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Review

Energy Efficiency Trends in The Built-Environment Globally and in Egypt: A Literature Review

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Abstract: Buildings consume 30% of the total energy consumption around the globe and 29% of the energy consumption in Egypt which in 2022 had a total population of 102 million, out of which 43 % live in urban areas . The operation of buildings contributes to around 30% of global CO2 emissions due to their high energy consumption (IEA, 2022a). Among the efforts made towards improving the energy efficiency of buildings are Advanced Energy Design Guides (AEDGs), building rating systems, codes, and standards. Furthermore, numerous research studies that are either literature review studies, experimental studies, or computational studies addressed the topic of energy efficiency in buildings. These are all examined in this literature review with the purpose of identifying the research gap in available research with a focus on Egypt. The identified gap is the development of a prescriptive path for the GPRS energy efficiency category based on whole building energy simulations.

Keywords: buildings; energy efficiency; design guides; rating systems; egypt; review

1. Introduction

Building's energy consumption contributes to around 30% of total global final energy consumption where the energy consumption of the building sector only accounted for 132 EJ in 2021(IEA, 2022b). This energy consumption was reflected by an equally significant carbon footprint of 28% of global energy sector related emissions (IEA, 2022a). The energy consumption and CO2 emissions of the building sector in comparison to other sectors are demonstrated in Figure 1 and Figure 2 below. According to IEA forecast, the total built area of the building sector is expected to grow by 20% by 2030 . This will be reflected on both the energy consumption and carbon footprint of buildings and thus, efforts must be made to improve the energy efficiency of buildings and ensure sustainability of the building sector by reducing its energy consumption and consequently its carbon footprint.

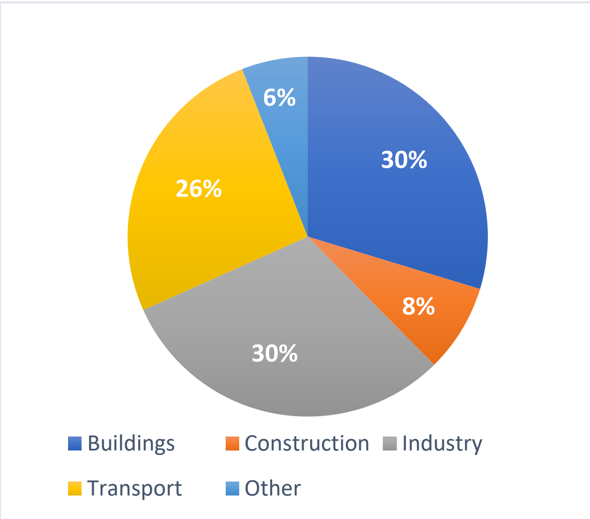

Figure 1. Total Final Global Energy Consumption in 2021 (UNEP, 2022).

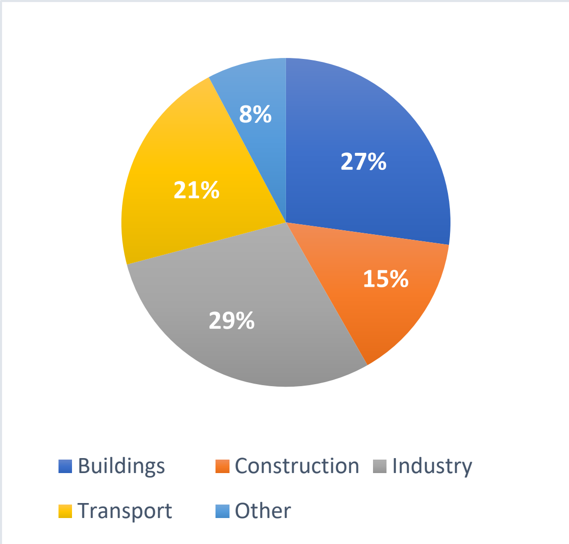

Figure 2. Global Energy and Process CO2 Emissions in 2021 (UNEP, 2022).

In 2021, the global mean average temperatures were about 1.1 °C above pre-industrial levels. The seven years up to and including 2021 recorded the hottest temperatures historically around the world. As climate change and urbanization push temperatures higher, the need for space cooling increases. And those with the most cooling needs have the least access to air conditioning. On Average, countries with developing economies experience 2150 cooling degree days (CDDs) per year as opposed to 700 CDDs experienced by countries with advanced economies. Yet, only 30% of households in developing countries have air conditioning and as low as 7% in Africa compared to 50% in advanced economies (IEA, 2022b). Recent data published by Sustainable Energy for All (SEforALL) shows that at least 1.17 billion people worldwide lack access to cooling services (SEforALL, 2023). This means that not only the efficiency of cooling appliances is of major importance to reduce energy demand, carbon emissions and household bills, but also the efficiency of the building envelope is even more critical specially to those with no access no air conditioning.

Temperature rise followed a similar yet more extreme trend in Egypt. In the years between 1901 and 2013, the average temperature increase per decade was 0.1°C which then accelerated to 0.38°C per decade between 2000 and 2020. This temperature increase was higher than the world average by 0.07°C and resulted in 300 CDDs increase during that period in Egypt (IEA, 2023a). According to IEA, the total number of CDDs reached 1461 in 2020(IEA, 2023b). In 2022, the population growth rate in Egypt was projected by the United Nations to be 1.55% (United Nations, 2022) . Heat waves, together with population growth and urbanization is expected to significantly increase the cooling demand for electricity which is already estimated by UNDP to be 50% of all electricity consumption during peak summer months in Cairo (IEA, 2023a).

According to the Egyptian Electricity Holding Company (EEHC) annual report, the highest energy consumption is attributed to households which represent 40.5% of total energy sold in the financial year 2020/2021(EEHC, 2021). The percentage of households energy consumption compared to other sectors is shown in Figure 3 below. In 2022, Egypt published its first updated Nationally Determined Contribution (NDC) highlighting its efforts and ambitions goals to combat climate change. Among those efforts is promoting green buildings through the activation of the energy efficiency code for residential and commercial buildings established by the Housing and Building Research Center (HBRC) and developing 16,960 residential units according to green building standards by 2030 (*Egypt ' s First Updated Nationally Determined Contributions*, 2022). Therefore, although this review will include energy efficiency building related studies for different types of buildings, it will be mainly focused on residential buildings due to the significance of their energy consumption.

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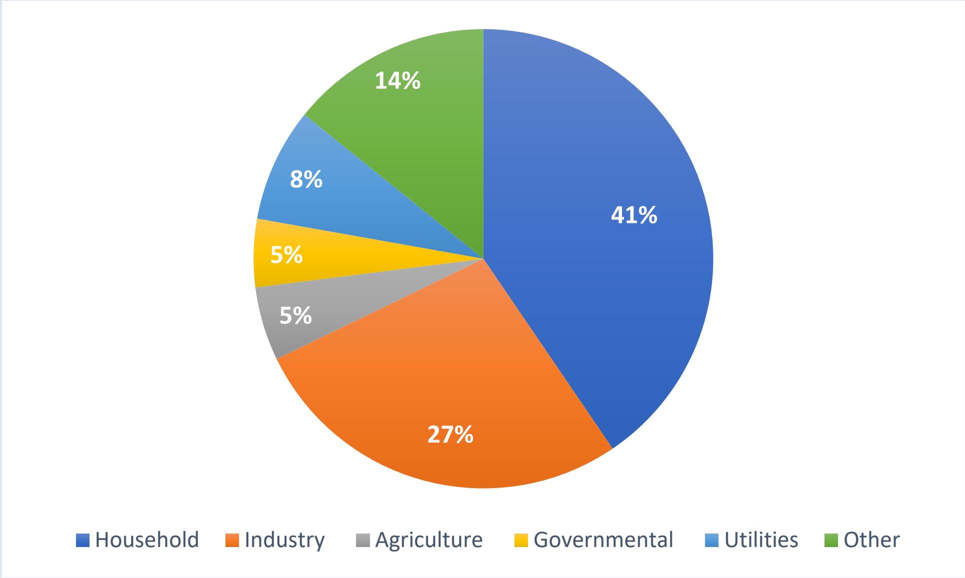

Figure 3. Quantities of Sold Energy by Purpose in 2020/2021 (EEHC, 2021).

This Literature review explores trends in the field of energy efficient buildings globally, regionally, and locally in Egypt. Egypt is identified as one of the high-impact nations, which is expected to experience prolonged elevated temperatures putting is significant population at increased risk from a lack of access to cooling, primarily due to poverty and gaps in electricity access (SEforALL, 2023). Literature addressing energy efficient buildings design guidelines is examined in terms of strategies and measures recommended to improve building energy performance, evaluation parameters and criteria upon which these recommendations were made, and methods and software tools used in the process of developing these guidelines. The purpose of this literature review is to examine international best practices, benchmark existing literature focused on Egypt (local) up against global and regional literature and identify the gap in the available guidelines for energy efficient buildings in Egypt.

2. building Energy Efficiency Guides and Rating Systems

2.1. Ashrae Advanced Energy Design Guides

The solution of zero energy buildings is faced with many challenges including high initial cost, limited incentives, and lack of social awareness (Manzoor *et al.*, 2022). One of the solutions to address these challenges are the American Society for Heating Ventilation and Air Conditioning Engineers (ASHRAE) AEDG achieving 30% and 50% Energy Savings towards a Net Zero Energy Building in addition to their guidelines on achieving zero energy buildings. The AEDGs are developed in collaboration with the American Institute of Architects (AIA), the Illuminating Engineering Society (IES), the U.S. Green Building Council (USGBC) and the Department of Energy (DOE) in the US.

ASHRAE advanced energy design guides are a series of publications that provide energy saving recommendations beyond the minimum requirements of ASHRAE standard 90.1-2004, Bonnema et al., (2012). These design guides are building type specific depending on occupancy classification and building size including a guide for small to medium size offices, a guide for small hospitals and healthcare facilities, another one for large hospitals and others. Table 1 provides a summary for ASHRAE AEDGs to date.

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Table 1. Summary of ASHRAE Existing AEDGs.

AEDG	Building Category	Guide Scope	Date Published
30% Energy savings	Small Office Buildings	This guide is intended for office buildings that have a total area of up to 20,000 ft² and uses unitary heating, ventilation, and air conditioning (HVAC) equipment.	14/8/2008
	Small Retail Buildings	This guide is intended for small retail buildings that have a total area of up to 20,000 ft² and uses unitary HVAC equipment.	14/8/2008
	K-12 School Buildings	This guide is intended for elementary, middle, and high schools' buildings. Its guidelines only apply to classrooms, administrative spaces, assembly spaces, gymnasiums, hallways, kitchens, media centers and science labs. It does not apply to wet labs, dry labs, indoor pools or any other area with special HVAC or contamination control requirements.	14/8/2008
	Small Warehouses and Self-Storage Buildings	This guide is intended for warehouse with an area of up to 50,000 ft² and self-storage buildings with unitary HVAC equipment. It excludes special warehouses such as refrigerated warehouses and unheated ones.	14/8/2008
	Highway Lodging	This guide is intended for hotels found along highways, consisting of up to 80 rooms and going up for four stories or less. It excludes hotels with significant commercial cooking or refrigeration equipment.	9/6/2009
	Small Hospital and Healthcare Facilities	This guide is intended for small healthcare facilities of area up to 90,000 ft². It includes critical access hospitals with 25 beds or less and medical office buildings of area greater than 20,000 ft². The guidelines in this guide does not address steam heat and sewage disposal.	5/11/2009
50% Energy Savings	Small to Medium Office Buildings	This guide is intended for office buildings with a total area up to 100,000 ft². It applies to all types of offices including medical offices without medical examination equipment. The guidelines exclude specialty areas such as data centers.	28/4/2011
	K-12 School Buildings	This guide is intended for elementary, middle, and high school buildings of all sizes. Like the 30% Energy Savings Guide for K-12 schools, the guidelines of this guide exclude wet labs, dry labs, indoor pools or any other area with special HVAC or contamination control requirements.	28/9/2011
	Medium to Big Box Retail Buildings	This guide is intended for retail stores with a total area 20,000 ft²-100,000 ft². The guide also covers smaller or larger stores with similar space types. It, however, excludes areas with special HVAC and contamination control requirements such as commercial kitchens. It also excludes centralized refrigeration systems.	30/12/2011
	Large Hospitals	This guide is intended for medium and large hospitals which are typically at least 100,000 ft².	1/5/2012
	Grocery Stores	This guide is intended for grocery stores of area 25,000-65,000 ft² and have medium or low temperature	18/3/2015

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		refrigerated cases and walk-ins. This guide applies to smaller or larger stores with similar space types. It covers administrative places, dining facilities, medical spaces, sterilization area, storage areas, equipment spaces, pharmacies, and labs.	
	K-12 School Buildings	This guide is intended for elementary, middle, and high school buildings of all sizes. Like the 30% and 50% Energy Savings Guides for K-12 schools, the guidelines of this guide exclude wet labs, dry labs, indoor pools or any other area with special HVAC or contamination control requirements.	11/1/2018
Zero Energy	Small to Medium Office Buildings	This guide is intended for offices with total area 10,000 ft^2-100,000ft^2 and building height less than 75 ft. The guide also applies to large office buildings that are made up of sections of the same size range. The recommendations of this guide exclude food service or labs or any other areas with special HVAC or contamination control requirements.	14/6/2019
	Multifamily Buildings	This guide is intended for residential buildings covered by ANSI/ASHRAE/IES Standard 90.1 which go up to 20 floors. The guidelines exclude indoor pools, food service and domestic water well pumping and sewerage disposal areas.	14/4/2022

There are three categories of the ASHRAE advanced energy design guides which are 30% energy savings, 50% energy savings and zero energy guides. The energy saving strategies presented in these design guides are improved building envelope insulation and better glazing with overhangs, reduced lighting power intensity and plug and process load and better controls as well as integrating daylighting, higher efficiency HVAC equipment and Service Water Heating (SWH) systems. The guidelines provide specific energy saving design strategies for each of the 8 climate zones in the US, which can be further used as surrogate for other climates globally. The energy savings from these measures were assessed and quantified through building energy simulations using EnergyPlus software (Bonnema *et al.*, 2013).

For Example, the recommendations presented in (Bonnema, Pless and Doebber, 2010) to achieve 30% energy savings in small hospitals and healthcare facilities included some minimum and maximum values of a set of design parameters. These values are different for each climate zone. Taking building envelop in climate zone 5 as an example, the minimum R-values recommended in the guide for insulation of roofs, walls and floors are 30 ft^2.°F.hr/Btu, 13 ft^2.°F.hr/Btu, and 16.7 ft^2.°F.hr/Btu respectively. Meanwhile maximum values were recommended for vertical fenestration thermal transmittance (U-value) and solar heat gain coefficient (SHGC), and window to wall ratio (WWR). These maximum values are 0.29 Btu/ ft^2.°F.hr, 0.34, and 40% respectively (Bonnema, Pless and Doebber, 2010). These parameters can be used to quantify and evaluate the energy efficiency of prospective design strategies.

2.2. Buiding Rating Systems

Many building rating systems are developed around the world with the aim of making buildings more sustainable. In this section of the literature review, we look at nine (9) building rating systems: Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), Comprehensive Assessment System for Built Environment Efficiency (CASBEE), GREEN STAR, The German Sustainable Building Council rating system (DGNB: Deutsche Gesellschaft für Nachhaltiges Bauen), ESTIDAMA Pear Rating System (PRS), MOSTADAM, Green Pyramid Rating System (GPRS), and TARSHEED. These are the most widely known rating systems, and they are chosen to be representative of best practices from

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different continents around the world. Table 2 provides a summary to compare the different building rating schemes.

Table 2. Sustainable Building Rating System Comparison.

Rating System, Country of Origin, & Source	Development Basis	Categories & Weights[1]	Scope
BREEAM v6.0 (UK) (Fowler and Rauch, 2006; Rezaallah and Khoraskani, 2012; Ferreira *et al.*, 2023; *BREEAM-SE New Construction v6.0 Technical Manual 1.1*, 2023)	Original	Management – 10.82% Health and Wellbeing – 17.53% Energy – 18.4% Transport – 7.65% Water – 3.94% Materials – 16.73% Waste – 7.87% Land Use and Ecology – 9.84% Pollution – 7.22% Innovation (Bonus) – 10%	Communities Infrastructure New Construction (residential and commercial) In-Use (commercial) Refurbishment and Fit Out (residential and commercial)
LEED v4 (US) ('LEED v4 BDC Reference Guide', 2013; 'LEED v4 for Homes Design and Construction Checklist', 2014; Mohamed, Alwan and Marzouk, 2018)	Original	Integrative Process – 2% Location & Transportation – 15% Sustainable Sites – 7% Water Efficiency – 12% Energy & Atmosphere – 37% Materials & Resources – 9% Indoor Environmental Quality – 18% Innovation (Bonus) – 6% Regional Priority (Bonus) – 4%	Building Design and Construction (core and shell, schools, healthcare, retail, data centers, hospitality, warehouses, and distribution centers) Interior Design and Construction (commercial, retail & hospitality) Operation and Maintenance (existing buildings, existing interiors, schools, retail, data centers, hospitality, warehouses, and distribution centers) Residential (single family & low to mid rise multifamily) Neighborhood Development Cities and Communities
CASBEE[2] (Japan) (Fowler and Rauch, 2006; Dahal, 2017)	Original	Indoor Environment Quality of Service On-site Environment Energy	New Construction (buildings, detached houses & dwelling units)

[1] The weights presented are for multi-family residential buildings if available.

[2] The weight of each category varies depending on the project.

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		Resources and Materials Off-site Environment	Existing Buildings Renovation (buildings & housing) Temporary Construction Urban Development Cities
GREEN STAR v1.3 (Australia) (Fowler and Rauch, 2006; Nguyen and Altan, 2011; 'Design & As Built | Green Building Council of Australia', 2017)	BREEAM LEED	Management – 14% Indoor Environmental Quality – 17% Energy – 22% Transport – 10% Water – 12% Materials – 14% Land Use and Ecology – 6% Emissions – 5% Innovation (Bonus) – 10%	Communities Buildings – Design & As Built Interiors Performance – Existing Buildings
DGNB version 2023 (Germany) ('DGNB System – Sustainable and green building', 2020; DGNB SYSTEM KRITERIENKATALOG GEBAUDE NEUBAU, 2023; Ferreira et al., 2023)	Original	Process Quality – 12.5% Site Quality – 5% Environmental Quality – 22.5% Social and Functional Quality – 22.5% Technical Quality – 15% Economic Quality – 22.5%	Districts Construction Sites New Construction (office, residential, educational, hotel, consumer market, shopping center, department store, logistics, production, and assembly buildings) Renovated and Existing Buildings Interiors Buildings in Use Deconstruction of Buildings
PRS v1.0 (UAE) (*The Pearl Rating System for Estidama Building Rating System Design & Construction*, 2010; Ramani and García De Soto, 2021)	BREEAM LEED [3]	Integrated Development Process – 7% Natural Systems – 7% Livable Buildings – 21% Precious Water – 24% Resourceful Energy – 25% Stewarding Materials – 16% Innovating Practice (Bonus) – 2%	Design and Construction (villa, building, community) Public Realm
MOSTADAM V1.1 (Saudi Arabia) (*Mostadam Rating System Residential*	BREEAM LEED	Site Sustainability – 9% Transportation and Connectivity – 7% Region and Culture – 7% Energy – 27%	Design and Construction (communities, residential & commercial)

[3] Author's observation

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Buildings D+C Manual, 2019)		Water – 24% Health and Comfort – 14% Materials and Waste – 4% Education and Innovation – 4% Policies, Management and Maintenance – 4%	Operation and Existing (communities, residential & commercial)
GPRS v2 (Egypt) (Harb, 2019; HBRC, 2019)	LEED	Sustainable Site – 10% Energy Efficiency – 28% Water Efficiency – 30% Materials & Resources – 12% Indoor Environmental Quality – 12% Management Protocols – 8% Innovation and Added Value (Bonus) – 5%	New Construction
TARSHEED (Egypt) (Harb, 2019; BUILD ME Project-Phase II Status of Energy Efficiency in the Egyptian Building Sector Dr. Dalia Sakr, Egypt Green Building Council, 2020)	The Excellence in Design for Greater Efficiencies (EDGE) rating system	Energy – 46% Water – 19% Habitat – 35%	Residential Commercial Communities School Healthcare

When comparing the LEED rating system to BREEAM rating system, it is observed that there is a difference in the adoption of local priorities. LEED dedicates a specific category to reflect the local priorities of each region and add the credits earned in this category as bonus to the total score while BREEAM does not allocate credit to local priorities (Rezaallah and Khoraskani, 2012). Furthermore, rating systems like GREEN STAR, PRS, MOSTADAM and GPRS which were developed based on LEED do not include the regional priority category. However, they reflect the adoption of their own regional priorities through changing the given weight of each category of the LEED categories to allocate more credits for more valuable resources such as fresh water in a country such as Saudi Arabia.

The two rating systems that stand out in terms of categories weights are CASBEE due to the complexity if its calculation method allocated different weights to each category based on the specifics of each project. DGNB stands out due to the categories weights is which allocates equal weights to environmental, social, and economic quality and is the only rating system that focuses on the economic aspects of sustainable buildings (Ferreira *et al.*, 2023). Another significant difference among these rating systems is their level of implementation. All of the aforementioned are implemented on a voluntary basis except PRS which is mandatory in all buildings in UAE (Ramani and García De Soto, 2021).

Shifting the focus towards Egypt, in 2005 the first Energy Efficiency Building Code (ECP 306-2005) for residential building was developed by the Egyptian government. The code included minimum and maximum values for the following design elements: building envelope, ventilation and thermal comfort, HVAC and SWH systems, lighting, and electric loads. In 2008, the unified building law (LAW 119 for 2008) was issued, and as a result compliance with BEEC became mandatory to obtain a construction license (Edeisy and Cecere, 2018). In alignment with the government efforts for sustainable building development in Egypt, the Green Pyramid Rating system (GPRS) was presented by the Housing and Building National Research center (HBRC) in 2011 to serve

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as baseline for green building assessment. The GPRS was based on the LEED rating system developed by the U.S. Green Building Council. Another green building rating system developed in Egypt is TARSHEED, which was developed by the Egypt Green Building Council based on the Excellence in Design for Greater Efficiencies (EDGE) rating system developed by the international finance corporation (Harb, 2019).

2.3. Building Energy Efficiency Studies

In addition to building rating systems, numerous studies addressed the issue of energy efficiency in buildings. In our review, we categorize the studies into three groups based on their methodology: literature review studies, experimental studies, and computational studies. In analyzing these studies, we will start with studies on global level, then narrow it down to studies within the Middle East and Northern Africa (MENA) region and finish with local studies in Egypt. In addition to their methodology, we are interested in their suggested energy efficiency measure, their evaluation parameters and if their recommendation is directed towards a certain building use (residential, commercial, etc.) or addresses buildings in general regardless of their function.

2.4. Global Studies on Energy Efficient Building Design

2.4.1. Global Literature Review

In 2019, Tennakoon et al. researched strategies to reduce not only the operational energy of the building but the embodied energy as well. The results of this study were extracted through extensive literature review in addition to interviews with professional experts. The strategies recommended for achieving simultaneous operational and embodied energy savings are categorized into five categories. The first category is Material selection, which includes selecting natural materials that are locally sourced and evaluated based on life cycle assessment. The second category is Design approach, which recommends reuse of existing structures and designing for future expansions. The third category is Building morphology, which includes natural lighting and ventilation and reduction of roof height in air-conditioned spaces. The fourth category is Procurement process, which recommends adoption of Building Information Modeling (BIM) technologies, Sustainable Public Procurement (SPP) guidelines and Life Cycle Cost (LCC) assessments. And the last category is Other, which includes following energy efficiency guidelines and adopting sustainable concepts early in the project (Tennakoon *et al.*, 2019). These strategies can be applied to all building types and are not building function specific. Similarly, Machairas, Tsangrassoulis and Axarli as well as Østergård, Jensen and Maagaard (2014; 2016) addressed the general building stock in their literature where Østergård, Jensen and Maagaard (2016) focused on building simulations, while Machairas, Tsangrassoulis and Axarli (2014) focused on algorithms for optimizations, both with the purpose of supporting the decision-making process in building design.

Other recent literature reviews studies include (Erebor *et al.*, 2021; Mostafavi, Tahsildoost and Zomorodian, 2021). Mostafavi, Tahsildoost and Zomorodian (2021) examined 48 studies on the energy consumption and carbon footprint of high-rise buildings, including commercial and residential use, during the period 2005-2020. The study concluded that energy savings up to 78.9% can be achieved through enhancing building envelope, 17% through optimizing floorplan layout, and 45 % through utilization of natural ventilation. The review also demonstrated that up to 25% of operational energy and 60% of embodied carbon emissions of high-rise buildings can be reduced mainly by improving the envelope heat transfer coefficient and increasing the utilization of recycled materials. Among their findings, was that 53% of the reviewed literature used simulation methods in their investigation, while 6% used analytical methods and the remaining 41% followed a hybrid approach. It was also observed that most of the building energy simulations conducted in these studies used EnergyPlus (EnergyPlus™, 2017). Erebor et al. (2021) focused on energy efficiency design strategies implemented only in office buildings and examined 36 articles published between 2007 and 2019. Their review concluded that the most implemented energy efficiency measures in

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office buildings are enhancing building envelope, optimizing building orientation and integration of daylighting techniques as well as renewable energy systems.

Similar to Mostafavi, Tahsildoost and Zomorodian (2021), Kheiri and Shah, Pandit and Gaur (2018; 2021) also addressed both commercial and residential buildings in their literature review study. However, Kheiri and Shah (2018) also explored trends in educational and other types of buildings. Both studies analyzed different methodologies to optimize buildings design and they both came up with consistent results. Out of 49 studies reviewed by Shah, Pandit and Gaur (2021), the most used optimization technique is parametric analysis covering a percentage of 71% with the rest 29% of the studies utilizing genetic algorithm for optimization. The authors also concluded that parametric analysis is typically coupled with EnergyPlus being the most widely used simulation software followed by TRNSYS (University of Wisconsin-Madison Solar Energy Laboratory, 1975). Meanwhile Kheiri and Shah (2018) also concluded that EnergyPlus is the most used energy performance assessment software and genetic algorithm is the most widely utilized optimization algorithm using MATLAB (The MathWorks Inc., 2022) to optimize the efficiency of building geometry and envelope.

2.4.2. Global Experimental Studies

Fang et al. and Zhang et al. (2014; 2018) experimentally investigated the potential of optimizing building envelope to reduce the cooling load of the building. Given the nature of experimental studies and unlike computational or literature review studies, the author can only focus on one design parameter. Fang et al. (2014) focused on wall insulation while Zhang et al. (2018) focused on windows glazing. Fang et al. (2014) concluded that thermal insulation can save up to 23.5% of the energy consumption of air conditioning in the summer. And Zhang et al. (2018) concluded that using triple glazed windows with built-in venetian blinds can reduce the head gain through the window by up to 42.3% in the cooling season.

2.4.3. Global Modeling Studies

During our literature review, we were mainly interested in the software used for whole building simulation, suggested design strategies, optimization method if any, economic considerations, and building occupation category (commercial, residential, etc.). Li and Wong, Palmero-Marrero and Oliveira, Aldawoud, and Carreras et al.(2007; 2010;2013;2016) investigated buildings in general regardless of their occupancy. They all performed whole building energy simulations using different software tools namely EnergyPlus (Li and Wong, 2007; Carreras et al., 2016), TRNSYS (Palmero-Marrero and Oliveira, 2010) and DOE-2 (Aldawoud, 2013). Among those, the study conducted by Carreras et al. (2016) was the only one that did not stop at whole building energy simulation but went ahead and also performed optimization and cost analysis on his proposed design recommendations which included replacing polyurethane by mineral wool and improving thermal insulation. Li and Wong and Palmero-Marrero and Oliveira (2007; 2010) explored the effect of shading on building energy consumption. Li and Wong (2007) focused on shading due to nearby obstructions while Palmero-Marrero and Oliveira (2007) focused on the effect louver shading devices. These two studies concluded that shading could reduce building energy consumption by 30% due to external obstructions and up to 59% using louvers (Li and Wong, 2007; Palmero-Marrero and Oliveira, 2010).

There are studies that address specific types of buildings such as institutional buildings. Among those are the studies conducted by Tavares and Martins, Kini et al., and Sim, Suh and Otto (2007; 2021; 2021). Tavares and Martins (2007) evaluated different energy efficient design strategies using VisualDOE™ (VisualDOE 3.0 Program Documentation, 2001) simulations. They concluded that compared to the Portugal legislation for building energy efficiency, energy savings of up to 78% of heating needs, 46% of cooling needs, 31% of electricity consumption, 34% of maximum heating power, 33% of maximum cooling power, and 30% of electrical power maximum demand can be reached through whole building energy simulation research. Kini et al. (2021) performed energy simulations using EnergyPlus on a small school building and concluded that not only energy saving can be achieved through efficient design, but also heat balance, ventilation, thermal comfort,

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daylighting, and overall occupants' wellbeing can be improved. Sim, Suh and Otto (2021) on the other hand utilized energy simulation using Design Builder (DesignBuilder 2.1, 2009) to optimize the integration of a PV system on a campus building while considering lifecycle costs .

Other studies focused on commercial buildings use. Sailor, Roetzel and Tsangrassoulis, Susorova et al., Huang, Niu and Chung, (2008; 2012; 2013;2014) all used EnergyPlus in their simulations. Sailor (2008) used energy simulation to evaluate the impact of a green roof model and observed that a thicker soil layer of the green roof resulted in lower heating and cooling loads due to increased roof insulation. While Roetzel and Tsangrassoulis (2012) used building energy simulation to quantify the impact of climate change on thermal comfort and building energy consumption. Their research concluded that climate change can affect thermal comfort by 25-30% and peak heating loads by 40-100% depending on building design and occupants behavior. Susorova et al. (2013) proved that geometric factors such as room dimensions and window size can save up to 14% of total energy consumption in hot climates. Huang, Niu and Chung (2014) Coupled EnergyPlus with Daysim (Reinhart, 2005) to evaluate both thermal and daylighting performance of glazing and shading designs. They concluded that low-e glazing achieves best performance in cooling dominant climates while double layer glazing performs worst. They also observed that the thermal and daylighting performance of blind louvers is reduced when the reflectivity of the louvers decreases. .

In addition to simulation-based studies focused on optimizing the design efficiency of commercial buildings, there are also numerous studies that investigated the design of residential buildings through whole building energy simulations. Among those studies, Yik and Bojić, Griego, Krarti and Hernández-Guerrero, Ascione et al., Chen and Yang, and Gou et al. (2006;2012;2015; 2016, 2017; 2018, 2019). What these studies have in common in addition to utilizing EnergyPlus in their Simulation, is that they have coupled building energy simulation with optimization techniques to achieve the highest energy efficient design. Some of these studies focused on high-rise residential buildings such as Chen and Yang (2016, 2017) while others such as Ascione et al. and Gou et al. (2015;2018, 2019) directed their investigation towards mid-rise residential buildings. Yıldız and Arsan and Yao et al. (2011;2018) also focused on mid-rise residential buildings in their investigation. However instead of searching for an optimum design solution, they were more concerned with the impact of different design parameters and thus, they performed a sensitivity analysis. Yıldız and Arsan (2011) concluded that north-oriented room with large windows and south-oriented rooms with small windows have the best energy performance in hot and temperate climates. Following in Table 3 is a summary of reviewed modeling studies on a global level highlighting the studied building type, utilized simulation software and if any cost/financial analysis has been performed to verify the economic feasibility of suggested energy efficiency measures.

Table 3. Global Studies Using Energy Modeling and Simulation.

Reference	Building Type	Simulation Software	Cost analysis
(Abouaiana and Mendonça, 2022)	Residential	EnergyPlus	Yes
(Kini *et al.*, 2021)	Institutional	EnergyPlus	No
(Sim, Suh and Otto, 2021)	Institutional	Design Builder	Yes
(Giouri, Tenpierik and Turrin, 2020)	Commercial	EnergyPlus	No
(Rodrigues *et al.*, 2019)	Residential and Commercial	EnergyPlus	No
(Ascione *et al.*, 2019)	Residential	EnergyPlus	Yes
(Chen *et al.*, 2019)	Commercial	EnergyPlus	No
(Chen and Yang, 2018)	Residential	EnergyPlus	No
(Li, Wang and Cheung, 2018)	Commercial	EnergyPlus	No
(Yao *et al.*, 2018)	Residential	EnergyPlus	No
(Zhang *et al.*, 2018)	Generic	Window 7.4	No

		(Lawrence Berkeley National Laboratory, 2019)	
(Gou *et al.*, 2018)	Residential	EnergyPlus	No
(Song *et al.*, 2017)	Commercial	TRNSYS	Yes
(Chen and Yang, 2017)	Residential	EnergyPlus	No
(Chen and Yang, 2016)	Residential and Commercial	DOE-2 (York and Cappiello, 1981)	No
(Aparicio Ruiz *et al.*, 2016)	Residential	LIDER-CALENER	No
(Ascione *et al.*, 2016)	Residential	EnergyPlus	No
(Carreras *et al.*, 2016)	Generic	EnergyPlus	Yes
(Ascione *et al.*, 2015)	Residential	EnergyPlus	Yes
(Ioannou and Itard, 2015)	Residential	EnergyPlus	No
(Huang, Niu and Chung, 2014)	Commercial	EnergyPlus	No
(Pikas, Thalfeldt and Kurnitski, 2014)	Commercial	IDA-ICE (Kalamees,2004)	Yes
(Susorova *et al.*, 2013)	Commercial	EnergyPlus	No
(Calleja Rodríguez *et al.*, 2013)	Residential	EnergyPlus	No
(Aldawoud, 2013)	Generic	DOE-2	No
(Kim *et al.*, 2012)	Commercial	DOE-2	Yes
(Griego, Krarti and Hernández-Guerrero, 2012)	Residential	EnergyPlus	Yes
(Roetzel and Tsangrassoulis, 2012)	Commercial	EnergyPlus	No
(Bambrook, Sproul and Jacob, 2011)	Residential	IDA-ICE	Yes
(Bichiou and Krarti, 2011)	Residential	DOE-2	No
(Jaber and Ajib, 2011)	Residential	TRNSYS	Yes
(Yıldız and Arsan, 2011)	Residential	EnergyPlus	No
(Zemella *et al.*, 2011)	Commercial	EnergyPlus	No
(Palmero-Marrero and Oliveira, 2010)	Generic	TRNSYS	No
(Wang, Gwilliam and Jones, 2009)	Residential	EnergyPlus	No
(Sailor, 2008)	Commercial	EnergyPlus	No
(Gratia and De Herde, 2007)	Commercial	TAS (Jones, 2000)	No
(Li and Wong, 2007)	Generic	EnergyPlus	No
(Tavares and Martins, 2007)	Institutional	VisualDOE™	No
(Yik and Bojić, 2006b)	Residential	EnergyPlus	No
(Cheung, Fuller and Luther, 2005)	Residential	TRNSYS	No
(Gratia, Bruyère and De Herde, 2004)	Commercial	TAS	No

2.5. Regional Studies on Energy Efficienct Building Design

Having explored trends in sustainable building design in literature on a global level, we now look at studies conducted within the MENA region. In this section we will analyze studies originating from United Arab of Emirates (UAE), Saudi Arabia (SA), Tunisia, and Jordan. The first thing to be

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noted is that out of seven (7) papers studied on the regional level, four (4) were conducted in UAE. The four studies are all simulation based except the study conducted by Friess and Rakhshan (2017) which was a literature review. In their review, Friess and Rakhshan explored passive building envelope measures that improves the energy performance of the building. Among their findings was that thermal insulation and natural ventilation can save up to 20% and 30 % respectively in residential buildings. Friess et al. and Watfa at al. (2012;2021) also studied residential building energy efficiency using whole building energy simulation. Watfa at al. (2021) explored the potential of Building Information modeling (BIM) in designing energy efficient buildings and utilized AECOsim (Bentley, 2012) for evaluation of energy performance. They focused on building orientation and window to wall ration while Friess et al. (2012) focused on thermal insulation and used EnergyPlus for energy performance evaluation. Salameh et al. (2020) on the other hand studied the integration of photovoltaic façade system in commercial buildings and concluded that they can reduce around 30% of the annual electricity consumption.

Other simulation-based studies conducted within the MENA region include Ihm and Krarti, Bataineh and Alrabee, and Alhuwayil at al. (2012; 2018; 2019). All three studies used building energy simulation to improve the energy efficiency of residential buildings. Both studies conducted by Bataineh and Alrabee and Alhuwayil at al. (2018; 2019) utilized EnergyPlus for energy simulations and both of them also conducted cost analysis as part of their investigation. Ihm and Krarti (2012) on the other hand utilized DOE-2 coupled with optimization techniques to achieve the optimum design solution for energy efficient residential buildings. The design strategies recommended based on their investigation are adding roof insulation, reducing air infiltration, installation energy efficient appliances, lighting fixtures, and heating and cooling equipment. They concluded that these design strategies can reduce the energy consumption of the building by 50% (Ihm and Krarti, 2012).

Table 4. Regional Studie Using Energy Modeling and Simulation.

Reference	Building Type	Simulation Software	Cost analysis
(Watfa, Hawash and Jaafar, 2021)	Residential	AECOsim	Yes
(Salameh *et al.*, 2020)	Commercial	DOE-2	No
(Alhuwayil, Abdul Mujeebu and Algarny, 2019)	Residential	EnergyPlus	Yes
(Bataineh and Alrabee, 2018)	Residential	EnergyPlus	Yes
(Friess, Rakhshan, Tamer A. Hendawi, *et al.*, 2012)	Residential	EnergyPlus	No
(Ihm and Krarti, 2012)	Residential	DOE-2	No

2.6. Local Studies on Energy Efficienct Building Design

In a similar fashion to how we examined global literature, this local literature will also analyze literature review studies as well as computational studies that focused on the local context in Egypt. However, none of the local literature examined here followed an experimental approach towards building energy efficiency.

Some of the literature review studies that analyzed literature specific to Egypt included building energy efficiency research in general without focusing on a particular building type, examples of those studies are Tuominen et al., Edeisy and Cecere and Abd El Aal (2015;2018;2020). Other literature review studies focused on a specific building type such as the studies conducted by Harb, Rasmy and Alaa et al. (2019; 2011; 2021) which focused on educational buildings. Harb (2019) evaluated different building rating systems and provided sustainable design guidelines for new and existing schools. These guidelines are based on literature review and data collected from surveying an existing school building through multiple visits. However, no evaluation of the impact of these guidelines on the building performance was conducted. Similarly, Alaa et al. (2021) analyzed the impact of applying the Green Pyramid Rating system based on published literature without any further verification.

In addition to literature review studies, local studies also included computational studies to evaluate the energy efficiency of different design strategies. These computational studies can be divided based on the type of building use being analyzed into institutional, commercial, and residential buildings focused studies. Starting with institutional buildings energy simulation studies, Radwan et al. and William et al. (2016; 2019; 2020) evaluated energy efficient retrofitting strategies in hospitals using HAP 4.9 (Carrier, 2014) and EnergyPlus respectively. Both studies focused on enhancing three design aspects which are insulation, glazing and lighting. William et al. a dedicated outside air system (DOAS) was added to the advanced energy model which improved its energy efficiency by 67%. Other institutional buildings simulation studies analyzed different types of institutional buildings such as airports in (Shafei, Tawfik and Khalil, 2019) which recommends LED lighting and renewable energy implementation and government buildings in (Hegazy, 2019) which evaluates the impact of nano aerogel glazing on energy performance.

The majority of local institutional simulation studies, however, focused their investigation on educational buildings. Among these studies are the studies conducted by El-Darwish and Gomaa, Samaan et al. and Ahmed (2017; 2018; 2019), all of which analyzed energy efficiency measures in existing school buildings using EnergyPlus. Actually, all educational buildings focused simulation studies analyzed in this literature review on a local level utilized EnergyPlus with the exception of the study conducted by (Omar, Khattab and Abdel Aleem, 2022a) which used HOMER (UL Solutions, 2018) for energy simulation. This study was also unique in the fact that it did not only evaluate the retrofitted model based on energy performance but also based on environmental and economic performance. Similarly, (Eman, 2022a) evaluated the use of double facades in educational buildings based on energy consumption and emissions. Meanwhile (Ragab and Abdelrady, 2020; Emil and Diab, 2021a) evaluated their advanced energy models for educational buildings based the results of both energy and cost analysis. Another evaluation criterion that was used in this category of simulation studies is thermal comfort in (Anber, 2022a).

The second type of local simulation studies are the ones focused on the energy efficiency of commercial buildings. Similar to the institutional buildings' simulation studies, the majority of commercial buildings simulation studies reviewed utilized EnergyPlus. Among those studies are the studies conducted by (Abd, Monem and Gindi, 2020; Osama El-Sherif, Mohamed and Fatouh, 2020; Hamza, Alsaadani and Fahmy, 2022) which in addition to analyzing the impact of energy efficiency measures in office buildings, also evaluated the potential of renewable energy application in the form of PV installation. The three studies achieved a reduction in annual energy consumption by 60%, 65% and 42% respectively. Some of the commercial buildings' simulation studies using EnergyPlus focused on high-rise buildings such as the study conducted by (El-Agami, Hanafy and Osman, 2021) while other studies focused on mid-rise buildings such as those in (Mahmoud and Elkhiary, 2019; Ramadan, 2022). Other simulation software utilized in commercial buildings energy efficiency studies include e-Quest (Hirsch, 2010) in (Fahmy *et al.*, 2019; Abdelraouf, Atef El-Desouky and Moustafa, 2022) and IES-VE (IES, 2004) by (Ahmad and Reffat, 2018) which reduced energy consumption by 40% using different daylighting systems.

The third category of simulation reviewed relates to residential buildings. These studies could be divided based on the topology of the building. Some of the studies focus their recommendations on either single family, or multi-family low-rise, mid-rise, or high-rise buildings. Other studies, however, investigate residential buildings in general regardless of their topology. Examples of these studies are found in (Michel and Hend Elsayed, 2006; Dabaieh *et al.*, 2015; Fahmy *et al.*, 2018; Hegazy, 2020a; Ghamri and Anglani, 2022; Mahdy *et al.*, 2022).

The rest of the residential simulation studies can be further categorized into two categories single-family and multi-family focused studies. (Nabih *et al.*, 2011a; Mourad *et al.*, 2014; Elhadad, Baranyai and Gyergyák, 2018) all investigated energy efficiency measures in single-family residential buildings while the studies in (Aldali and Moustafa, 2016; Abouaiana and Mendonça, 2022) investigated energy efficiency measures in low-rise multi-family residential buildings. Although

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slightly different in scope, both (Nabih *et al.*, 2011a; Aldali and Moustafa, 2016) both used Ecotect (Autodesk, 2011) and performed a sensitivity analysis to optimize the effectiveness of their recommendations. The benefit of using Ecotect according to (Nabih *et al.*, 2011a) is that it performs thermal and lighting analysis simultaneously.

Out of twenty-two (22) residential simulation studies analyzed in this review on a local level, fourteen studies focus on mid-rise residential buildings. The majority of these studies performed simulations using EnergyPlus either in combination with OpenStudio (Guglielmetti, Macumber and Long, 2011) such as in (Nafeaa, Mohamed and Fatouha, 2020) or in combination with DesignBuilder which is more common. The study conducted by (Nafeaa, Mohamed and Fatouha, 2020) concluded that reducing the heat transfer coefficient of walls, adding shading, using double glazing and installing LED lighting can reduced the cooling demand by 7%, 13%, 14%, and 17% respectively. Examples of mid-rise buildings simulation studies using DesignBuilder and EnergyPlus can be found in (Edeisy and Cecere, 2017; Khalil, Fikry and Abdeaal, 2018; Ahmad *et al.*, 2021; GamalEldine and Corvacho, 2022) which all evaluated the energy model performance based on energy consumption and thermal comfort. In addition, (Khalil, Fikry and Abdeaal, 2018; Ahmad *et al.*, 2021) performed cost analysis on their recommended design strategies, (Edeisy and Cecere, 2017) measured building emissions and (GamalEldine and Corvacho, 2022) applied PV system to reach nearly zero energy building.

Table 5. Local Studies Using Energy Modeling and Simulation.

Reference	Building Type	Simulation Software	Cost analysis
(Hamza, Alsaadani and Fahmy, 2022)	Commercial	EnergyPlus	No
(Mahdy *et al.*, 2022)	Residential	EnergyPlus	No
(GamalEldine and Corvacho, 2022)	Residential	EnergyPlus	No
(Abdelraouf, Atef El-Desouky and Moustafa, 2022)	Commercial	e-Quest	Yes
(Anber, 2022b)	Institutional	EnergyPlus	No
(Ramadan, 2022)	Commercial	EnergyPlus	No
(Anber and Khalifa, 2022)	Residential	EnergyPlus	No
(Eman, 2022b)	Institutional	EnergyPlus	No
(Omar, Khattab and Abdel Aleem, 2022b)	Institutional	HOMER	Yes
(Emil and Diab, 2021b)	Institutional	EnergyPlus	Yes
(El-Agami, Hanafy and Osman, 2021)	Commercial	EnergyPlus	No
(Ahmad *et al.*, 2021)	Residential	EnergyPlus	Yes
(Nafeaa, Mohamed and Fatouha, 2020)	Residential	EnergyPlus	No
(Osama El-Sherif, Mohamed and Fatouh, 2020)	Commercial	EnergyPlus	No
(Mohamed Abdelsalam, Mohamed EL Razzaz and Elnekhaily, 2020)	Residential	EnergyPlus	No
(Abd, Monem and Gindi, 2020)	Commercial	EnergyPlus	No
(Ragab and Abdelrady, 2020)	Institutional	EnergyPlus	Yes
(Hegazy, 2020b)	Residential	EnergyPlus	No
(Hegazy, 2019)	Institutional	Ecotect	Yes
(William *et al.*, 2020b)	Institutional	EnergyPlus	Yes
(William *et al.*, 2019)	Institutional	EnergyPlus	No

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(Ahmed, 2019b)	Institutional	EnergyPlus	No
(Shafei, Tawfik and Khalil, 2019)	Institutional	EnergyPlus	No
(Elhadad *et al.*, 2019)	Residential	IDA ICE	No
(Mahmoud and Elkhiary, 2019)	Commercial	EnergyPlus	No
(Fahmy *et al.*, 2019)	Commercial (Heritage)	e-Quest	No
(Samaan, Farag and Khalil, 2018b)	Institutional	EnergyPlus	No
(Fahmy *et al.*, 2018)	Residential	EnergyPlus	No
(Elhadad, Baranyai and Gyergyák, 2018)	Residential	IDA ICE	No
(Khalil, Fikry and Abdeaal, 2018)	Residential	EnergyPlus	Yes
(Ahmad and Reffat, 2018)	Commercial	IES-VE	No
(Albadry, Tarabieh and Sewilam, 2017)	Residential	EnergyPlus	Yes
(Attia, Hamdy and Ezzeldin, 2017a)	Residential	EnergyPlus	No
(El-Darwish and Gomaa, 2017b)	Institutional	EnergyPlus	No
(Edeisy and Cecere, 2017)	Residential	EnergyPlus	No
(Aldali and Moustafa, 2016)	Residential	Ecotect	No
(Radwan *et al.*, 2016b)	Commercial and Institutional	HAP	No
(Reda *et al.*, 2015)	Residential	TRNSYS	No
(Dabaieh *et al.*, 2015)	Residential	EnergyPlus	Yes
(Mourad *et al.*, 2014)	Residential	ENER-WIN (ENER-WIN, n.d.)	No
(Fahmy, Mahdy and Nikolopoulou, 2014)	Residential	EnergyPlus	No
(Attia *et al.*, 2012)	Residential	EnergyPlus	No
(Nabih *et al.*, 2011b)	Residential	Ecotect	No
(Hanna, 2011)	Residential	Overall Thermal Transfer Value (OTTV) equations programmed into Excel	No
(Michel and Elsayed, 2006)	Residential	DOE-2	No

3. Discussion

Rating systems, helpful as they are, do not always accommodate for the social and economic context of the building. They also do not provide specific design strategies with their direct impact on the building performance. Furthermore, and most important to our research is that when examining one of the most prominent rating systems used around the globe which is LEED and Egypt's local rating system which is GPRS, one difference is observed in the implementation of the energy efficiency category. In LEED, there are two paths for achieving credits in the energy efficiency category; the whole building simulation path and the prescriptive path which refer to ASHRAE 30% and 50% AEDGs. Meanwhile in the GPRS, only the building energy simulation path is found, and no prescriptive path is available for each percentage of energy savings. GPRS refers to the Egyptian Energy Efficiency Building Code (ECP 306-2005) (HBRC, 2015) for energy efficient design recommendations. However, the impact of those recommendations is not quantified as an energy saving percentage and has to be verified using whole building simulations.

In addition to AEDGs and rating systems, 114 studies were analyzed in this review. This includes 51 global studies, 7 regional studies, and 56 local studies. These studies followed different approaches towards buildings energy efficiency. Out of the 51 global studies examined, 8 are literature review studies, 2 are experimental and 42 are simulation-based studies. The distribution of global simulation-based studies based on building type is shown in Figure 4, while their distribution based on simulation software is shown in Figure 5. Figure 6 shows that only 26% of the literature performed cost analysis.

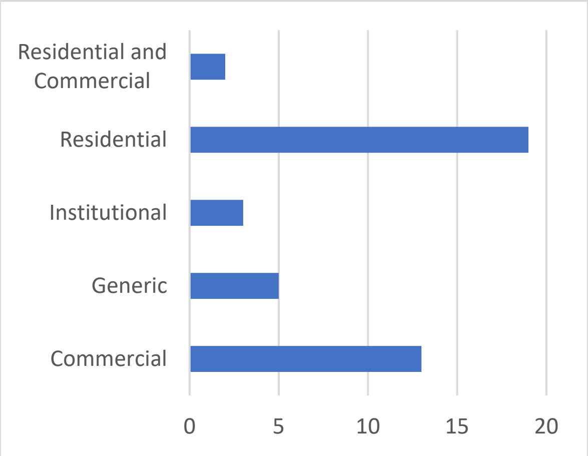

Figure 4. Global Simulation Studies by Building Type.

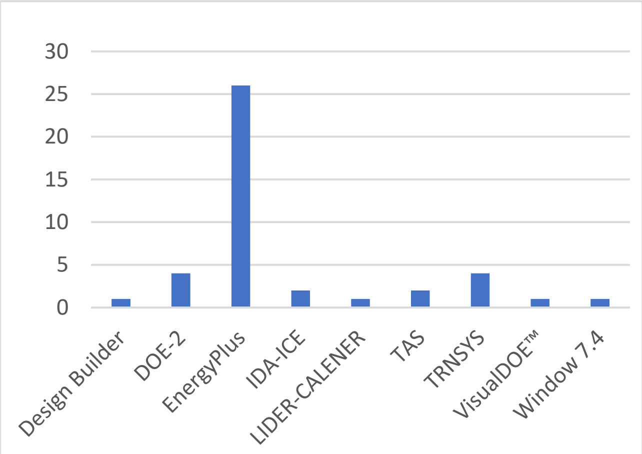

Figure 5. Global Simulation Studies by Simulation Software.

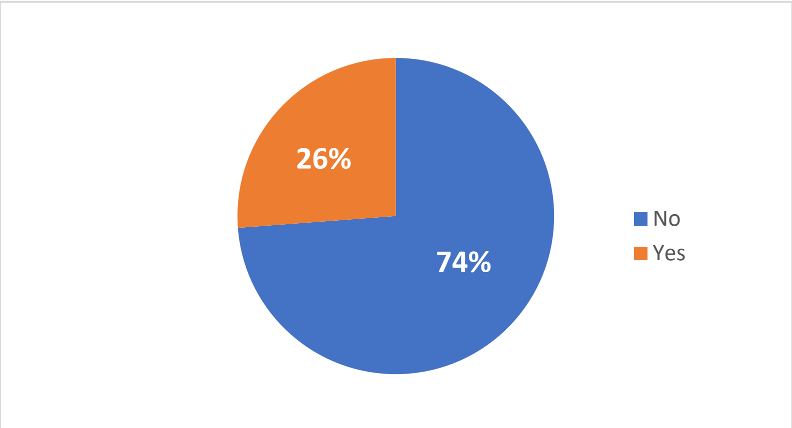

Figure 6. Global Simulation Studies based on Cost Analysis Performance.

On the other hand, none of the regional or the local literature examined here followed an experimental approach towards building energy efficiency. Out of 7 regional studies examined in this review, 1 is a literature review and the remaining are simulation-based studies whose share of cost analysis performance is 50%. All of the regional studies were focused on residential buildings

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with the exception of the study conducted by (Salameh *et al.*, 2020). As for local studies examined in this review, out of 56 local studies, 10 are literature review studies, 46 are simulation-based studies. However, 40% of the literature review papers were concerned with residential buildings. Among those are the studies conducted by Alsaadani, Attia et al., and Hanna (2022; 2017; 2013). Alsaadani concluded that EnergyPlus is the most widely used simulation engine in residential building energy efficiency research in Egypt.

Simulation-based studies on a local level followed a similar trend to what has been observed earlier in global studies. A majority of 51% of the studies focused on residential buildings, and 69% of the studies used EnergyPlus as the simulation engine as demonstrated in Figure 7 and Figure 8 below. Out of twenty-two (22) residential simulation studies analyzed in this review on a local level, fourteen studies focus on mid-rise residential buildings, and none include recommendations for high-rise residential buildings. This could be due to the fact that residential buildings represent 91.2% of total buildings in Egypt. In addition, mid-rise apartment buildings represent 92% of residential buildings in urban cities and 89% of residential buildings in rural areas (CAPMAS, 2017). However, when compared to global studies, more simulation-studies focused on Egypt should include economic evaluation of the proposed design measures. Figure 9 shows the distribution of local simulation-based studies based on whether or not a cost analysis was performed.

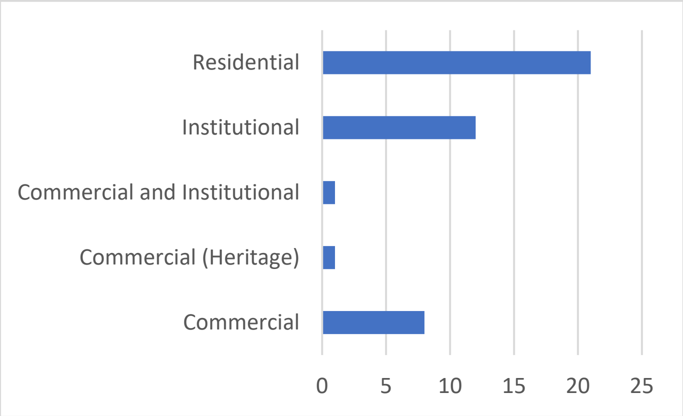

Figure 7. Local Simulation Studies by Building Type.

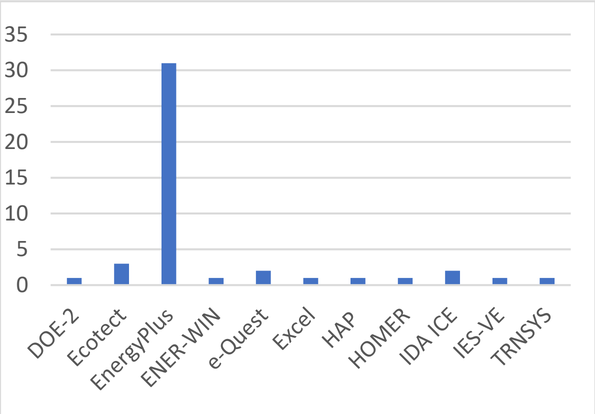

Figure 8. Local Simulation Studies by Simulation Software.

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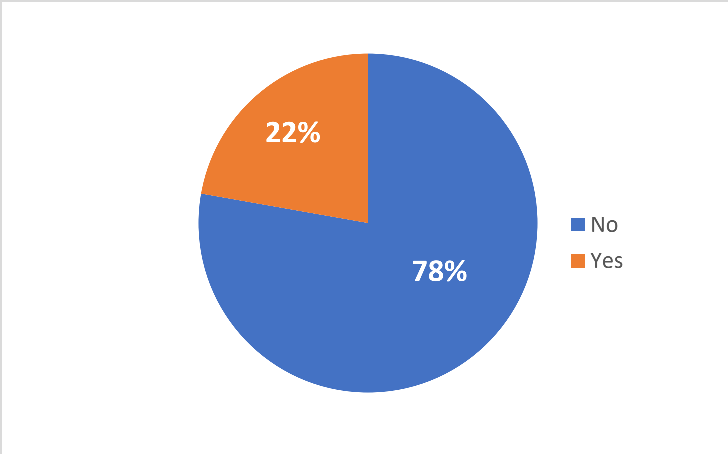

Figure 9. Local Simulation Studies based on Cost Analysis Performance.

4. Conclusions

In this literature review, we examined sustainable building rating systems, design guides and state of the art research related to energy efficient building design. ASHRAE AEDGs were examined in terms of their purpose, methodology of development and recommendations. These design guidelines are referred to by the LEED rating system as a method to satisfy the requirements of the prescriptive path of the energy efficiency category. Furthermore, various national, regional, and international sustainable building rating systems were reviewed and compared based on their development basis, categories and weights, and scope. In the case of Egypt, there are no AEDGs developed specifically for Egypt, but there are two main green building rating systems which are Tarsheed and GPRS. GPRS does not provide a prescriptive path for satisfying the energy efficiency category, however, it refers to the Egyptian Energy Efficiency Building Code (ECP 306-2015) which does not quantify the energy savings to be achieved following its recommendations. While Tarsheed has the advantage of providing simple, practical and straightforward recommendations in terms of applications, the energy savings resulting from those recommendations are also not quantified.

This literature review also included buildings energy efficiency studies based on literature review, experimental, or computational work. A common trend that was observed on a global, regional, and local level is that the majority of the energy simulation studies focused on residential buildings. As for simulation engines, Energyplus is found to be the most widely used.

In addition to energy efficiency measures, the application of renewable energy to achieve net-zero buildings was investigated in 15 out of 124 articles reviewed. It was observed that none of the literature reviewed related to Egypt and the MENA region followed an experimental approach. Furthermore, only 26% of global simulation studies and 22% of local simulation studies verified the economic feasibility of their recommendations through the performance of a cost analysis. Performing an economic analysis is a key enabler for the decarbonization of the built environment.

Therefore, we recommend that future research focus on:

- Developing a prescriptive path for the GPRS energy efficiency category.
- Quantifying energy savings and verifying economic feasibility of energy efficiency recommendation.
- Performing regional and local experimental work related to energy efficient building design.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Figure S1: Total Final Global Energy Consumption in 2021; Figure S2: Global Energy and Process CO2 Emissions in 2021; Figure S3: Quantities of Sold Energy by Purpose in 2020-2021; Figure S4: Global Simulation Studies by Building Type; Figure S5: Global Simulation Studies by Simulation Software; Figure S6: Global Simulation Studies based on Cost Analysis Performance; Figure S7: Local Simulation Studies by Building Type; Figure S8: Local Simulation Studies by Simulation Software; Figure S9: Local Simulation Studies based on Cost Analysis Performance; Table S1: Summary of ASHRAE Existing AEDGs; Table S2: Sustainable Building Rating System Comparison; Table S3: Global Studies Using Energy Modeling and

Simulation; Table S4: Regional Studie Using Energy Modeling and Simulation; Table S5: Local Studies Using Energy Modeling and Simulation.

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