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The Analysis of the EDGE Certification System on Residential Complexes to Improve Sustainability and Affordability

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Abstract: In this paper, the characteristics of the Excellence in Design for Greater Efficiencies (EDGE) green building certification system in terms of the scope of certification, and environmental and social strategies focused on 6024 units in the 17 EDGE-certified residential buildings in South Africa was investigated. This research analyzed the efficiency of energy, water, embodied energy in materials, and annual CO_2 emissions and their contribution to solving housing issues in the given context. This research revealed that the design of EDGE-certified buildings focuses on the "efficiency first" approach and reduced energy and water demand more than on-site energy production. In energy-saving strategies, energy-saving solutions are three times (69.2%) higher than energy-generating solutions (23.1%). The results on resource savings showed that, on average, embodied energy in materials (54%) is the most reduced resource, followed by water (31%) and energy (29.7%). The statistical analysis indicated that there is no statistically significant correlation between energy, water, embodied energy in materials, and CO_2 savings with floor areas of the buildings. In addition, this research highlighted how EDGE certification has positively contributed to solving South Africa's resource shortage and affordable housing scarcity problems.

Keywords: green building certification; EDGE; residential building; South Africa; resource saving; energy efficiency; affordable housing

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1. Introduction

Throughout history, the building sector has been facing economic, social, and technical problems caused by misuse of available resources, climate change, and overpopulation [1]. Particularly, excessive energy consumption, CO_2 emissions, and water shortage have become global issues [2]. Consequently, buildings have been negatively criticized for playing a big role in environmental pollution. According to the International Energy Agency (IEA) in 2018, the building and construction sector recorded 36% of global final energy use and 39% of energy-related CO_2 [3]. To address this international issue, a lot of institutions and countries have introduced building certification systems, which are being used to study the consumption of energy and other resources from the planning stage to the demolition stage using the life cycle analysis method and the assessment of the built environment [4]. In addition, the importance of the indoor environment including thermal, air, lighting, and acoustic, and the value of post-occupancy for a better quality of life, occupant health, and productivity has been highlighted [5–8]. The built environment industry has grown significantly to reach enhanced energy efficiency, environmental impact, building management, and user satisfaction over the past few decades [4].

According to a study conducted by the US Environmental Protection Agency (EPA) on Americans, an average person spends 93% of their life indoors and 87% inside buildings [9]. Out of 24 h, more than 12.7 h per day is spent sleeping and living at home [10]. For this reason, residential building quality holds a significant role and directly impacts everyone. Nevertheless, due to the increase in population, especially in major cities all over the world, the housing problem and its affordability remain a big issue in society [11]. In 2018, an estimated 29.2% of the urban population in the world and 53.6% of Sub-Saharan Africa's population lived in slums [12].

The green building certification system has highlighted its benefits to the sustainability of buildings. Generally, certification systems play a big role in ameliorating building quality, assisting the execution and advancement of regulations, and promoting the building industry to achieve objectives of sustainable development [13–15]. Lots of research has been conducted on well-known building certification systems to show the benefit of building certification systems such as Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), German Sustainable Building Council (DGNB), Green Star, Haute Qualite Environnementale (HQE), Comprehensive Assessment System for Built Environment Efficiency (CASBEE), The Green Standard for Energy and Environmental Design (G-SEED) and so on. Building owners, designers, clients, and occupants pursue green building certification because it has many economic and environmental benefits including energy and water savings, reduced waste and CO_2 emissions, increased occupancy rate and market value, enhanced productivity, and better health and user satisfaction [15]. Table 1 shows the certification criteria of different certification systems. Some certifications have common criteria, sometimes named differently. It is important to remember that each certification credit has its own sub-component and requirements and is given different points based on its impacts and focus. Additionally, the same criteria may be covered under different categories or combined with other aspects. Some elements, such as CO_2 reduction, are included in some criteria but are not considered criteria on their own.

Table 1. Overview of certification criteria of different certification systems [16–22].

Item	EDGE	BREEAM	LEED	DGNB	HQE	CASBEE	G-SEED
Energy	✓	✓	✓	-	✓	✓	✓
Water	✓	✓	✓	✓	✓	-	✓
Materials	✓	✓	✓	-	-	✓	✓
Indoor Environment	-	-	✓	✓	✓	✓	✓
Resources	-	✓	✓	✓	-	✓	✓
Land use	-	✓	-	✓	✓	-	✓
Transport	-	✓	✓	✓	-	-	✓
Site	-	-	✓	✓	✓	✓	-
Waste	-	✓	-	✓	✓	-	-
Ecology	✓	✓	-	-	-	-	✓
Innovation	-	✓	✓	-	-	-	-
Management	-	✓	-	-	-	-	✓
Pollution	-	✓	-	-	-	-	✓
Atmosphere	-	-	✓	-	-	-	✓
Health and wellbeing	-	✓	-	-	-	-	-
Integrative process	-	-	✓	-	-	-	-
Location	-	-	✓	-	-	-	-
Regional priority	-	-	✓	-	-	-	-
Resilience	-	✓	-	-	-	-	-
Economic quality	-	-	-	✓	-	-	-
Biodiversity	-	-	-	✓	-	-	-
Functionality	-	-	-	✓	-	-	-
Safety and security	-	-	-	✓	-	-	-

Table 1. *Cont.*

Item	EDGE	BREEAM	LEED	DGNB	HQE	CASBEE	G-SEED
Technical quality	-	-	-	✓	-	-	-
Process quality	-	-	-	✓	-	-	-
Olfactory comfort	-	-	-	-	✓	-	-
Maintenance	-	-	-	-	✓	-	-
Quality of service	-	-	-	-	-	✓	-
Life cycle Assessment	-	-	-	✓	-	-	-
Components	-	-	-	-	✓	-	-
Off-site environment	-	-	-	-	-	✓	-

However, there are relatively fewer certified green buildings in Africa compared to other continents. Despite LEED being the most certified green building certification system in the world, for example, the list of top 10 countries with the most LEED-certified projects (US excluded) does not include any African country [23]. In particular, Sub-Saharan countries need building certification in order to overcome their continuous building problems. Therefore, green building certification systems should be actively introduced to improve both the economy and the quality of life. The certification system of Excellence in Design for Greater Efficiencies (EDGE) focuses on the major problems in not only developed countries but also developing countries, especially Africa, where it helps to build resource-efficient buildings [24].

The EDGE building certification system was established in 2014 by the International Finance Corporation (IFC). The Green Buildings Council of South Africa (GBCSA) exclusively provides EDGE certification for homes in South Africa [25]. EDGE helps calculate costs, focuses on resource (energy, water, embodied energy in materials) efficiency, saves time through a streamlined process, and provides bioclimatic modeling [26]. EDGE-certified building types include educational facilities, residential buildings, accommodation facilities, medical facilities, light industry, office buildings, and retail and warehouses [27].

This study intends to examine EDGE in South Africa through its application in residential buildings. EDGE's main purpose is to ensure that a building has successfully met goals to reduce the building's negative impact on the environment by supporting the design and construction of sustainable buildings and providing a validating certificate. In addition, EDGE has been adopted in South Africa toward solving housing shortages and energy problems [24].

Growing demand for housing and scarcity of resources such as water and electricity are major problems [28]. South Africa is known to have high mortgage rates of about 10% [29,30]. According to Statistics South Africa in 2017, the unemployment rate in South Africa was 27.7% [31]. This means there are many people who cannot afford a good home. EDGE was introduced in South Africa to solve the country's problems while providing green buildings. Certified buildings have minimal operating costs and low rental fees. In addition, low utility bills and rents have reduced the economic burden and encouraged residents to use their remaining deposits as an opportunity to invest in health and education [30]. South Africa's GDP growth has declined from 1.49% in 2018 to −6.43% in 2020, which increased to 4.91% in 2021 [32]. To overcome this decline, residential buildings have received more attention than any other type of building. Through that, it was possible to find solutions to water and energy shortages and other related crises. So, new measures were taken including the introduction of the EDGE building certification system in South Africa [24]. IFC's EDGE certification system was launched in South Africa with the aim of focusing on the residential real estate sector. The certification system includes the EDGE app, innovative software designed to help home builders track and regulate the financial viability of their projects [33]. This free app allows officials and developers to assess the costs and advantages of strategies related to carbon reduction [34]. Despite the falling market prices in South Africa, housing demand is still high. A total of 86% of the market was estimated to be residential complexes as the new target to solve the housing shortage problem [28]. The green investment fund was distributed to utilities and materials such as heating and cooling, ventilation, energy-saving technologies, photovoltaics, green walls, glazing and windows, water-efficient technologies, and so forth.

According to National Geographic, only 3% of the water on earth is freshwater and only 1.2% of the freshwater is potable water [35]. With less water consumption in buildings with EDGE certification, other South African residents can have better access to water. South Africa consumes 65 L/person/day more than the world's average water consumption [36]. In addition, South Africa is expected to have water scarcity in 2025 and a water deficit of 17% by 2030. This water challenge will be aggravated by existing climate change. EDGE certification is the solution needed for South African residential complexes to reduce water consumption. An elevated carbon footprint is the main culprit of global warming. To combat global warming, it is important to reduce CO_2 emissions, consume less energy, recycle, use fuel/energy efficient devices, and so on.

2. Methodology

The aim of this paper is to explore characteristics of the EDGE certification system through its application in residential complexes located in South Africa. This paper particularly focused on the 6024 units in 17 residential complexes as shown in Table 2 which received EDGE certificate from 1 July 2017 until 19 June 2022. The characteristics analysis of buildings was performed based on (1) the features of the environmental technical strategies applied in 17 residential complexes, (2) the buildings' energy, water, and embodied energy in materials savings and annual CO_2 savings, and (3) solution to housing issues and accommodation capacity based on housing units. Building-related data from the EDGE website were examined as a given priority and supplementary data from the buildings' real estate developers [37,38]. Each data collected at the preliminary through final stage of certification includes certification level, building's location, photos, floor area (m^2), the savings on energy, water, and embodied energy in materials, annual CO_2 savings, and technical solutions to save energy, water, and materials. Table 2 summarizes the main features of 17 EDGE-certified residential complexes. In this study, we used correlation and regression analysis to find the relationship between energy, water, embodied energy in materials, CO_2 savings, and floor area using the SPSS program [39].

Table 2. Seventeen residential complexes with EDGE certification [40].

Building Name	Floor Area (m^2)	Certification Stage [1]	Certification Date
Devland Gardens	36,868	PEC	19 June 2022
The Block	21,582.72	PEC	1 November 2021
Terenure	20,077.28	PEC	1 November 2021
Southgate Ridge	20,542.32	PEC	1 November 2021
Erand Creek	18,273.36	FEC	1 August 2021
The Eden	14,087	FEC	1 December 2020
The Residence	28,242	FEC	1 December 2020
Green Court and Stepney Green	22,557	FEC	1 November 2020
Urbika Apartments	146.467	PEC	1 November 2020
Celebration Retirement Village	19,046	PEC	1 February 2019
Waterfall Park	21,361	FEC	1 January 2019
Zevenwacht Lifestyle Estate	17,297	PEC	1 July 2018
Belhar Gardens	21,886	FEC	1 March 2018
The Village (Clubview)	17,300	FEC	1 November 2017
Candlewood Crescent	10,124	FEC	1 October 2017
Tygerberg 3 Student Residence	3120	PEC	1 September 2017
Fourleaf Estate	4080	FEC	1 August 2017

[1] PEC: Preliminary EDGE Certificate, FEC: Final EDGE Certification.

3. EDGE Building Evaluation System in South Africa

3.1. EDGE Environmental Strategies in 17 Residential Complexes

EDGE's representative environmental strategy is improving energy efficiency. A total of 6024 units in 17 EDGE residential complexes have shown technical solutions that reduce energy consumption and thus occupants pay less in utility fees. The strategies include window-to-wall ratio (WWR), openings, green roofs, air filtration systems, energy-efficient artificial lighting, elevators, ceiling fans, and air exchange system to reduce indoor and outdoor temperature differences. General cleaning, washing, toilet flushing, equipment, water for heating, ventilation, and air conditioning (HVAC) kitchen, swimming pool, rainwater collection, and water recycling were considered in various ways for water management. Insulation materials, structural members of buildings (beams, floor slabs, interior and exterior walls, roofs), multi-pane glass, and low-E glass were mainly applied as materials [26,41].

3.2. EDGE Certification Process

EDGE's certification process consists of a total of six steps, and all steps must be completed before a certificate is granted. First, the applicant uses the EDGE web-based software to register general information for the project. Second, the applicant registers for the project and pays the applicable fees. Third, the applicant selects an EDGE auditor from the provided list. Fourth, the applicant uses the EDGE app to collect and submit all relevant documents and then pays a certification fee after submitting the application. Fifth, the EDGE auditor and GBCI (Green Business Certification Inc., Washington, DC, USA) review the submitted application of the project in detail. Sixth, if all previous processes are successfully completed, EDGE certification is granted to the project. EDGE Advanced is awarded only if the project achieves at least 40% of the projected energy savings and at least 20% of the projected water savings. After receiving EDGE certification, EDGE Zero Carbon certification may be pursued. This process is not mandatory and can only be carried out by projects granted EDGE Advanced [42]. Table 3 summarizes the characteristics of the EDGE certification system.

Table 3. Summarized characteristics of EDGE certification system.

Aspects	Information	
Country [40]	More than 140 countries Active in 35 countries, More active in Colombia, Ecuador, India, Indonesia, Mexico, South Africa, Vietnam	
Energy [41,43]	Energy efficiency, Low energy consumption, renewable energy	
Materials and chemical products	Selective choice of materials material recycling	
Target and priority [44]	Resource savings (energy, water and embodied energy in materials), affordability, solve housing shortage	
Who may be a licensee [41]	Architect Engineer Developer Building owner	
Level of certification [16]	3 levels (including EDGE Zero Carbon Certification (optional))	
License validity and renewal [16]	LEVEL 1: Certified LEVEL 2: EDGE Advanced LEVEL 3: Zero Carbon	Not required Not required Every 4 years with 100% renewables Every 2 years with purchased offsets
Building type [27]	Educational facilities, Residential complexes, hospitality facilities, medical centers, light industries, offices, retail, and warehouses (Only Residential complexes in South Africa).	

Table 3. *Cont.*

Aspects		Information	
Certification standard [16]		20% reduction in operational energy consumption, embedded energy, embodied energy	
Consideration for calculation [43]		Building type, occupant use [27]	Homes, hotels, offices, hospitals, retail, education
		Climate condition	Temperature, wind velocity, humidity, solar radiation, rainfall, CO_2
		Location	
		Design, specifications	Base case, Improved case
On-site audit [41]		V	
WWR [43]		Reduced WWR	30%—residential building 55% non-residential building
Insulation [43]		Roof, ground/raised floor slab, exterior walls	
User demand [43]	Overall energy demand	Heating, ventilation, air conditioning, plug loads, fans, cooking, hot water,	
	Hot water demand	Cold water supply Temperature (mean annual temperature of location) Hot water delivery temperature (40 °C) Energy needs for hot water Fuel energy needed	
	Lighting energy demand [43]	Use "quick method" under EN 15193'S energy requirements—installed lighting power, annualized usage	
	Water demand [43]	Fresh water, recycled water, rainwater harvested => water "savings"	

3.3. *EDGE Zero Carbon Certification*

There are three levels of EDGE certification; Level 1: EDGE Certified, LEVEL 2: EDGE Advanced, and LEVEL 3: EDGE Zero Carbon [16]. EDGE Advanced projects are eligible for EDGE Zero Carbon certification under the conditions of 20% water and embodied energy savings, 40% energy savings, and 100% energy savings through renewable or carbon offsets [27,41,43]. There are three requirements in total. First, the building must be one of the building types mentioned by the EDGE, such as educational facilities, residential buildings (homes), accommodation facilities, medical facilities, light industry, office buildings, and retail and warehouses. Second, the normal building occupancy rate must be at least 75%. Finally, only EDGE Advanced certified buildings can apply [27,41,43]. Requirements, timing, and renewal of each level are presented in Table 4.

Table 4. Comparison between EDGE's levels of certification [16,27].

Elements	Level 1: EDGE Certified	LEVEL 2: EDGE Advanced	LEVEL 3: EDGE Zero Carbon
Requirements	20% or more savings in energy, water and embodied energy in materials	EDGE certified with 40% or more on-site energy savings	EDGE Advanced with 100% renewables on-site or off-site or purchased carbon offsets to complete at 100%. All energy must be accounted for, including diesel and LPG.
Timing	At preliminary and final certification stages	At preliminary and final certification stages	At least one year after final EDGE certification with 75% occupancy, when operational data must be submitted.
Renewal	Not required	Not required	Every four years with 100% renewables and every two years with purchased offsets.

4. Result

4.1. Environmental Technical Strategies

In this paper, we analyzed (1) the features of the environmental technical strategies applied in 6024 units in 17 residential complexes, (2) the buildings' energy, water, and embodied energy in materials savings, and annual CO_2 savings, and (3) solution to housing issues and accommodation capacity based on housing units. Due to overpopulation in big cities, housing shortages are frequent. The results of this study showed that 70.6% of residential complexes with EDGE certification are located in major cities such as Cape Town and Johannesburg, and 23.5% in cities or towns that are close to a major city.

The energy, water, and materials technical solutions of the 17 residential complexes are shown in Tables 5–7, respectively. Each solution applies to different locations or elements of buildings. Among these, there are indoor, outdoor, common areas, internal and external walls, roof, and floors. No building has all the technical strategies, but all buildings have at least 50% of all the strategies. The Block and Tygerberg 3 Student Residence had the highest total number of solutions, followed by Green Court and Stepney Green and The Eden. On the other hand, Fourleaf Estate and Waterfall Park had the least number of strategies. The smaller and the lower the building is, the fewer number of strategies it possesses.

Table 5. Summarized energy-related technical solutions of the 17 residential complexes in South Africa with EDGE certification [40].

Technical Solutions	Location	Percentage of Buildings with the Corresponding Solutions
Lighting controls	Common spaces Outdoor	41.2% 11.7%
Reflective paint	Roof External walls Tiles and roof	11.7% 5.9% 5.9%
Energy-saving lighting system	Indoor Outdoor Common areas	70.6% 58.8% 35.3%
Reduced window-to-wall ratio	Window + wall	100%
Heat pump (hot water generation)		35.3%
Low-E coated glass		5.9%
Solar photovoltaics		29.4%
Smart electricity meters		58.8%
External shading devices		17.6%
Solar hot water collectors		41.2%
Roof insulation		35.3%
External wall insulation		11.7%
Natural ventilation		5.9%

Table 6. Summarized water-related technical solutions of the 17 residential complexes in South Africa with EDGE certification [40].

Technical Solutions	Location	Percentage of Buildings with the Corresponding Solutions
Low-flow faucets	Bathroom sinks Washbasins Kitchen sinks	41.2% 64.7% 88.2%
Low-flush toilet	Toilet	5.9%
Low-flow showerheads		88.2%
Dual-flush (for) water closets		88.2%
Single flush water closets		11.7%

Table 7. Summarized materials-related technical solutions of the 17 residential complexes in South Africa with EDGE certification [40].

Technical Solutions	Location	Percentage of Buildings with the Corresponding Solutions
Hollow core precast slab	Floor Roof	41.2% 29.4%
Steel sheets on timber rafters	Roof External walls	47% 11.7%
Solid dense concrete block	Internal External	58.8% 64.7%
Cored bricks with internal and external plaster	Internal walls External walls	11.7% 5.9%
Cored bricks with plaster on both sides	Internal walls Externals walls	5.9% 5.%
Cement fiber boards on metal studs	Internal walls External walls	5.9% 5.9%
Exposed cored bricks with internal plaster	External walls	5.9%
Clay roofing tiles on timber rafters	Roof	5.9%
Micro concrete tiles on steel rafters	Roof	17.6%
Cellulose roof insulation		5.9%
Finished concrete flooring		5.9%
Facing bricks		11.7%
Ceramic tiles (for) flooring		41.2%
Cork (for) flooring		5.9%
Aluminum window frames		17.6%
Floor slabs of hollow core precast slab roof		11.7%
Timber floor construction		5.9%
Cored bricks with plaster on both sides flooring		5.9%
Recycle of existing slabs, roof, internals and externals walls, flooring frames		11.7%

4.1.1. Energy Saving Strategy

Energy technical solutions are shown in Table 5. The table also shows the percentage of buildings that have the corresponding solutions depending on which part or location of the building it is installed. Energy technical solutions were divided into three major parts: energy-saving solutions (69.2%), energy-generating solutions (23.1%), and energy measurement (7.7%).

Buildings' design focused more on "efficiency first" and energy and water demand reduction than on-site energy generation. All energy-saving strategies were designed and installed during construction. Consequently, the building user has little to no extra work to do other than use the given environment well. Energy-saving solutions comprise lighting controls, reflective paint, an energy-saving lighting system, reduced window-to-wall ratio, low-E coated glass, external shading devices, roof and external wall insulation, and ventilation. Energy-generating solutions consist of solar photovoltaics and solar hot water collectors. In energy use solutions there is a heat pump (hot water generation) and in energy measurement, there are smart electricity meters. All buildings had a reduced window-to-wall ratio (gross glazing area (m^2)/gross exterior wall area (m^2). In particular, buildings are designed to prevent thermal bridging where heat and energy leak, especially shown in Belhar Gardens [34]. Smart meters record a monthly energy footprint and show energy consumption, which helps residents save on utility bills [41,45]. Reduced wall-to-wall ratio, natural ventilation, insulated roofs, and walls optimized energy efficiency and saved electricity bills. [46].

4.1.2. Water Saving Strategy

Of all the three groups of technical solutions, water had the least number of strategies. Water strategies focused on controlling water flow in the bathroom and kitchen. Low-flow fixtures were installed for the purpose of water consumption and decreasing energy. When they are used, water usage reduction is expected to be more than 50% [47]. A total of 88.2% of buildings had low-flow faucets in kitchen sinks, low-flow showerheads, and dual-flush water closets installed. Dual-flush toilets are known to be more environmentally friendly and more water-saving than single-flush toilets. Water technical solutions are shown in Table 6 below.

4.1.3. Material Use and Saving Strategy

There are different strategies used on different components of a building such as a floor, internal and external walls, and roof. Solid dense concrete blocks were the highest with 64.7% on externals and 58.8% on internals. On average, 11.7% of buildings have recycled existing slabs, roofs, internal and external walls, and flooring frames. Material technical solutions are shown in Table 7 below.

In particular, the Tygerberg 3 Student Residence building at Stellenbosch University used lightweight steel construction instead of bricks and mortar, 90% of the steel structure was recycled, and no water was needed during the construction process, which means that it is carbon neutral. Its construction time was reduced by 40%, building costs up to 13%, and construction waste from between 25% to less than 0.1% of building bulk [48]. In Fourleaf Estate, the community is required to do recycling [49].

4.2. Environmental Improvement

Buildings with EDGE certification conserve and protect natural resources. Each project creates a base case at the design stage based on assumptions. The assumptions are made by using national or local building performance codes, market studies, and data collection about actual buildings in the country where the project is based. A project selects technical measures to reduce corresponding resource consumption. A building satisfies the EDGE standards by proving that the difference in consumption between the base case and the improved case is above the required value [43]. Figures 1–4 represent energy savings (%), water savings (%), embodied energy in materials savings (%), and total annual CO_2 savings (ton), respectively, of the 17 buildings. South African residential complexes with EDGE certification had an average of 29.7% energy savings, 31% water savings and 54% embodied energy in material savings. All buildings with EDGE certification had a total of 5979.41 tons of CO_2 savings annually. Generally, the total number of savings (energy, water, and embodied energy in materials) increased from 2017 to 2020 with a slight decline in between. None of the seventeen buildings had EDGE Zero Carbon Certification and only two of them have achieved LEVEL2: EDGE ADVANCED. Even though residential complexes comprised more than 73% of all EDGE-certified buildings in South Africa, they occupy only 33.3% of all LEVEL2: EDGE ADVANCED achievers. EDGE Zero Carbon level is harder to achieve compared to other levels. For this reason, only three of all buildings with EDGE certification reached the EDGE Zero Carbon level.

4.2.1. Energy Savings

Given 17 residential complexes, on average, the total energy is saved by 29.7% compared to the base case which does not have an EDGE certification system in South Africa. Urbika Apartments had the highest energy savings with 53%, followed by Belhar Gardens with 41%. Waterfall Park and Terenure had the lowest savings of 21%. Even though Terenure had the lowest in energy savings, its high savings in "embodied energy in materials" made it come fourth in the overall ranking, even before the highest energy saver, Urbika Apartments. Figure 1 shows the energy savings of each building.

Due to the fact that South Africa's climate is warm, a reduced WWR minimizes the heat gain from windows and keeps the indoor air cool. Consequently, residents can save money from summer cooling and sometimes from winter heating. One-third of the electricity used in Tygerberg 3 Student Residence was produced by solar photovoltaics and its 25 units do not need air conditioning or space heating to achieve thermal comfort [48].

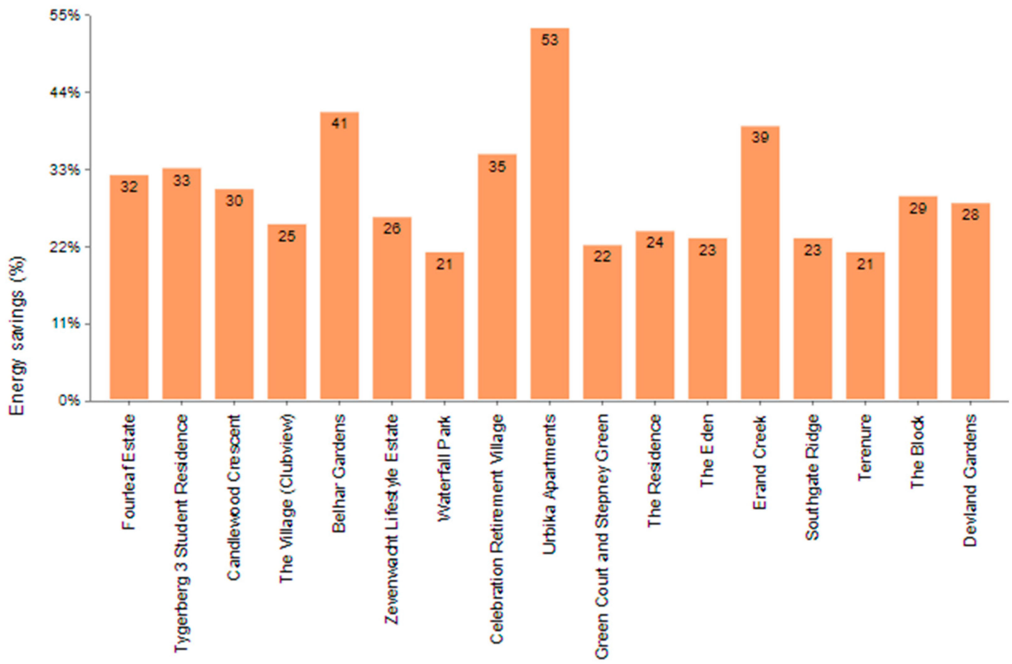

Figure 1. Energy savings (%) of the 17 South African residential complexes with EDGE certification.

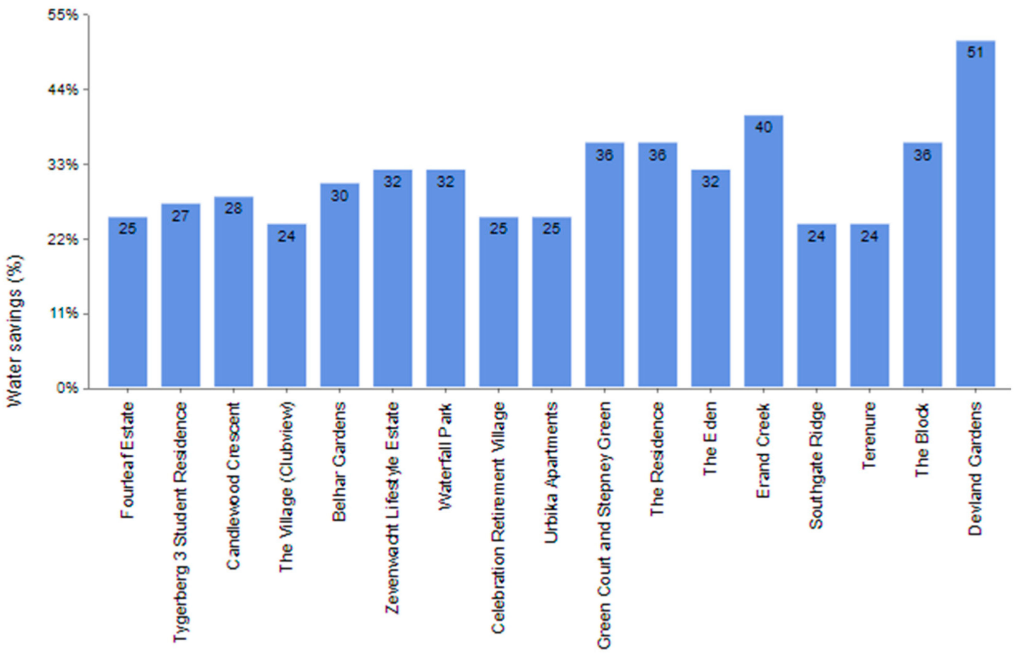

Figure 2. Water savings (%) of the 17 South African Residential complexes with EDGE certification.

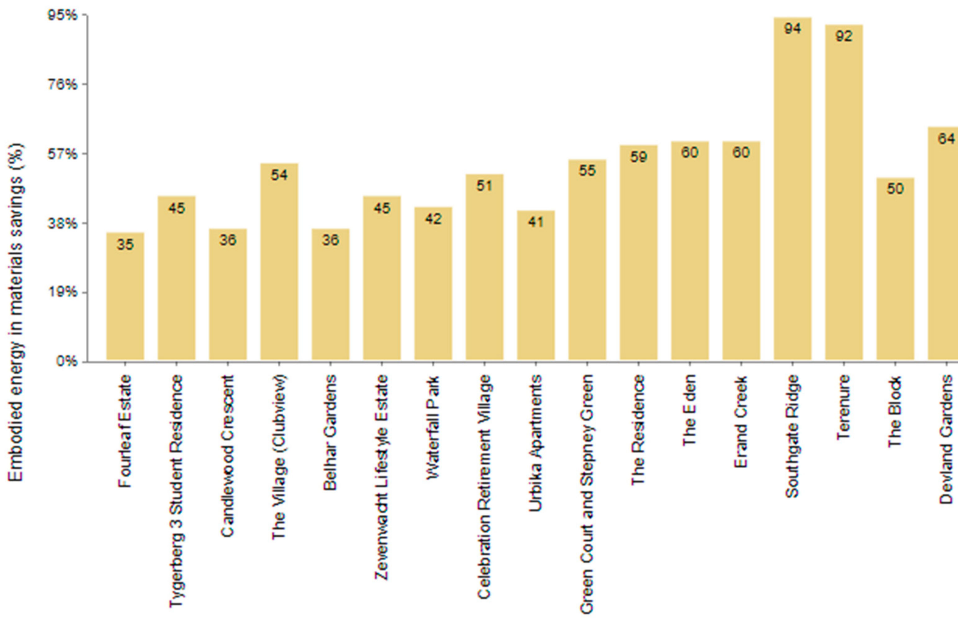

Figure 3. Embodied energy in materials savings (%) of the 17 South African residential complexes with EDGE certification.

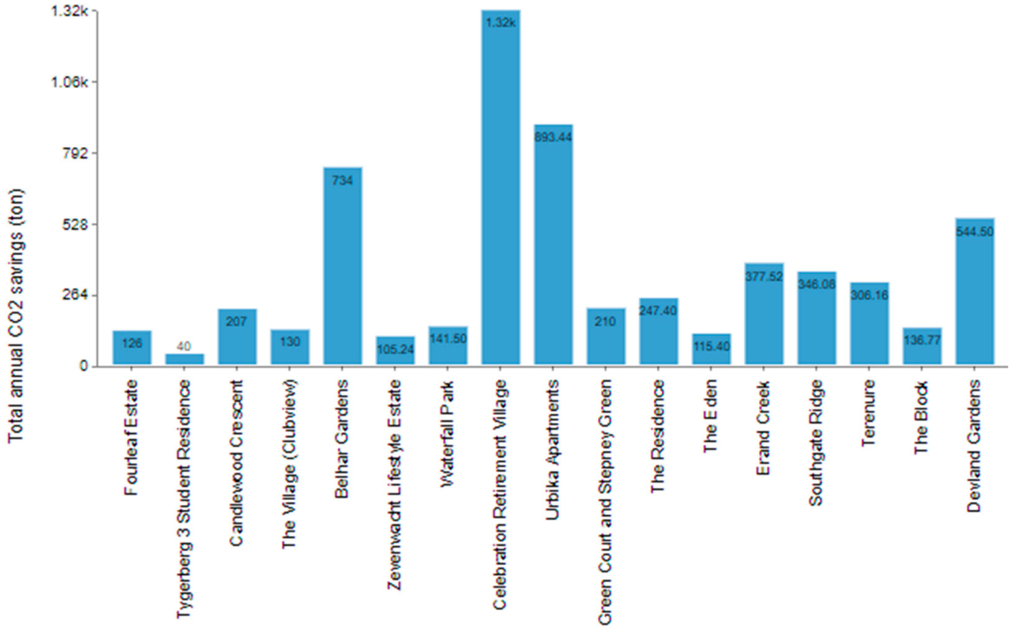

Figure 4. Total CO_2 savings (annually (ton) of the 17 South African residential complexes with EDGE certification.

4.2.2. Water Savings

Water use reduction is important due to its scarcity in big cities such as Cape Town. Water has been restricted in 2018 and there is a severe water shortage caused by drought [50]. This caused water to become the most expensive utility bill for residents in cities such as Johannesburg [47]. On average, buildings saved 31% of water. Similar to energy savings, only one building had more than 50% savings. Devland Gardens had the most saving with 51% followed by Erand Creek with 40%. The Village (Clubview), Southgate Ridge, and Terenure came last with only 24% savings. Figure 2 shows the water savings for each building.

4.2.3. Embodied Energy in Materials Savings

The less embodied energy in materials a project has, the more sustainable the construction is, and the lower the carbon footprint emitted from the project [51]. In general, 17 buildings had the highest savings in embodied energy in materials. On average, buildings saved 54% of embodied energy in materials. Southgate Ridge had the highest with 94%, followed by Terenure with 92%. Fourleaf Estate had the lowest savings, with 35%. The lowest savings in "embodied energy in materials" was higher than the average of both energy and water savings. Embodied energy can be reduced when materials such as hollow core precast floor slabs, micro concrete tiling on roofs, and core brick walls are used in construction [47,52]. Figure 3 shows embodied energy in the materials savings of each building.

4.2.4. Total Annual CO_2 Savings

The purpose is to reduce the total CO_2 footprint that a project could have emitted into the atmosphere. Carbon reduction or removal is calculated in one metric ton (ton) of CO_2 or equivalent greenhouse gas (GHG). CO_2 emissions of the improved case and the carbon offset's value are compared to determine the percentage of the total offset. There are no restrictions on the kind and origin of carbon offsets. This can be from renewable energy, energy efficiency improvements, methane (CH_4) and CO_2 capture and storing, or forest restoration and conservation. On average, buildings saved 351.73 tons of CO_2. The savings range from 40 to 1318.4 tons per year where there was a significant gap in CO_2 savings among buildings. Celebration Retirement Village had the highest annual CO_2 savings with 1318.4 tons, followed by Urbika Apartments with 893.44 tons. Tygerberg 3 Student Residence had the lowest savings of only 40 tons. Figure 4 shows the total annual savings of each building.

4.2.5. Statistical Analysis of Relationship between Energy, Water, and CO_2 Savings and Floor Area

Figures 5–8 show the correlation between energy savings, water savings, embodied energy in materials, CO_2 savings, and floor area. Figures 5, 7 and 8 show no correlation whereas Figure 6 shows a moderate correlation.

The results of the relationship of energy, water, embodied energy in materials, and CO_2 savings with floor areas show that there is no strong correlation as shown in Table 8. There was a low positive correlation between the energy savings and floor area; a moderate positive correlation between water savings and floor area; a low positive correlation between embodied energy in materials savings and floor area; and a very low positive (negligible) correlation between the CO_2 savings and floor area.

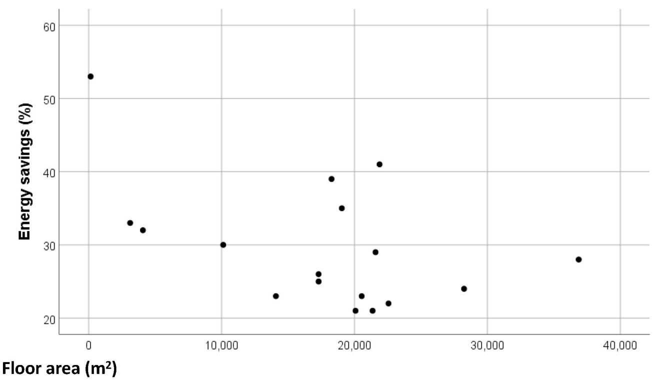

Figure 5. Energy savings per floor area.

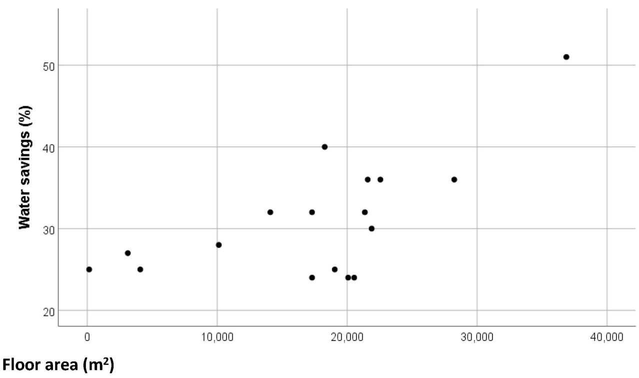

Figure 6. Water savings per floor area.

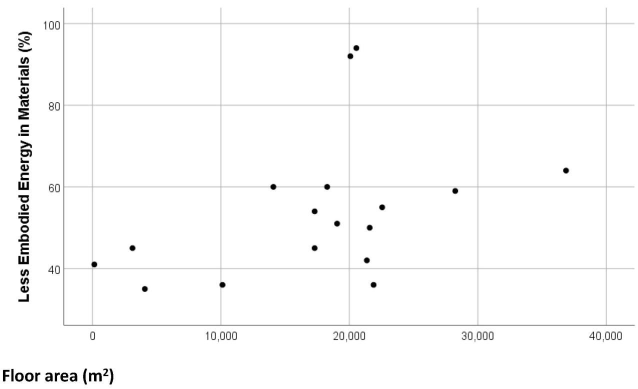

Figure 7. Embodied energy savings in materials per floor area.

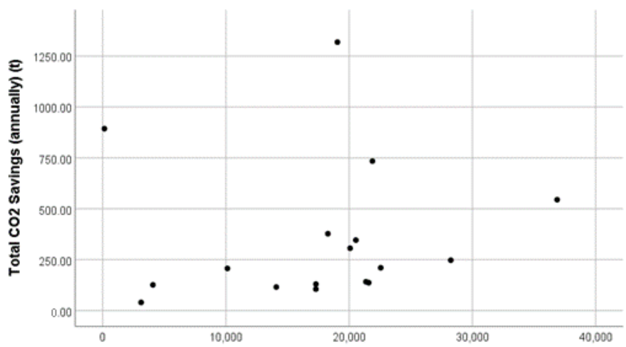

Figure 8. CO_2 savings per floor area (m^2).

Table 8. Statistical data about the relationship between energy, water and CO_2 savings and floor area.

Savings	**Correlation Coefficient R**	**Coefficient of Determination R^2**	**Estimated Regression Equation (Y = aX + b)**
Energy in materials savings	0.485	0.235	Energy savings = 0 floor area + 37.619
Water savings	0.666	0.444	Water savings = 0.001 floor area + 21.799
Embodied energy savings	0.418	0.175	Embodied energy in materials savings = 0.001 floor area + 40.327
CO_2 savings	0.067	0.004	CO_2 savings = 0.002 floor area + 308.2

4.3. Solution to Housing Issues and Accommodation Capacity

The critical housing issues in South Africa can be characterized by the lack ofxs quality and affordability [12]. Only 20.4% of urban households can afford a house with their financial capacity [12]. EDGE supports affordability and its projects are increasing in many African countries, including South Africa [53]. Given our data, the results of this research show that EDGE-certified buildings helped to solve some concurrent issues in residential complexes offering (1) a high capacity to accommodate many people, (2) affordability, (3) utility fee saving, and (4) improved quality of life. The average number of housing units is 376. Tygerberg 3 Student Residence is excluded as there was a lack of information. Devland Gardens had the highest with 870 units, followed by Celebration Retirement Village with 774 units and Belhar Gardens with 630 units. Zevenwacht Lifestyle Estate had the lowest of 95, which is almost four times lower than the average. Based only on the number of units, buildings with numbers of housing units are more likely to solve the housing shortage because they can accommodate a large number of people. However, considering that the buildings have a mix of one, two, and three bedrooms in one unit, it is impossible to determine which one can accommodate more people. Figure 9 shows the number of housing units each residential building possesses.

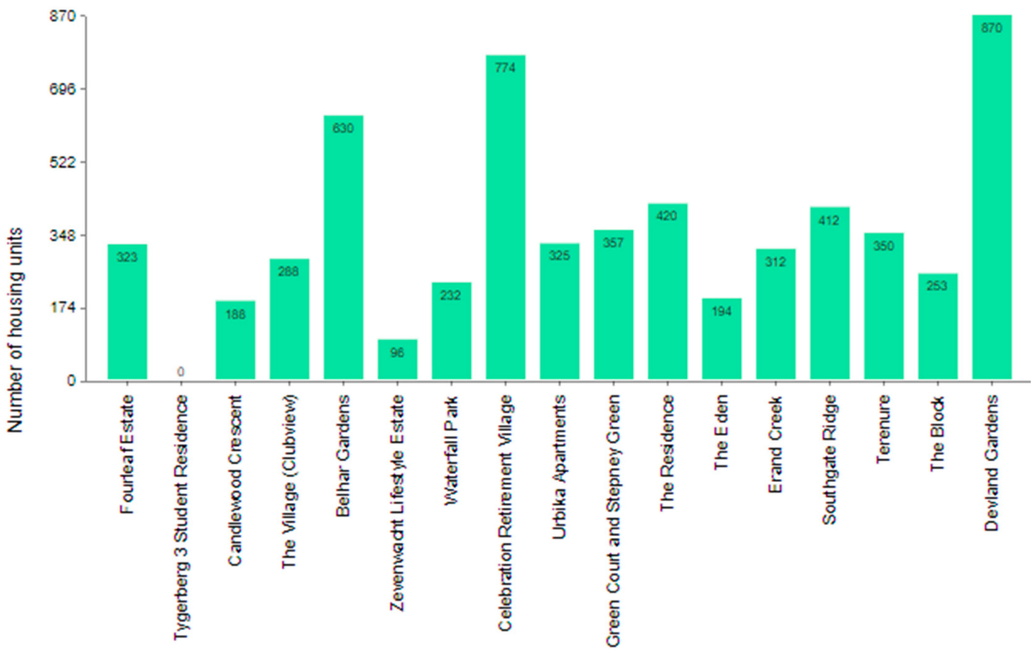

Figure 9. Number of housing units of the 17 South African residential complexes with EDGE certification.

A total of 76.5% of all the 17 EDGE-certified buildings are recognized by EDGE as affordable housing. Furthermore, the majority of developers of 17 EDGE-certified buildings are interested in affordability. A total of 47% of the buildings are developed by International Housing Solutions (IHS), a South African real estate developer which focuses on developing affordable green housing [46,54,55]. In addition, 17.6% are developed by Transcend Residential Property Fund (TPF) which invests in affordable housing [51]. Central Developments Property Group also develops affordable housing; however, its EDGE-certified building, Celebration Retirement Village focuses more on providing good retirement space than affordability [56]. The Social Housing Regulatory Authority (SHRA) granted full accreditation to Devland Gardens for providing affordable housing in Johannesburg [47]. Table 9 shows the affordable buildings and their developers.

Table 9. Affordability in the 17 EDGE-certified buildings.

Building Name	Affordable Housing [40]	Developer/Client [40–57]
Devland Gardens	✓ [1]	Instratin, IHS [4]
The Block	✓	TPF [5]
Terenure	✓	TPF
Southgate Ridge	✓	TPF
Erand Creek	✓	IHS
The Eden	✓	IHS
The Residence	✓	IHS
Green Court and Stepney Green	✓	IHS
Urbika Apartments	N/A	Similan Properties
Celebration Retirement Village	N/A [2]	Central Developments Property Group
Waterfall Park	✓	IHS
Zevenwacht Lifestyle Estate	N/A [2]	MSP [6]
Belhar Gardens	✓ [1]	MHA [7]
The Village (Clubview)	✓	IHS
Candlewood Crescent	✓	RPP Developments, IHS
Tygerberg 3 Student Residence	N/A [3]	STAG African
Fourleaf Estate	✓	Similan Properties

[1] social housing [2] retirement home, [3] student accommodation, [4] International Housing Solutions, [5] Transcend Residential Property Fund, [6] Multi Spectrum Property, [7] Madulammoho Housing Association.

EDGE-certified buildings have helped the affordability. The Madulammoho Housing Association (MHA), for example, the owner of Belhar Gardens, has played a big role by providing low-cost housing even students can live in. A total of 70% of Belhar Garden units are reserved for households that earn between USD 216 and USD 432 monthly income. The rest is for those with a combined household income that is less than 216 USD [50]. Similarly, Waterfall Park offers two-bedroom, one-bath and two-bedroom, two-bath homes with rent between USD 365 and USD 389 [55]. The affordability of the buildings has caused high competition between buyers and renters. For instance, The Village (Clubview) has a high demand for its units where the properties are between USD 340 and USD 424 because of its ideal location and high quality in addition to the affordability [46].

The 17 buildings with EDGE certification not only solve housing affordability but also provide a quality life to their residents. Projects are situated in a good location where occupants can find work opportunities, access to public transport, educational facilities, and other amenities in the vicinity [45]. Celebration Retirement Village's community is involved in contributing to environmental sustainability such as reducing their carbon footprint despite their old age. The building gives a convenient and safe environment to the retired. Residents can access amenities including a hair salon, restaurant, library, and swimming pool within the perimeter of the project [56]. Zevenwacht Lifestyle Estate, another retirement building with EDGE certification prioritizes the health of its retired residents where there are healthcare centers and assisted living suites. Residents can also enjoy outdoor activities such as hiking trails in nearby mountains [52].

5. Discussions

The EDGE has played a critical role in the development of sustainable architecture and the building industry in improving the quality of buildings, especially in developing countries including South Africa. However, given the seventeen projects with EDGE certification, only three buildings have reached the EDGE Zero Carbon level and none of them are in South Africa. Therefore, buildings are encouraged to have EDGE Zero Carbon Certification as it helps reduce the environmental impact caused by the building industry. Moreover, EDGE should encourage building developers to focus and invest not only in quality but also affordability that ordinary citizens can use. It is important to remember that not all green buildings are certified, and all buildings should aim for sustainability. As the world is facing an environmental crisis, it is crucial to revise the impact of the built environment on our natural environment and its contribution to protecting it. A small daily improvement in resource efficiency produces a long-term, positive and tangible impact on humans and the environment. Large buildings use more resources, which negatively impacts the environment and the economy more than smaller buildings. On the other hand, a small percentage of resource-saving can result in bigger savings. Therefore, EDGE should regulate and give detailed guidelines on savings based on the size of the project. EDGE has fewer areas of focus compared to other certification systems. As a result, it should be expanded to other areas such as indoor environmental quality, transport, waste management, ecology management, sustainable sites, local environment, among others. More aspects conditioned to certify will provide better quality buildings.

In future studies, we considered that it is necessary to expand the application cases of various certification systems and facilities to not only residential but also other building types such as office buildings and medical facilities to conduct a broad and in-depth analysis including the post-occupancy evaluation and life cycle analysis. In future research, we will also study the correlation between social economic status, WWR, and location with energy and water consumption.

6. Conclusions

Through this study, characteristic analysis of the EDGE certification system was conducted by focusing on 6024 units in 17 residential complexes. This study highlights that EDGE tackles South African housing issues and improves building performance through its certification. Thus, the purpose of EDGE in South Africa reflects the country's big issues with residential complexes. In particular, it measures energy savings, water savings, embodied energy in materials, and total CO_2 savings (annually) for each building at both the preliminary and final EDGE Certification stages. Based on the results of this study, energy and water "efficiency first" solutions were prioritized over on-site energy generation during the design of buildings. The average savings for 17 EDGE-certified residential buildings from August 2017 to June 2022 are as follows: energy (29.7%), water savings (31%), embodied energy in materials (54%), and total annual CO_2 savings (351.73 t). All buildings reduced energy consumption through a reduced WWR. Buildings installed low-flow plumbing fixtures such as faucets and showerheads. A total of 88.2% of buildings had low-flow faucets in kitchen sinks, low-flow showerheads, and dual-flush water closets installed. Consequently, water usage was expected to be reduced to more than 50%. In materials used on buildings, solid concrete blocks were installed in 64.7% of all buildings. Buildings with outdoor energy-saving lighting systems and smart electricity meters equally accounted for equally 58.8% of all cases. Among all technical solutions, energy-saving solutions were the most used accounting for 69.2% of all technical strategies, followed by energy-generating solutions (23.1%). Lastly, energy measurement accounted for only 7.7%. According to the statistical analysis, there is no statistically significant relationship between energy, water, embodied energy in materials, and CO_2 savings with floor areas.

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Abbreviations

BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
CO_2	Carbon dioxide
DGNB	German Sustainable Building Council
EDGE	Excellence in Design for Greater Efficiencies
EPA	U.S. Environmental Protection Agency
GBCSA	The Green Buildings Council of South Africa
GDP	Gross Domestic Product
G-SEED	The Green Standard for Energy and Environmental Design
HQE	Haute Qualite Environnementale
HVAC	Heating, Ventilation, and Air Conditioning
IEA	International Energy Agency
IFC	International Finance Corporation
HIS	International Housing Solutions
LEED	Leadership in Energy and Environmental Design
LPG	Liquefied petroleum gas
MHA	The Madulammoho Housing Association
MSP	Multi Spectrum Property
SHRA	The Social Housing Regulatory Authority
TPF	Transcend Residential Property Fund
USD	United States Dollar
WWR	Window-to-wall ratio

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