysis

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Abstract

Building performance and occupants' comfort lie at the core of building design targets. Principles of green architecture and building physics are not given enough thought and consideration. In the best cases, some thought is given to such factors but without a scientific methodology, which takes into consideration appropriate climatic data and appropriate assessment tools. Most importantly, the interference of the environmentalist in architecture projects comes usually very late in the design processes. Facing these facts has driven most countries to adopt official strategies and policies to deal with building's performance. The rating systems are among these initiatives. The author of this chapter adapts a detailed methodology to aid the integration of the principles of the green architecture in the early stages of design using rating systems. The Leadership in Energy and Environmental Design (LEED) 1 that was developed in the USA by the U.S. Green Building Council (USGBC) for Core and Shell has been employed as the main design target. This chapter presents a brief about the world green initiatives and discusses the results of applying the methodology of integrating the green architectural principles at the early stages of design processes—through precedent analysis.

Keywords: rating system, LEED, sustainability targets, computer simulation, post occupancy evaluation

1. Introduction

More than half of the world's population lives in cities; in 2050 the people living in urban areas are expected to increase up to 70% [1]. Cities are the major reasons of pollution; it produces 60% of carbon dioxide and greenhouse gas emissions, through using energy generations, industry, vehicles, and biomass use. Therefore, now climate change is challenging cities to reduce their impacts and adjust to changing condition [2]. Therefore, the increasing demand towards sustainability is pushing toward rapid changes in policies, laws, and regulations around the world regarding products and processes to encourage more sustainable projects [3]. Also, sustainability solves the local issues of communities in innovative progress, for implementing sustainability is different for every community, but they share common goals for a healthy environment, smart growth, and human well-being [4]. Consideration to sustainability principles in building industry is vital for natural environment and human being. Adopting passive strategies and measures that respond to and achieve the responsive design lies directly under the responsibility of architectural designers [5]. Green architecture principles and science are usually not given enough thought and consideration. Factors such site characteristics, climate, and orientation, environmental design of the building, and choice of building materials are being neglected in most cases. In the best cases, some thought is given to such factors but without a scientific methodology that takes into consideration using the appropriate climatic data and the appropriate assessment tools. Consequently, buildings often have a poor indoor environment quality which in turn affects human comfort, health, and efficiency [6, 7]. Most importantly, the interference of the environmentalist in architecture projects comes usually very late in the design processes. Consequently, buildings often have a poor indoor environment quality which in turn affects human comfort, health, and efficiency. Most importantly, the interference of the environmentalist in architecture projects comes usually very late in the design processes. The integration of these green principles in the field at the early stages of the design processes lies at the core of the current research. However, to get the best benefits of these strategies and measures, detailed target identification must be set. Adopting these concepts has driven most countries to adopt official strategies and policies in order to insure appropriate building designs.

2. Sustainability and green buildings initiatives

The application of sustainability is carried out by different stakeholders including academic initiatives, government initiatives, other sector initiatives, in addition to private sector initiatives. Moreover, these initiatives vary in its nature and way of application; some of them are building standards and codes, framework and programs, in addition to rating systems [8].

The standard is a set of guidelines and criteria to assure the quality of the products. Standards related to building industry are created by organizations such as the International Standards Organization (ISO), which defines and develops worldwide standards that frequently become law or form the basis of industry norms. ISO defines a standard as "a document, established by consensus, approved by a recognized body that provides for common and repeated use as rules, guidelines, or characteristics for activities or their results." There are other institutions such as the American National Standards Institute (ANSI), the American Society for Testing and Materials (ASTM), or the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) [8].

Green codes could be classified into two types: prescriptive and performance, with outcome-based as a third option. A prescriptive path is a fast, definitive, and conventional approach to code compliance. It provides tables to quantify certain levels of strictness for materials and equipment. Performance-based codes are designed to achieve certain results, rather than meeting prescribed requirements for individual building elements. Outcome-based codes establish a consumption target for energy, water, etc. One example of the green codes is the International Green Construction Code (IgCC) that provides a comprehensive set of requirements in order to reduce the harmful effects of buildings on the natural environment [8].

Programs and frameworks are database that provide datasets relating to most aspects of sustainability. Examples of such programs and frameworks are the RFCS, CPI, CPDP, and UNEP-SBCI. The reference framework of sustainable cities (RFSC) encourages sustainability and integrated urban development aligned with Europe 2020 guidelines and objectives [9]. The city prosperity initiative (CPI) measures sustainability at the urban level to allow local and central governments to use data [10]. The climate positive development program (CPDP) addresses the challenges of rapid urbanization and climate change [11]. In addition, there is the United Nations Environment Program-Sustainable Building and Climate Initiative (UNEP-SBCI), which is a partnership of major public and private sector stakeholders in the building sector, working to promote sustainable building policies and practices worldwide [12]. The Passivhaus standard was developed in Germany in the early 1990s, and the first dwellings to be completed to the Passivhaus standard were constructed in Darmstadt in 1991 [13].

Rating systems assess the environmental impacts of buildings, constructions, infrastructure, urban-scale project, and community projects. The rating systems designed to assist projects to be more sustainable by providing frameworks with a set of criteria's that cover several aspects of a project's environmental impact [14]. Rating systems utilize the key performance indicators (KPI) to assure high quality of sustainability applications [14]. KPI are employed for building designers and decision-makers to measure the socioeconomic and environmental impacts on environment, infrastructure, waste system, regulations, pollutions, citizen's access to services, and more [15]. The significance of the sustainable design increased in the 1990s. The Building Research Establishment's Environmental Assessment Method (BREEAM) was the first green building rating system in the UK that addressed the required KPIs for better environmental performance of buildings. In 2000, the U.S. Green Building Council (USGBC) developed another rating system, which is the Leadership in Energy and Environmental Design (LEED). Others also responded to the growing interest and demand for sustainable design including additional rating systems that most of them were influenced by these early programs but are tailored to their own context with specific priorities. Other trails for rating systems intended to address broader issues of sustainability or evolving concepts such as social aspects, net zero energy, and living and restorative building concepts. It is estimated that there are nearly 600 green product certifications in the world with nearly 100 in use in the USA, and the numbers continue to grow [16]. Many other rating systems became a great evidence of adapting the sustainability principles in building industry [17, 18]. The rating system is based on four major components [14].

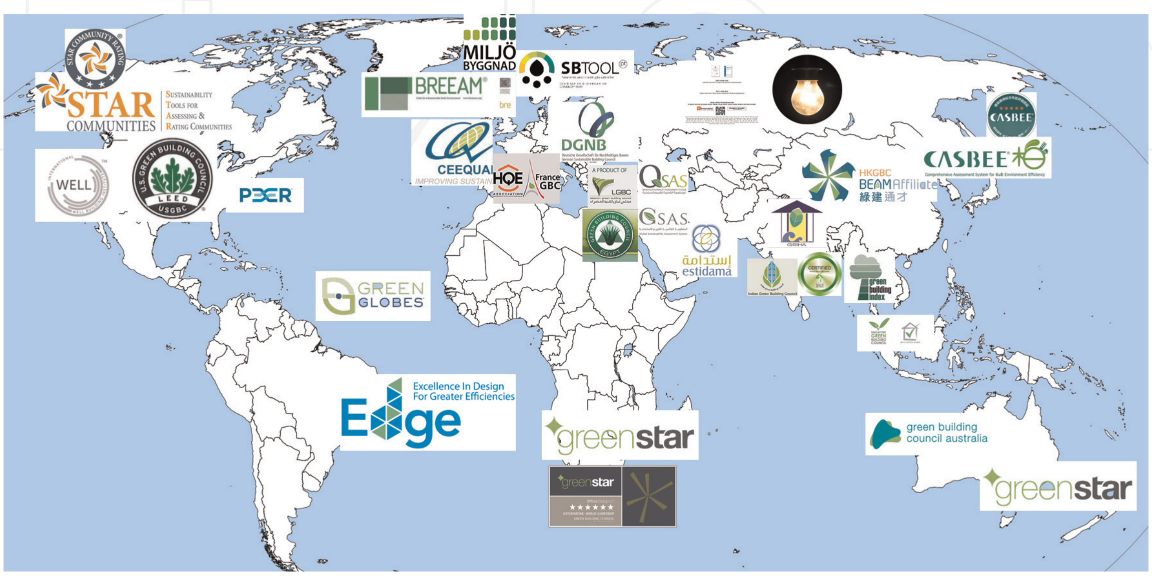

Figure 1.
Common rating assessment systems around the world (by the author).

Tool	Year	Country	Targets	Main categories for buildings	Certification levels	Development basis	Notes and aim
Building Research Establishment Environmental Assessment Method (BREEAM)	1990	UK/International	• Buildings • Interiors • Infrastructure • Master planning projects	Energy and water use Internal environment (health and well-being) Pollution, transport Materials, waste ecology, and Management processes	Pass, Good, Very good, excellent	Original	It is the world's leading sustainability assessment tool to recognize and reflect the value in higher-performing assets across the built environment lifecycle, from new construction to in-use and refurbishment [24] (https://www.breeam.com/)
Leadership in Energy and Environmental Design (LEED)	2000	USA/International	• Buildings • Interiors • Neighborhood development • Cities and communities	Sustainable Sites Water Efficiency Energy and Atmosphere Materials and Resources Indoor Environmental Quality (IEQ) Innovation in Design Regional Priority	Certified, Silver, Gold, Platinum	Original	LEED is available for virtually all building, community, and home project types. LEED provides a framework to create healthy, highly efficient, and cost-saving green buildings. LEED certification is a globally recognized symbol of sustainability achievement [25] (https://new.usgbc.org/leed)
Indian Green Building Council Rating Systems (IGBC Rating Systems)	2001	India	• Buildings • Interiors • Residential Societies • Cities and Communities • Villages • Health and Well-being Rating	Sustainable Architecture and Design, Site Selection, and Planning Water Conservation Energy Efficiency Building Materials and Resources, IEQInnovation and Development	Certified (Best Practices), Silver (Outstanding Performance), Gold (National Excellence), Platinum (Global Leadership)	LEED	All the IGBC rating systems are voluntary, consensus-based, market-driven building programs. The rating systems are a perfect blend of ancient architectural practices and modern technological innovations. The ratings systems are applicable to all five climatic zones of the country [26] (https://igbc.in/igbc/)
Comprehensive Assessment System for Built Environment Efficiency (CASBEE)	2001	Japan	• Buildings • Interiors • Heat Island • Urban Development • Cities	Energy efficiency Resource efficiency Local environment Indoor environment	_S _A _B+ _B _C [14]	Original	CASBEE was developed by a research committee established in 2001 through the collaboration of academia, industry, and national and local governments, which established the Japan Sustainable Building Consortium (JSBC) under

Tool	Year	Country	Targets	Main categories for buildings	Certification levels	Development basis	Notes and aim
			• Health checklist				the auspice of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) [27] [28] (http://www.ibec.or.jp/CASBEE/english/)
Green Globe International Standard for Sustainability	2002	International	• Accommodation and hospitality • Transport and tour operators • Conference venues • Meeting planners • Management and public relations	Energy Indoor Environment Site Water Resources Emissions Project/Environmental Management	Certified, Gold, Platinum	BREEAM	Green Globe provides certification, training and education, and marketing services in 83 countries worldwide for the sustainable operations and management of travel and tourism companies and their related supplier businesses [29] (https://greenglobe.com/)
The Green Star rating system (Green Star)	2002	Australia	• Communities • Buildings • Interiors • Operational Performance	Management processes IEQ Energy, Transport Water, Materials Land Use Ecology Emission, Innovation	Best Practice, Australian Excellence, World Leadership	BREEAM, LEED®	The Green Star rating system assesses the sustainable design, construction and operation of buildings, fit-outs, and communities [30] (https://new.gbca.org.au/green-star/rating-system/)
Performance Excellence in Electricity Renewal (PEER)	2003	US/International	• Power system performance • Electricity delivery systems	Reliability and resiliency Operations, Management and safety Energy efficiency and environment, Grid services Innovation and Exemplary Performance, Regional Priority	Certified, Silver, Gold, Platinum	LEED	PEER is the nation's first rating system that measures and improves power system performance and electricity delivery systems. Developed in a collaboration between the GBCI (Green Business Certification Inc.) and Bob Galvin, formerly of Motorola [31] (http://www.gbci.org/press-kit-peer)

Tool	Year	Country	Targets	Main categories for buildings	Certification levels	Development basis	Notes and aim
BCA Green Mark	2005	Singapore	• Buildings • Interiors • Districts • Infrastructure	Energy efficiency Water efficiency Environmental protection IEQ, and Other green and innovative features that contribute to better building performance	Certified, Gold, Gold Plus, Platinum	Undisclosed	The BCA Green Mark Scheme aims to drive Singapore's construction industry toward more environment-friendly buildings. It is intended to promote sustainability in the built environment and raise environmental awareness among developers, designers, and builders when they start project conceptualization and design, as well as during construction [32] (https://www.bca.gov.sg/green_mark/)
STAR Community Rating System	2007	USA	• Cities and Communities	Built Environment, Climate and Energy, Economy and Jobs, Education, Arts, and Community, Equity and Empowerment, Health and Safety, Natural Systems Innovation and Process	CERTIFIED: 3-STAR Community 4-STAR Community 5-STAR Community	LEED	Assess sustainability and measure progress to enhance the quality of life and human well-being [33] (http://www.starcommunities.org/)
Global Sustainability Assessment System (GSAS)	2007	Qatar	• Buildings • Districts • Infrastructures	Energy Water Indoor Environment Cultural and Economic Value Site Urban Connectivity Material Management and Operation	Urban Connectivity, Site, Energy, Water, Material, IEQ, Cultural and Economic Value, Management and Operations	LEED, BREEAM, Green Globe, CEPAS, CASBEE, and SBTool [34]	Create a sustainable environment that reduces the ecological impact and classify the social and cultural needs and the environment of the region [35] (https://www.gord.qa/gsas-trust)

DOI: http://dx.doi.org/10.5772/intechopen.87135

Tool	Year	Country	Targets	Main categories for buildings	Certification levels	Development basis	Notes and aim
Green Star Tools	2007	South Africa	• Buildings • Interior fit-outs • Precincts	Management IEQ, Energy Transport Water, Materials Land Use and Ecology Emissions Innovation	4 stars, Best Practice; 5 stars, South African Excellence; 6 stars, World Leadership	Australian Green Star which is based on BREEAM and LEED	An internationally recognized and trusted mark of quality for the design, construction, and operation of buildings, interior fit-outs. and precincts [36] (https://gbcsa.org.za/certify/green-star-sa/)
DGNB Global Benchmark for Sustainability	2007	Germany	• Buildings • Interiors • Urban districts	Environmental Quality, Economical Quality, Sociocultural and Functional Quality, Technical Quality, Process Quality, Site Quality	Bronze, Silver, Gold, and Platinum	Original	The DGNB System provides an objective description and assessment of the sustainability of buildings and urban districts. Quality is assessed comprehensively over the entire life cycle of the building [37] (https://www.dgnb-system.de/en/system/certification_system/index.php)
Sustainable Buildings Tool (SBTooL)	2009	Lithuania	• Buildings	Site Regeneration and Development, Energy and Resource Consumption, Environmental Loadings, IEQ, Service Quality, Social, Cultural and Perceptual Aspects, Cost and Economic Aspects	Best Practice, Good Practice, Minimum Practice, Negative [38]	Original	SBTool is a generic framework for rating the sustainable performance of buildings and projects. It may also be thought of as a toolkit that assists local organizations to develop local SBTool rating systems [39] (http://www.iisbe.org/sbmethod)
Green Pyramid Rating System (GPRS)	2009	Egypt	• Buildings	Sustainable Sites Water Efficiency Energy and Atmosphere Materials and Resources Indoor Environmental	Certified, Silver Pyramid, Golden Pyramid,	LEED	Establishment of the Egyptian Green Building Council: It is to provide a mechanism to encourage building investors to adopt BEECs as well as other sections of existing

Tool	Year	Country	Targets	Main categories for buildings	Certification levels	Development basis	Notes and aim
				Quality Innovation in Design Regional Priority	Green Pyramid, [40]		codes that satisfy both energy efficiency and environmental conservation by focusing on new construction [41] (http://egypt-gbc.org/ratings.html)
Green Star NZ	2009	New Zealand	• Buildings • Interiors • Communities	Management processes IEQ, Energy Transport Water, Materials Land Use Ecology Emission Innovation	Good Practice, Best Practice, NZ Practice, World Excellence	BREEAM	Green Star is a tool to support stakeholders in the property and construction sectors to design, construct, and operate projects in a more sustainable, efficient, and productive way [42] (https://www.nzgbc.org.nz/GreenStar)
Building Environmental Assessment Method (HK BEAM Plus)	2009	Hong Kong	• Buildings • Interiors • Neighborhood	Site aspects Material aspects Water use Energy use Indoor environmental quality Innovations and additions	Bronze, Silver, Gold, Platinum	BREEAM	BEAM Plus assessment is to offer independent assessments of building sustainability performance. BEAM Plus certification is a proven path for creating safer, healthier, more comfortable, more functional, and more energy-efficient buildings [43] (http://greenbuilding.hkgbc.org.hk/)
GREENSL® Rating System for Built Environment (GreenSL)	2010	Sri Lanka	• Buildings	Management Awareness Sustainable Sites Energy and Atmosphere Materials and Resources Indoor Environmental Quality, Process Innovation, and Design Social and Cultural	Certified, Silver, Gold, Platinum	Undisclosed	A Green Environmental Rating System applicable to Sri Lanka has been formulated as a “home-grown system” with all norms acceptable to leading rating systems [44] (http://srilankagbc.org/rating.php#)

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Tool	Year	Country	Targets	Main categories for buildings	Certification levels	Development basis	Notes and aim
Green Building Index (GBI)	2010	Malaysia	• Buildings including Historical Buildings • Interiors • Township	Sustainable Site Planning and Management Water Efficiency Energy and Atmosphere Materials and Resources IEQ Innovation in Design	Certified, Silver, Gold, Platinum	LEED	GBI is to promote sustainability in the built environment and raise awareness among developers, architects, engineers, planners, designers, contractors, and the public about environmental issues and our responsibility to the future generations [45] (http://new.greenbuildingindex.org/)
Green Rating for Integrated Habitat Assessment (GRIHA)	2010	India	• Buildings • Large Development • Cities	On-site Sufficiency; Water, Energy, Solid Waste Management Development Quality; Site Planning, Energy, Water, and wastewater management, Transport, Solid Waste Management, Socioeconomic	1 Star, 2 Stars, 3 Stars, 4 Stars, 5 Stars	Undisclosed	The GRIHA rating system consists of 31 criteria categorized under various sections such as Site Planning, Construction Management, Occupant Comfort and Well-being, Sustainable Building Materials, Performance Monitoring and Validation, and Innovation [46] (http://www.grihaindia.org/griha-rating)
Pearl Building Rating System (PBRS)	2010	Abu Dhabi	• Buildings	Integrated Development Process Natural Systems Livable Communities Precious Water Resourceful Energy Stewarding Materials Innovating Practice	1 Pearl, 2 Pearls, 3 Pearls, 4 Pearls, 5 Pearls	Undisclosed	The aim of the Pearl Building Rating System is to promote the development of sustainable buildings and improve quality of life. The PBRS encourages water, energy and waste minimization, and local material use and aims to improve supply chains for sustainable and recycled materials and products [47] (http://www3.cec.org/islandora-gb/en/islandora/object/greenbuilding%3A101)

Tool	Year	Country	Targets	Main categories for buildings	Certification levels	Development basis	Notes and aim
Miljöbyggnad (MB) "Environmental Building—system for sustainable building certification"	2010	Sweden	• Buildings	Energy, Materials, IEQ	Gold, Silver, Bronze	LEED and BREEAM	The MB system is based on the Swedish Building Regulations (BBR), which govern the entire country. It is relatively simple and includes only 15 items measured for certification [48] (http://insight.gbig.org/green-building-in-sweden-sgbc-miljobyggnad/ https://www.sgbc.se/certifiering/miljobyggnad/)
STO NOSTROY 2.35.4–2011 "Rating system for evaluation sustainability of residential and public buildings" **GOST R 54964–2012** "Environmental requirements for real estate"	2011/ 2012	Russia	• Buildings • Real estate	Quality of architecture, IEQ, Quality of sanitary protection and waste management, Operation, Training water management, Energy efficiency, Economic efficiency	Undisclosed	LEED, BREEAM, DGNB, and HQE	Buildings and civil construction. Rating system for evaluation sustainability of residential and public buildings and real estate. It defines the principles, categories, evaluation criteria, sustainability indicators of habitat, as well as weighting for ratings for buildings [21] (http://zvt.abok.ru/articles/47/Green_Building_Market_Situation_in_Russia)
Excellence in Design for Greater Efficiencies (EDGE)	2012	• World Bank Group • "Internationally"	• Buildings	Energy Water Materials	Pass/Fail [49]	Original	The EDGE application helps to determine the most cost-effective options for designing green within a local climate context. EDGE can be used for buildings of all vintages, including new construction, existing buildings, and major retrofits [50] (https://www.edgebuildings.com/marketing/edge)

Tool	Year	Country	Targets	Main categories for buildings	Certification levels	Development basis	Notes and aim
ARZ BRS Green Building Rating System	2012	• Lebanon	• Buildings	Energy Performance Thermal Energy Electrical Energy Building Envelope Materials, IEQ Water Conservation Operations and Management	Gold Silver Bronze Certified Registered projects	Edge	The ARZ Building Rating System is designed to measure the extent to which existing commercial buildings in Lebanon are healthy, comfortable places for working, and consuming the right amount of energy and water, while having a low impact upon the natural environment [51] (http://arzrating.com/)
Miljöbyggnad MB —"Environmental Building - system for sustainable building certification	2010	Sweden	• Buildings	Energy, Materials, and IEQ	Gold, Silver, or Bronze	LEED and BREEAM	The MB system are based on the Swedish Building Regulations (BBR), which govern the entire country. It is relatively simple, includes only 15 items measured for certification [48] (http://insight.gbig.org/green-building-in-sweden-sgbc-miljobyggnad/ https://www.sgbc.se/certifiering/miljobyggnad/)
High Quality Environmental (**HQE**) standard	2013	France/International	• Buildings • Urban Projects	Energy, Environment, Health, Comfort [23]	Pass, Good, Very good, Excellent, Exceptional	Original	HQE™ is the French certification awarded to building construction and management as well as urban planning projects. HQE™ promotes best practices and sustainable quality in building projects and offers expert guidance throughout the lifetime of the project [52] (https://www.behqe.com/)

Tool	Year	Country	Targets	Main categories for buildings	Certification levels	Development basis	Notes and aim
The WELL Building Standard® (**Well**)	2015	USA	• Health and Wellness of Buildings' occupants	Air, Water, Nourishment, Light, Fitness, Comfort, mind	Silver, Gold, Platinum	Original	It is a performance-based system for measuring, certifying, and monitoring features of the built environment that impact human health and well-being, through air, water, nourishment, light, fitness, comfort, and mind [53] (https://www.usgbc.org/article s/what-well)
Civil Engineering Environmental Quality (**CEEQUAL**) Assessment and Award Scheme	2015	UK/International	• Civil engineering • Infrastructure • Landscaping • Public realm projects	Project/Contract Strategy, Project or Contract Management, People and Communities, Land use and Landscape, The Historic Environment, Ecology and Biodiversity, Water Environment (fresh & marine), Physical Resources Use and Management, Transport [54]	Pass, Good, Very Good, Excellent	Original	CEEQUAL is the evidence-based sustainability assessment, rating, and awards scheme that challenges projects to deliver better outcomes in infrastructure sustainability, developed by the Building Research Establishment BRE, UK [55] (http://www.ceequal.com/)

Table 1.
Summary of the common rating assessment systems around the world (by the author after [8, 13, 19–23]).

- Categories: These form a specific set of items relating to the environmental performance considered during the assessment.

- Scoring system: This is a performance measurement system that cumulates the number of possible points or credits that can be earned by achieving a given level of performance in several analyzed aspects.

- Weighting system: This represents the relevance assigned to each specific category within the overall scoring system.

- Output: This aims at showing, in a direct and comprehensive manner, the results of the environmental performance obtained during the scoring phase.

Figure 1 and **Table 1** present the most common green rating systems all over the world chronologically. **Table 1** summarizes the most important features of those rating systems, in terms of year of establishment, coverage, main categories for building rating, level of certifications, its development base, and main aim with the main link of the source.

3. Case study analysis

In previous researches [56–58], the author of this chapter had set a detailed methodology to aid the integration of the principles of the sustainability in the early stages of design (**Figure 2**). The outputs of these researches have been employed in several real-life building projects on the regional level. The current research

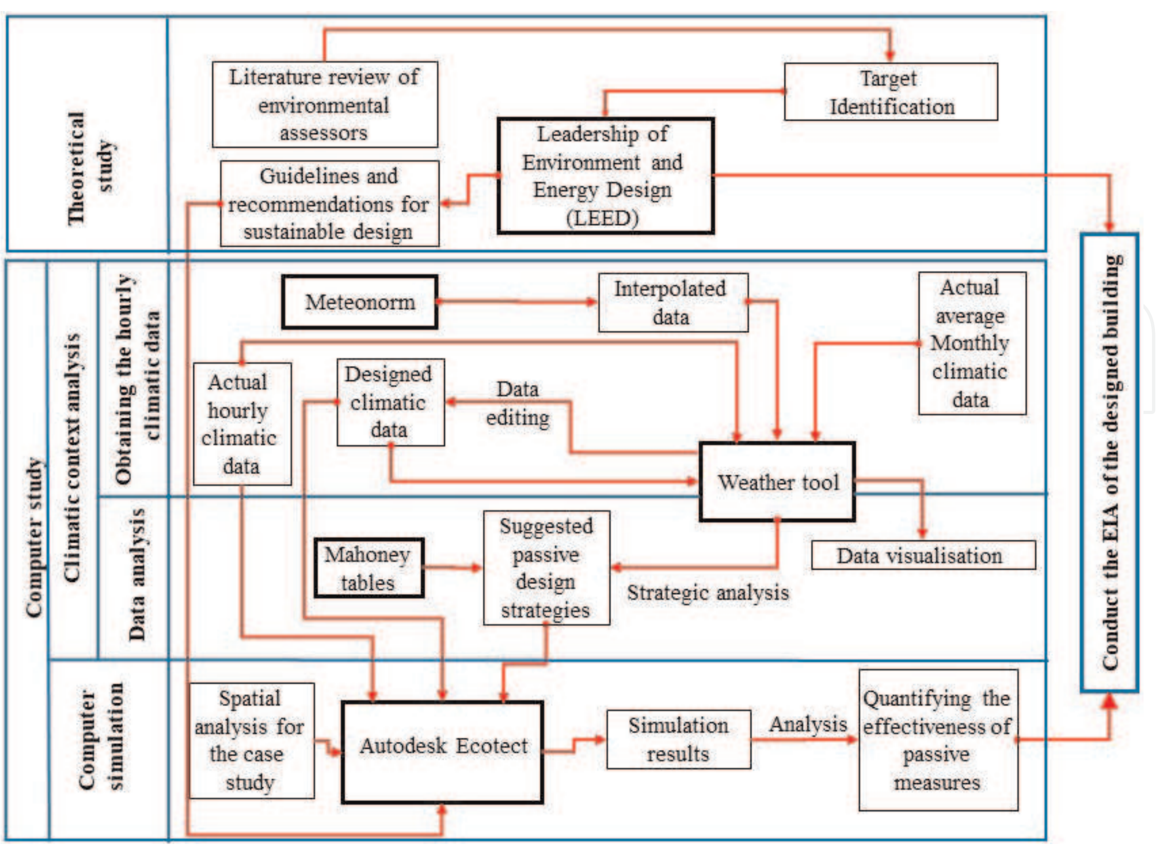

Figure 2.
Proposed detailed methodology to integrate the environmental assessment in the architectural design process [56].

presents one project as a case study analysis. The adopted methodology employs the environmental assessor "Leadership in Energy and Environmental Design" to measure the compatibility of the design with principles of sustainability. Also environmental software (Autodesk Ecotect, HTB2, and Weather Tool in addition to environmental tools such as psychometric chart, Mahoney tables, and Stereograph diagram and Solar Tool) have been used in order to analyze the context and quantify the effectiveness of proposed passive strategies and measures. By such, design proposals in the early stages of design (i.e., design concept, orientation of buildings, using passive strategies and techniques, facade designs and projections, colors of the buildings, opening size and design, etc.) could be quantified. LEED has 110 credits which cover all the different disciplines in building design and construction. However, the current application focuses on the related credits to the early stages of design which lie directly under the architect responsibility and can affect the total performance of the building.

4. Target identification

The adopted methodology employs the Leadership in Energy and Environment Design (LEED) 1 that was developed in USA by the U.S. Green Building Council for new construction as one of the most known environmental assessors in the market nowadays. The LEED tool aims to provide building stakeholders with a "report card" that indicates the health, efficiency, and comfort of the buildings. LEED recognizes the unique nature of the design and construction of ASHRAE Advanced Energy Design Guide [59] and addresses the specific needs of building spaces and occupant's health issues [60]. LEED is flexible to apply to all project types including healthcare facilities, schools, homes, and even the entire neighborhoods. LEED for Core and Shell can be used for projects where the developer controls the design and construction of the entire Core and Shell base building (e.g., mechanical, electrical, plumbing, and fire protection systems) but has no control over the design and construction of the tenant fit-out. Projects could include a commercial or medical office building, retail center, warehouse, or lab facility. It is designed to be complementary to LEED for commercial interiors and LEED for Retail: Commercial Interiors.

The allocation of points between credits is based on the potential environmental impacts and human benefits of each credit with respect to a set of impact categories. The impacts are defined as the environmental or human effect of the design, construction, operation, and maintenance of the building, such as greenhouse gas emissions, fossil fuel use, toxins and carcinogens, air and water pollutants, and indoor environmental conditions. A combination of approaches, including energy modeling, life cycle assessment, and transportation analysis, is used to quantify each type of impact. The resulting allocation of points among credits is called credit weighting [61]. These credit weightings are shown in **Figure 3**. LEED V4 are awarded according to the following scale in **Table 2**.

This work aimed at achieving the LEED Rating system (Core and Shell). Most of the LEED issues could be quantified by analyzing the design input data, while other issues such as Indoor Environmental Quality needs a quantification tool to be assessed. This methodology employs thermal comfort and energy efficiency as environmental design targets. The effectiveness of the proposed measures is determined according to its ability to passively achieve thermal comfort by using minimum amount of energy possible. This helps the designer to recognize successful LEED strategies and measurements for achieving credit category goals.

This work had set the guidelines for the architectural and engineering design of the GREENEDGE building based on analyzing the macroclimate for Cairo city and

LEED New Construction V4	
Category	**Total Credits**
Integrative Process	1
Location and Transportation	16
Sustainable Sites	10
Water Efficiency	11
Energy & Atmosphere	33
Materials & Resources	13
Indoor EnvironmentalQuality	16
Innovative in Design	6
Regional Priority	4
TOTAL	110

Figure 3.
The credits weighting of the environmental categories of the LEED, [7].

LEED ratings	LEED v3
Certified	40–49 points
Silver	50–59 points
Gold	60–79 points
Platinum	80+ points

Table 2.
Certification scale of LEED [18].

the microclimate data for the GREENEDGE site. This is done through using a specific scientific computer-based methodology developed by the author of the chapter through his research [6, 7, 56–58, 62–67] that mainly depends on a number of environmental design computer-based tools and especially the comprehensive environmental analysis and simulation tools. These tools are:

- The analysis sustainable building design software (Autodesk Ecotect)
- Climatic analysis software (Weather Tool)
- Solar analysis software (Solar Tool)
- Mahoney tables
- Shadowing analysis (Stereograph diagram)
- Synthesizing hourly climatic data (Meteonorm)

The use of computer software allow the visualization of the unseen environmental attributes in a three-dimensional interface, allowing by such comprehensive understanding of the issues involved in the assessment process.

5. Project understanding and location

The New Cairo Business Hub (GREENEDGE) is located at plot 84, First sector, New Cairo City Center, that is directly overlooking the southern 90 road right beside BNP Paribas Headquarters (**Figure 4**). The building is designed to be a class (A) office building with total plot area of 33,000 m2 of office spaces for banks and multinational companies at one of the most developed business districts in Egypt with all required amenities and facilities at place and surrounded by Egypt's biggest banks, headquarters, as well as notable multinationals.

5.1 Basic project information

Project name: THE GREENEDGE.
Land area: 7123 Sqm.
Footprint %: 25%.
No. of floors: Three basements + G + six typical floors.
Owner: Katamia for office Buildings—KOP.
Project developer: Redcon Real Estate Development.
Green Architecture and LEED Consultant: The author of the current chapter.

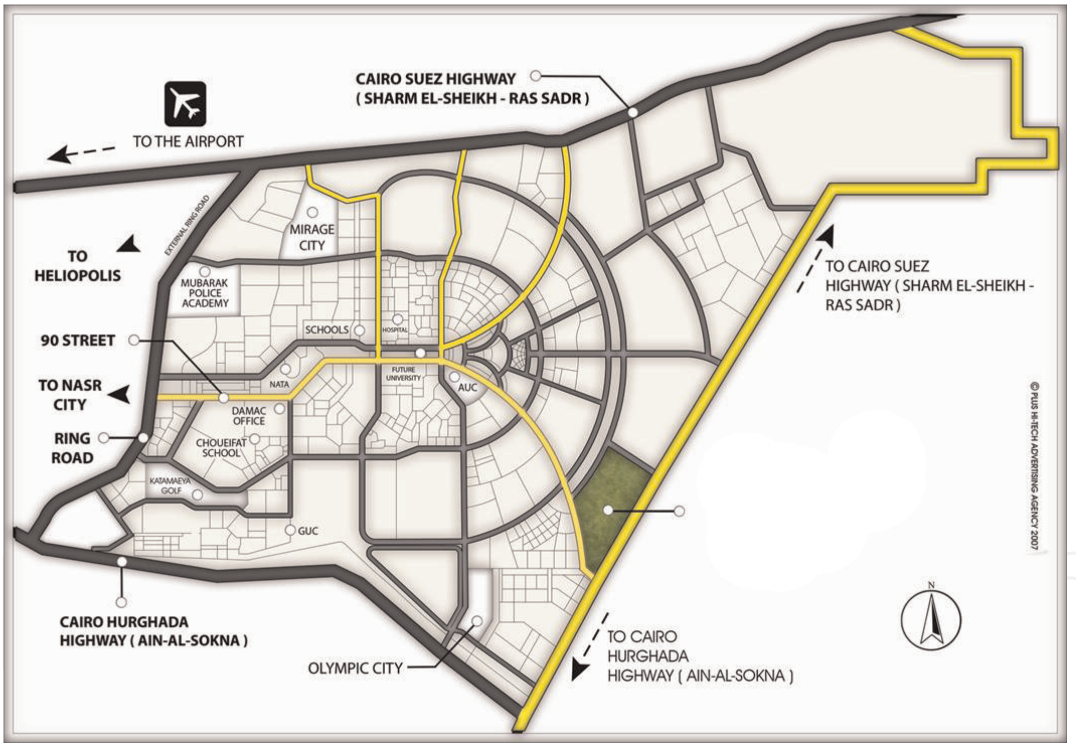

Figure 4.
New Cairo location and the location of GREENEDGE building, after Google maps [68] and new Cairo City Council [69].

6. Macroclimate analysis

Cairo's climate is a desert climate, which remains mostly dry and arid year-round. The hot weather in Cairo means that the humidity can rise at times, particularly during winter (December to February). At this time precipitation is more likely, and temperatures drop to 13–19°C. Cairo weather in the summertime (May to August) sees temperatures of 45–47°C. The Cairo International Airport weather Station was chosen to most represent the location of new Cairo. The hourly climatic data file generated by the USDOE was used in this report. On analyzing the hourly climatic data using Weather Tool, Cairo climate is classified as an arid climate where precipitation rarely occurs. Cairo has a hot desert climate (Köppen climate classification: BWh). The climate is generally dry. The temperatures are hot or very hot in summer days and warm or mild in winter days, but warm in summer nights and cool in winter nights. The temperature varies greatly, especially in summer; it ranges from 7°C at night to 40°C during the day. While the winter temperature does not fluctuate as wildly, it can be as low as 0°C at night and as high as 18°C during the day. Cairo receives less than 25 mm of precipitation annually in most areas and almost never rains in summer. Air temperatures are being outside the comfort zone most of the year. Only during 4 months (March, April, September, and October), a good percentage of the total hours is found to be located in the comfort zone. The prevailing wind is coming from the north to northwest most of the year with average air temperature, while hot wind comes from the west-south direction during specific times of the year. Prevailing wind are coming from the north to northwest most of the year with average air temperature, while hot wind comes from the west-south direction during specific times of the year. Rainfall is rare in Cairo and does not exceed 25 mm/the whole year.

Passive solar heating, thermal mass effect, night purge ventilation, natural ventilation, direct evaporative cooling, and indirect evaporative cooling to enhance the environmental performance of the GREENEDGE in Cairo were tested using Weather Tool. The analysis revealed that while thermal mass and night purge ventilation can enhance the thermal performance during the whole year, almost only natural ventilation can enhance significantly the environmental performance of the building during the summer season. While indirect evaporative cooling can enhance the thermal performance slightly during the summer time, passive solar heating can also contribute to the thermal enhancement during winter time. Using Mahoney table, it revealed that it is essential to deal with such climate to use the following strategies:

- Compact plans with interior courtyards
- Dual-targeting buildings that allow air circulation intermittent
- Small, 15 to 25% of the surface of the walls
- Openings in the north and south walls
- Construction heavy for strong thermal inertia for walls and roofs; jet lag more than 8 hours

7. Results and discussion

7.1 Existing design analysis

In this section, the original design of GREENEDGE building (**Figure 5**) will be explained, highlighting the problems, constrains, and potentials.

The GREENEDGE building in its base case was exposed to high incident solar radiation especially on its west and south facades that receive solar radiation every single day of the year with no any internal open spaces such as courtyards. This would affect negatively the building performance. Shaded open spaces are very preferable in the hot dry zones. They can reduce the daytime air and radiant temperatures inside the occupied space. The courtyard helps in maintaining cooled indoor temperatures. It provides a private internal open space that is visually and

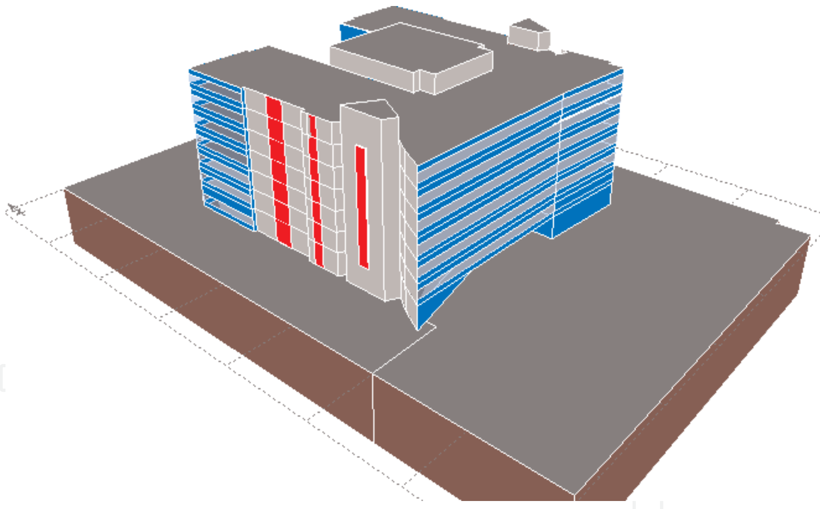

Figure 5.
The simulated GREENEDGE building as it is, done by the author after Autodesk Ecotect.

acoustically separated from the outside environment. The base case material for all the windows was single glazed that is not appropriate for such climate particularly for the west-south facades and high intensity of solar radiation.

7.2 Sustainable design enhancements

To deal with the current situation, several traditional and contemporary ideas have been adopted. The recommended ideas and solution could be classified under the recommended passive strategies that were raised from the climatic analysis using Weather Tool and Mahoney tables. This could be listed below.

7.2.1 Vegetation around the building

Maximizing the amount of vegetation inside and outside buildings affects positively the thermal performance of buildings. This could result in shading of the external surfaces of the building, shading the opened spaces, reducing and filtering the dust in the air, and elevating the humidity level [70]. However, vegetation in such climatic conditions could be expensive because of the limitation in the water supply for irrigation and by turn could be against the green architecture principles (**Figure 6**). Specific types of trees and irrigation technology should be selected to best suit the climatic context.

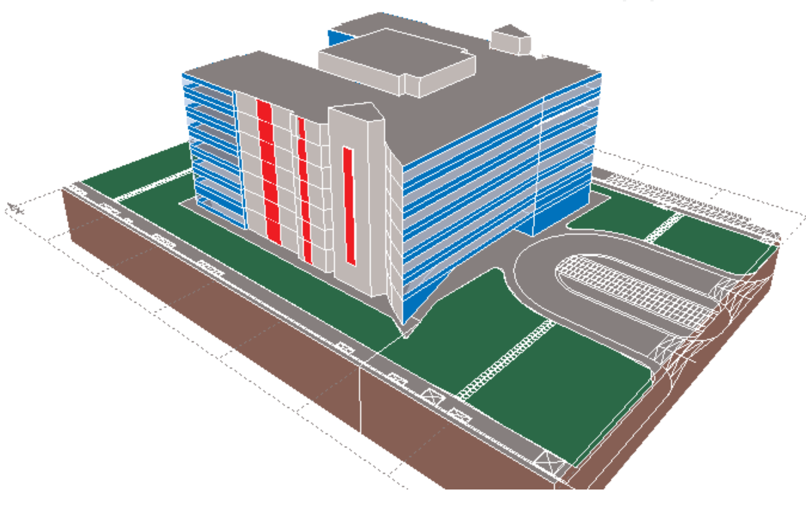

Figure 6.
Vegetation around the building (done by the author after Autodesk Ecotect).

Grass area has been avoided since it needs potable water for sprinkler irrigation system. According to the WHO guidelines for the use of treated wastewater for irrigation, gray water could not be used for adjacent area for man activity [71, 72], also because gray water can affect negatively the sprinkler heads. Moreover, high-efficiency drip irrigation systems can be 95% efficient, compared with 60–70% for sprinkler or spray irrigation systems [73]. Also, the use of native or adapted vegetation on the project site can assist project teams with earning more credits regarding sustainable sits.

7.2.2 Compact plans with interior courtyards that allow air circulation

A recommended northern courtyard with link between the courtyard and the backyard at the south orientation has been modified to the design. This can affect positively the thermal performance of the building. This link could be positioned at the first floors "called Takhtabush in vernacular architecture." This could be achieved by replacing the curtain glazing in this area to contemporary electronic Mashrabia (**Figure 7**).

This ensures a steady flow of air by convection [74]. Since the backyard is larger at the south orientation, and thus less shaded than the courtyard, air heats up more than in the courtyard. The heated air rising in the backyard draws cool air from the courtyard through the Takhtabush, creating a steady cool breeze.

7.2.3 Openings in the north and south walls, the exposed side of the human height of the wind, and interior wall openings

Window height and details have been modified to be in two parts with different heights. Those of the north direction must be the same in height with the human being. Opposite ones must be in a higher position to enable the required cross-ventilation. This will give the occupants the controllability of opening the upper or the lower parts according to the weather condition.

7.2.4 Heavy construction for strong thermal inertia for walls and roofs: Time lag more than 8 hours

In the hot dry climate, high heat resistance and high heat capacity of the envelope elements are necessary. High resistance minimizes the conductive heat flow into the building mass during the daytime. Actually, this would reduce the rate of cooling the building mass during nighttime, but it could be overcome by employing

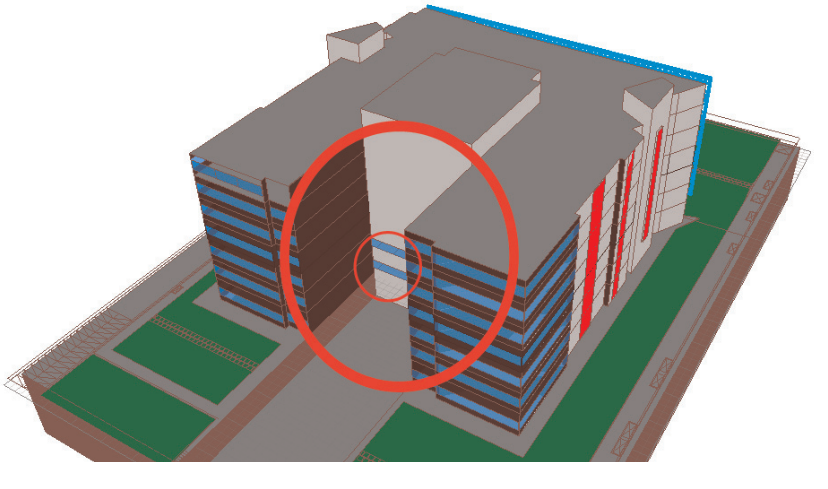

Figure 7.
Required opening between the courtyard and the backyard (done by the author after Autodesk Ecotect).

night purge ventilation strategy and new techniques of sunscreen which allow air movement [70, 75]. High thermal mass has been achieved traditionally by thick walls that are made of heavy materials such as stone, brick, adobe, and mud. To achieve this with the glazing wall, it has been modified to be double-tinted glazing. A U-value of 1.0 W/m^2 K has been used for the external facades. A canopy was added to the southern facade in the form of glazed sunscreen. Shading devices have been designed for the west facade to avoid the very hot solar rays of the afternoon. Firstly, a plan of blocking the solar rays of the summer season from 1:00 pm to 5:00 pm was achieved by 2.4 m depth shading device, which would not be accepted by the architectural consultant and the city council regulations. Therefore, the time range has been minimized to be between 1:00 pm and 3:00 pm and combined between the vertical and horizontal shading devices to minimize the depth of the devices to be 1.0 m (**Figure 8**). The same shading devices have been applied to the east facade for esthetic reasons.

7.2.5 Shaded roof

It also recommended to shade part of the roof, particularly the service area, with a pergola that can used for the photovoltaic cells to generate green power (**Figure 9**).

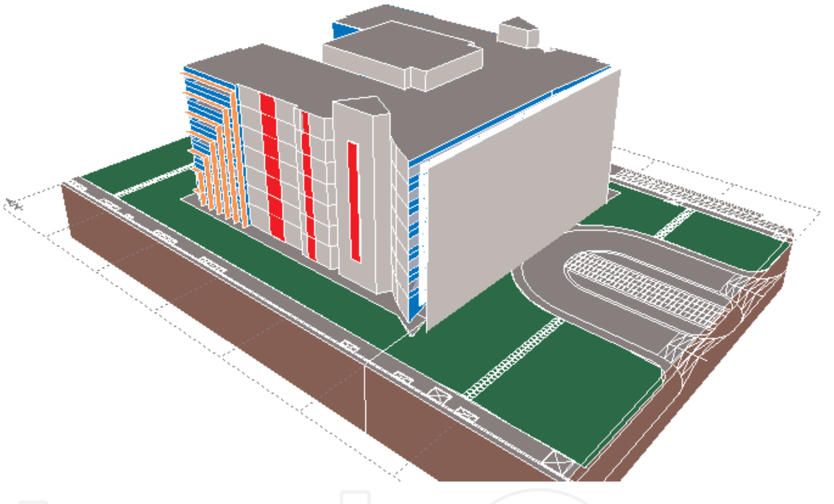

Figure 8.
Proposed vertical/horizontal shading devices on the west/east facades (done by the author after Autodesk Ecotect).

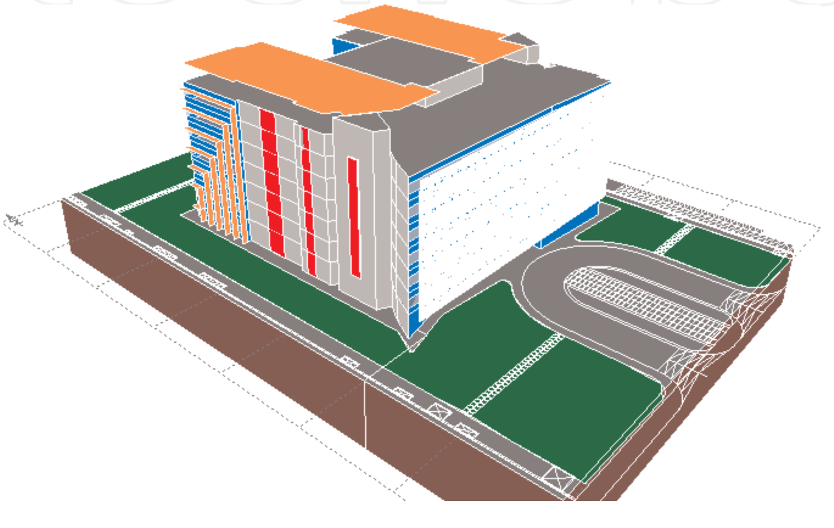

Figure 9.
Shading part of the roof (done by the author after Autodesk Ecotect).

7.2.6 Daylight and lighting views

To provide the building occupants with a connection to the outdoors, through the introduction of daylight and views into the regularly occupied areas of the building (**Figure 10**), it has been recommended to achieve a direct line of sight to the outdoor environment via vision glazing between 30 inches (75 cm) and 90 inches (225 cm) (**Figure 11**) above the finish floor for building occupants in 90% of all regularly occupied areas [73]. The floor area of the typical floor plan has been simulated using Autodesk Ecotect, and the daylight has been calculated on a height of 30 in (75 cm) above the floor. An interval of 5 foot (150 cm) has been employed in the analysis grid in the two directions X and Y. The first results did not satisfy the credit condition with the windows at sill height of 90 cm. Therefore, the height of the sill height was changed to be 30 in (75 cm).

By calculating the nodes of more than 25 fc (269.1 lux), the calculation showed that 472 out of 568 nodes are more than 25 fc and less than 500 fc. The percentage of area under the acceptable condition of the credit = 472/568 = 83.09% which is more than the required level by LEED (83.09% > 75%) (**Figure 12**).

7.3 Simulation results analysis

Using Autodesk Ecotect, the base case and the modified case have been modeled and simulated. The thermal performance of the third floor has been utilized for the

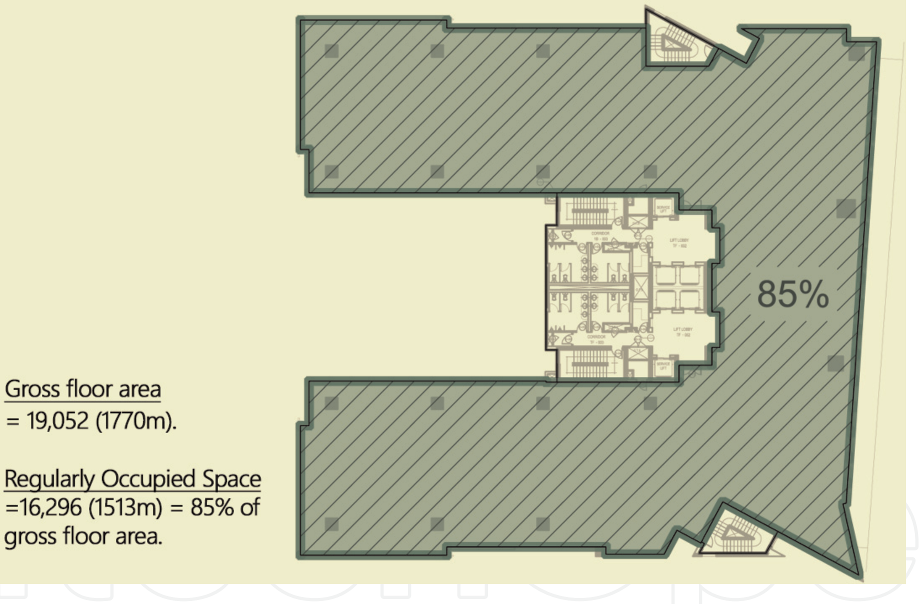

Figure 10.
Regularly occupied spaces to gross floor area (third floor) (done by the author).

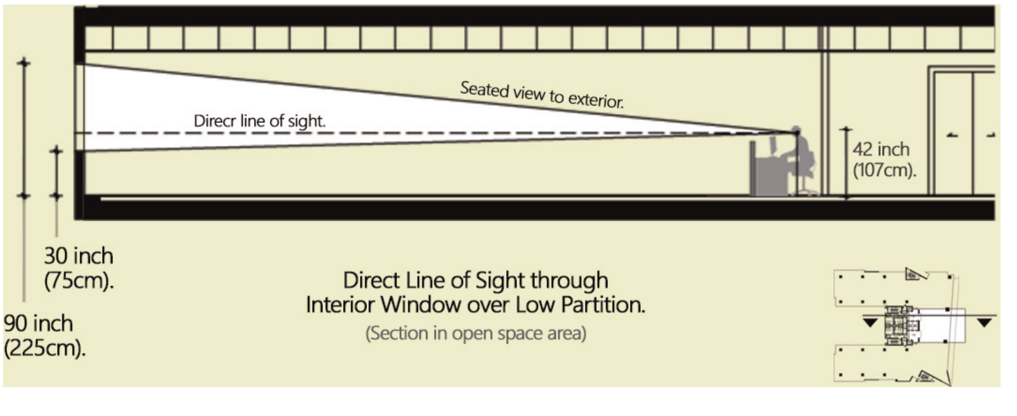

Figure 11.
Direct lines of sight to the exterior (done by the author).

comparison purpose. The same specifications of the zone in terms of air velocity, number of occupants, latent heat, operation hours, occupant activity and cloth, etc. were given for the two case scenarios. The passive heat gain breakdown of the building has been calculated for both the base case of the GREENEDGE building

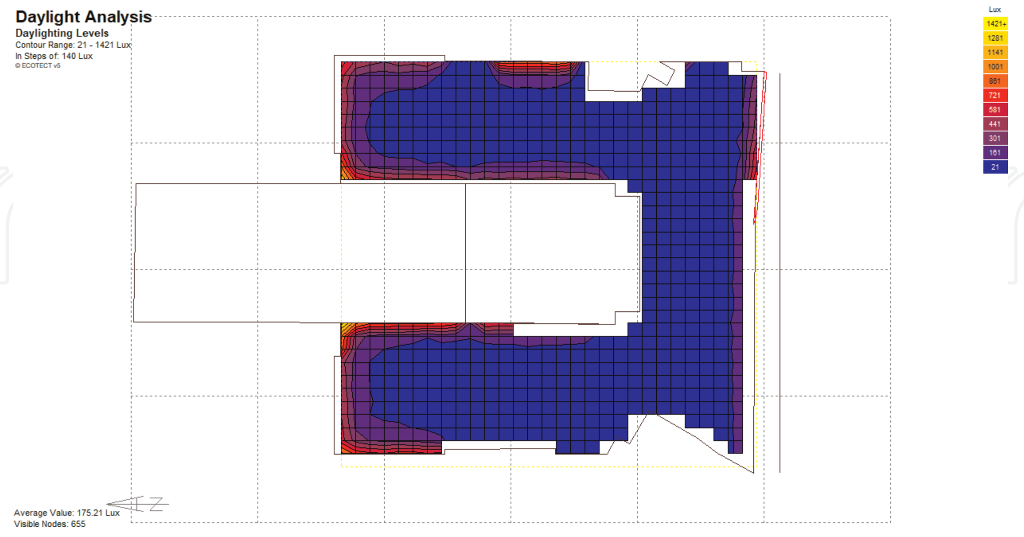

Figure 12.
Daylight levels at the third floor of the building on the 21st of September for all the occupied spaces (after Autodesk Ecotect).

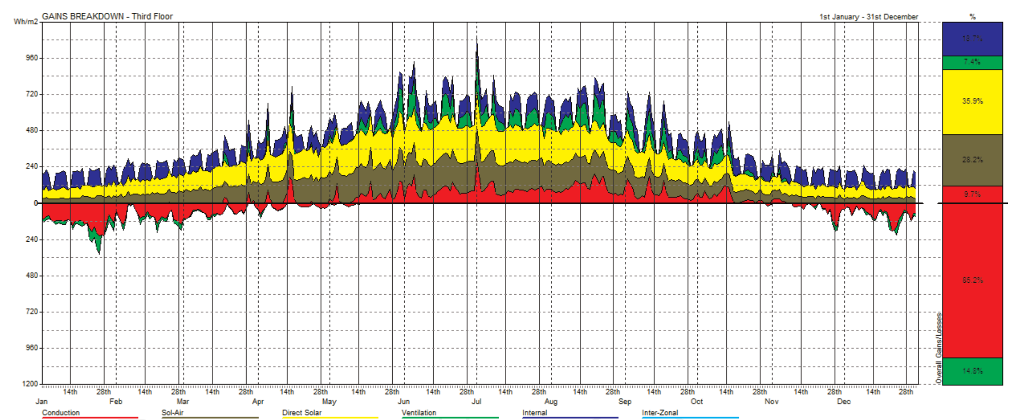

Figure 13.
Passive heat gain breakdown of the base case (done by the author using Autodesk Ecotect).

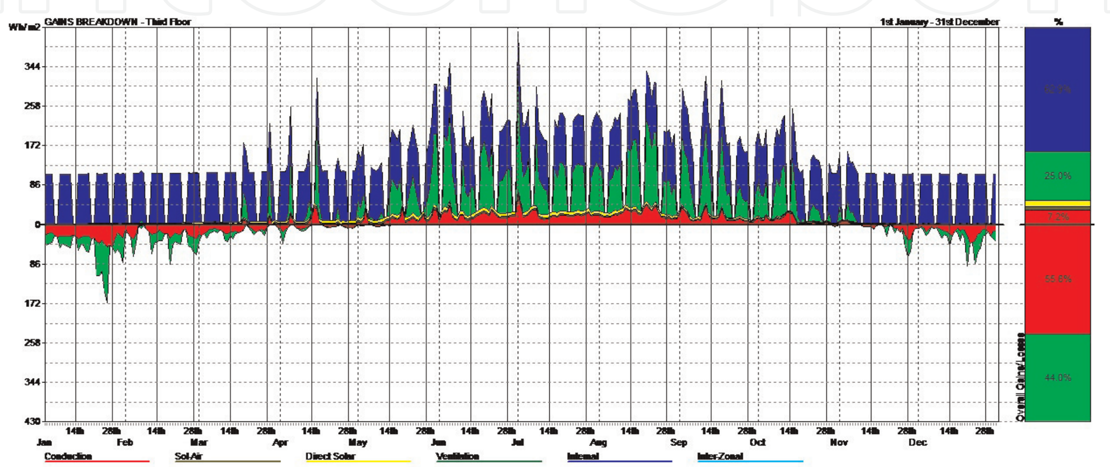

Figure 14.
Passive heat gain breakdown of the proposed case (done by the author using Autodesk Ecotect).

and the after modifications. **Figures 13** and **14** and show that the passive heat gain breakdown for the proposed case after modification was almost half the passive heat gain breakdown of the base case.

8. Conclusion

Although the GREENEDGE building is a mechanical-ventilated building (active ventilation), passive strategies and measures were followed to minimize the required energy for cooling and heating loads during the different seasons. The total hours of the years during energy consumption has been reduced by 12% after energy modeling analysis. The design recommendations could be summarized as follows:

1. Maximizing the amount of vegetation inside and outside buildings and using drip irrigation system to minimize the water consumption.

2. Having a northern courtyard with link between the courtyard and the external environment (the Takhtabush).

3. Shading part of the roof, particularly the service area, with a pergola that can be used for the photovoltaic cells to generate green power with the solar reflective index (SRI) not more than 29.

4. Placing vertical and horizontal shading devices on the west/east facades to block the solar radiation during the noontime of the day.

5. Windows has been modified to include two parts (lower and upper parts) that can give the occupants the controllability of opening the upper or the lower parts according to the weather condition. Those of the north direction must be the same in height with the human being. Opposite ones must be in a higher position to enable the required cross-ventilation.

6. Heavy construction for strong thermal inertia for walls and roofs: time lag more than 8 hours. To achieve this with the glazing wall, a doubled glazing with a U-value of 1.0 W/m^2 K has been used at the south and west facades.

7. A canopy has been added to the south facade in the form of Mashrabia, shading devices, or glazed screen.

The GREENEDGE building imitating the LEED goal for a golden certificate is packed with good design potentials which can lead for such project to be one of the first office buildings in Egypt to be certified with a Golden certification using the newly announced LEED for Core and Shell. It is worth mentioning here that the building has been achieved a Preliminary Platinum Certificate.

Acknowledgments

The author wishes to thank GREENEDGE owner, management bodies, and the design teams for their cooperation and efforts.

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