Azouz and Elariane
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RESEARCH

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Towards energy efficiency: retrofitting existing office buildings using smart technologies

Mona Azouz[1] and Sarah Elariane[2*]

*Correspondence: saraelariane@gmail.com

[1] Architecture & Environmental Studies, Housing and Building National Research Center, Giza, Egypt

[2] Smart and Sustainable Urban Development, Housing and Building National Research Center, Giza, Egypt

Abstract

Buildings are considered one of the main causes of increasing CO_2 emissions due to their excessive consumption of energy. The drive towards sustainability represents a challenge especially in existing buildings. The aim of the research is to support the built environment's move onto a low-carbon path using smart technologies. This research highlights the role of smart building technologies in increasing energy savings of office buildings in Egypt, taking into consideration their incremental cost. Based upon data available on Excellence in Design for Greater Efficiencies (EDGE) website, association rule has been applied using Apriori Algorithm to identify the most used smart technologies in EDGE-certified office buildings, in addition to the different smart-orientated retrofitting scenarios that could be applied. Using EDGE software, energy assessment of an existing office building in Egypt was performed. This assessment acts as a "reference point" to quantify the impact of each smart technology and retrofitting scenario on the energy savings, incremental costs, and payback period. Limitations of the application of the different smart technologies impacted the selection process for the different scenarios. These limitations can be summarized in the suitability of application in the existing building's systems, the availability and cost in the local market, and the potential of the building's infrastructure adaptation to the proposed technologies. Based upon the above limitations, the best scenario was selected. Results showed that smart technologies have a great role in retrofitting of office buildings reaching more than 20% energy savings. In addition, the high initial cost of applying smart technologies could be covered within around 3 years of operation. This research could be used as a guide for improving energy performance of existing office buildings in Egypt using smart technologies.

Keywords: Smart building technologies, Office buildings, Energy savings, Retrofitting existing buildings, EDGE, Association rule, Apriori algorithm

Introduction

In building sector, excessive energy consumption and CO_2 emissions have become global issues [1]. Consequently, buildings have been negatively criticized for playing a big role in environmental pollution, in addition of being responsible for up to 38% of the total global energy-related CO2 emissions in the last 5 years [2, 3].

Building sector must increase investment in energy efficiency to reduce CO_2 emissions. Crucially, the awareness of the importance of climate change action both domestically and at the global level is fast increasing in Egypt. The country is at a turning point in its commitment and action to tackle the consequences of climate change. In the 2030 Vision and sustainable development strategy, Egypt has also made commitments to integrate climate change in national development policies [4].

Recently, smart buildings and cities emphasize the role of intelligence of the built environment in energy savings. The development of smart building concept gives a push towards the use of smart technologies to increase energy savings in buildings.

Existing buildings are the biggest consumers of energy in the built environment and will undoubtedly be one of the key areas under scrutiny as the government works towards its target to reduce carbon emissions by 2030 [5]. The greatest integration of smart technologies in existing buildings worldwide has been in offices [6].

Commercial buildings waste as much as 30% of the energy they use, according to a study by the US Department of Energy. Some of the world's most iconic existing buildings have embraced smart technology with amazing results. The Empire State Building completed in 1931; it has been completely retrofitted with smart technology in the past decade and seen more than US $4.4 m of energy savings each year—and a 38% reduction in energy consumption [7]. Galatioto, A. et al. have conducted a study to evaluate energy savings due to the retoffiting of a historic office building in Carbonia, Sardinia, Italy. They concluded that the best retrofit action was that combined with the use of photovoltaic (PV) applications [8]. Shiyu Wan et al. suggested a framework for sustainable energy-efficient retrofits of office buildings in Beijing, China. They deduced that improvements in lighting and air-conditioning systems can reduce the total energy consumption of a large office building by around 8–13% [9]. Maatouk Khoukhi et al. selected an office building in UAE as a case study of the retrofitting of an existing office building to achieve lower energy consumption. They concluded that the upgrading in HVAC system and the use of variable air volume (VAV) can save energy by 8.49% [10].

In addition, advances in smart technology made it easier than ever to retrofit to existing buildings. In 2019, the percentage of commercial buildings including office buildings in Egypt was about 5.4% of the buildings stock, in addition to 6.75% combined use for commercial and residential. The percentage of electricity consumption by the commercial buildings represents 12.3% of total electricity consumption in Egypt. The breakdown of the electrical consumption of these buildings is 36% for lighting and 35–40% for cooling, ventilating, and air-conditioning (HVAC) systems [11]. That is why the research focuses on existing office buildings as an attempt towards smart energy-efficient buildings.

One of the important barriers in applying buildings smart technologies for energy efficiency is the cost. The economic viability and feasibility of using smart technologies in buildings are an issue discussed by many studies. Despite the high initial cost of smart technologies compared to the conventional ones, the benefits could exceed those costs within the lifespan of the project [12]. The initial cost, energy savings, and payback period of smart buildings technologies vary widely across technology and building types. For example, smart thermostats are cost effective in small projects than the automated building system which is more effective in large projects. Latterly, most of smart building technologies initial cost have declined such as smart controls and sensors devices that become smaller and embeddable. In addition, the wireless capability of many smart building technologies makes them retrofit friendly and decreases installation costs compared with wired technologies [6].

The research investigates the impact of applying smart building technologies on energy performance of existing office buildings in Egypt. The aim of the research is to discover the potential of using these technologies as a way to embrace the transformation of existing building to sustainable green buildings that save energy, shrink their carbon footprint, and reduce operation costs taking into consideration incremental costs, running costs, and payback period. This research could be used as a guide for retrofitting the existing buildings stock in Egypt into more energy-efficient buildings. Although the target of the research was the existing office buildings, but many of the energy-saving benefits of smart buildings could be applied to other types of commercial buildings, including education, laboratory, healthcare, and hospitality [6]. In order to achieve the objective, the association rule has been used to determine the frequently used smart building technologies in office buildings worldwide. This results in identifying different scenarios for the retrofitting of an office building in Egypt to minimize energy consumption.

The data mining was used to obtain hidden information and discover the correlation between events from large data. Data mining can be used for association rule mining. Association rule mining uses the frequent pattern to identify the relationship between items [13, 14].

The novelty of this research comes from applying Apriori Algorithm, which is used mainly to suggest products to users based on clients' cart, in determining the frequent smart building technologies used in office buildings worldwide.

The research begins with an inventory of the number of smart building technologies used for energy efficiency mentioned in literature review. Then, an analysis was performed on EDGE-certified projects available on EDGE website [15] focusing on office buildings, as actual case studies. The Apriori Algorithm was applied to identify the frequently used smart building technologies and to determine the usage of smart building technologies trends. Based upon Apriori Algorithm results, different smart-orientated retrofitting scenarios were proposed. A quantitative comparison between these scenarios was undertaken to identify the most cost-effective scenario to reduce energy consumption.

Smart building technologies

Smart building technologies were defined by Jennifer King and Christopher Perry as technologies that improve building operations [6].

Many efforts have been done to assess the smart readiness of buildings; most of indicators used in the assessment tools are based on smart technologies for buildings' energy efficiency. The European framework SRI (smart readiness indicator) evaluates the level of smartness of buildings based on a set of criteria, including heating, cooling, domestic hot water, controlled ventilation, lighting, dynamic building envelope, onsite renewable energy generation, demand side management, electric vehicle charging, monitoring, and control used in the buildings [16, 17].

This part reviews smart building technologies used for energy efficiency either mentioned in literature review or in existing case studies.

Smart building technologies for energy efficiency

There are many smart and efficient technologies that are used to save energy mentioned in literature review [1, 6, 18]. *Smart heating, ventilation*, and *air-conditioning systems* can decrease energy consumption by using sensors for monitoring and control which can detect unoccupied building zones, identify and diagnose faults, and improve occupant comfort. In addition, using *variable speed drive (VSD)* technology in HVAC systems controls the motor speed of fans based on the actual demand which minimizes the energy consumption. And integrating *economizer* into the building's HVAC systems can reduce energy consumption by using outside air with little or no mechanical cooling or heating. Installing *CO_2 sensors in HVAC systems* can minimize energy consumption by switching off mechanical ventilation when it is not required. *Submeters for HVAC systems* can help to reduce energy by increasing the user's awareness of energy consumption rate. *Smart lighting* consists of sensors that control light based on daylight availability or room occupancy to eliminate over light spaces, therefore minimizing energy consumption. *Smart plug loads* control cut off power to equipment that is not in use. *Smart shadings* respond to changes in sunlight or temperature which help in controlling the amount of solar heat and radiation that enters the building. *Building automation system (BAS)* help to decrease energy consumption by collecting and analyzing building systems' data and predicting changes in operations based on occupancy patterns, weather forecasts, and other factors. *Distributed energy resources (DER)* consist of renewable energy generation and storage systems that provide power independent of the grid. Adding a smart inverter to the DER helps manage onsite energy generation and storage. *Smart meters for energy* reduce energy demand through the increasing of users' awareness of their energy consumption. *Power factor corrections* reduce energy consumption by improving the quality of the power delivered to equipment.

Meanwhile, controls and sensors devices, HVAC-automated control, lighting control, smart shading, building automation, smart meters, building information systems, and other smart technologies are commonly used in office buildings [2, 6]. According to J. King and C. Perry, the office with 50,000 m^2 can reach 23% savings by applying lighting controls and remote HVAC control system. The variable frequency drive can save 15 to more than 50% of pump or motor energy, while smart thermostat of HVAC can save 5 to 60%, lighting control can reach up to 45% savings, smart plug can save up to 60%, smart shading can save more than 40%, and building automation and analytics save up to 25% of the total energy consumption [1, 6]. Vasilis, A. et al. argue that smart-orientated retrofitting scenarios focusing on building automation and control measures enhance building performance in terms of optimizing energy efficiency [19].

Smart building technologies in EDGE-certified buildings

This research uses EDGE-certified buildings as case studies to determine the most commonly used smart building technologies. The International Finance Corporation has developed the Excellence in Design for Greater Efficiencies (EDGE) to certify green buildings; EDGE-certified buildings resulted in 2,035,704 MWh/year energy saving from 2014 to 2022 [20]. A data analysis of 592 EDGE-certified projects in 49 countries from 2014 to 2022 has been conducted using Tableau Software for data visualization to identify the commonly used smart building technologies in different types of EDGE-certified buildings [15]. Then, an analysis has been undertaken for 99 EDGE-certified office buildings to determine the commonly used smart building technologies in office buildings.

Commonly used smart technologies in different buildings' typologies

This part of the study starts by a comparative analysis for the applied smart building technologies used versus the passive measures in different types of buildings as shown in Fig. 1. Passive measures were used more in comparison to smart building technologies. The greatest contribution of smart technologies in existing buildings has been in offices [6], that is why the research focuses on office buildings. Offices, education buildings, hospitals, and retails used multiple types of smart building technologies to increase energy savings.

Most of certified projects applied passive measures to minimize energy consumption. Window-to-wall ratio and efficient lighting were the frequently used passive measures. For smart technologies, lighting controls, cooling system efficiency, and onsite renewable energy were the commonly used as shown in Fig. 2.

By comparing smart building technologies used, it is obvious that cooling system efficiency, lighting control, and onsite renewable energy were the most common smart technologies applied. Meanwhile, some smart building technologies available in the market

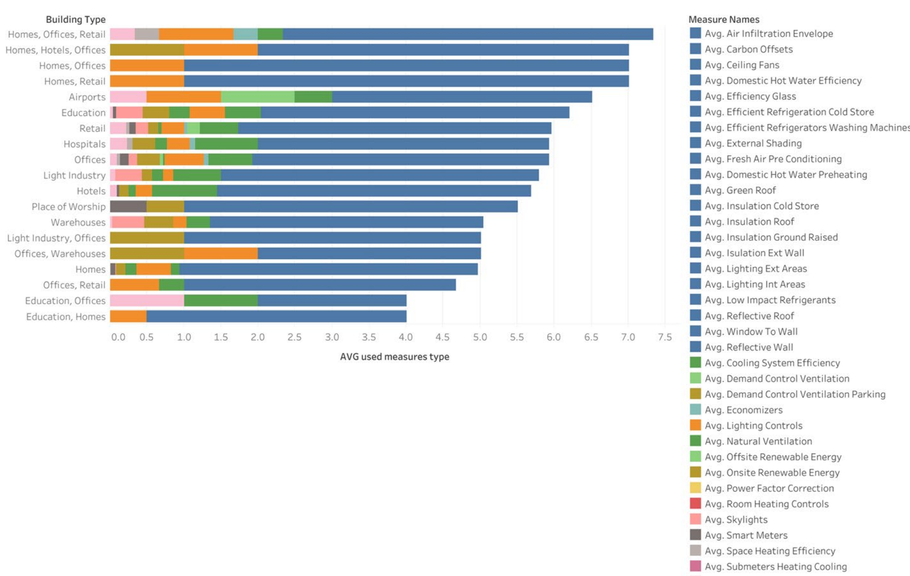

Fig. 1 Passive measures vs smart technology measures by building type

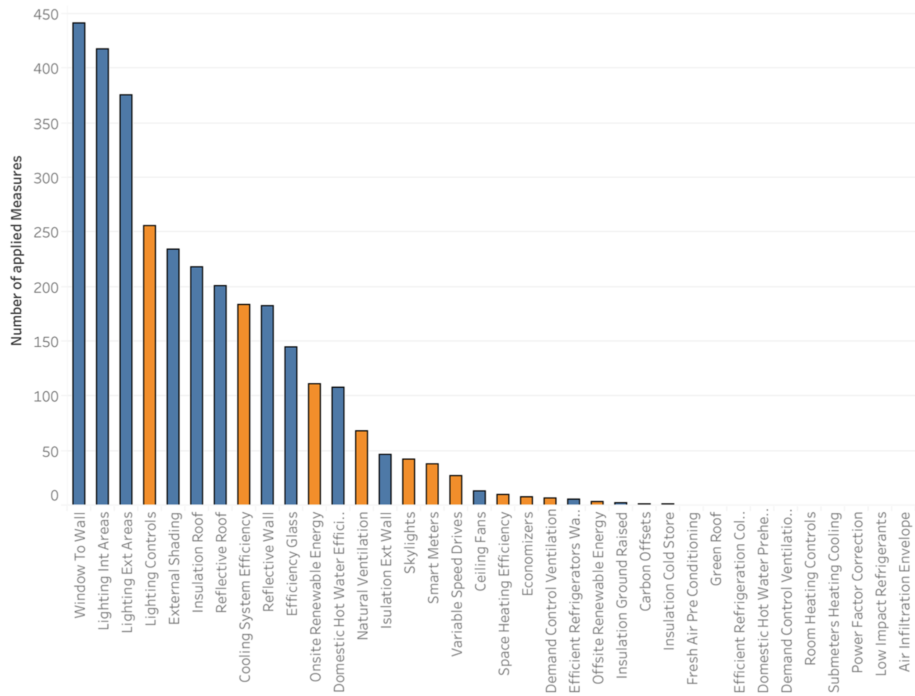

Fig. 2 Passive measures vs smart technology used to increase energy savings

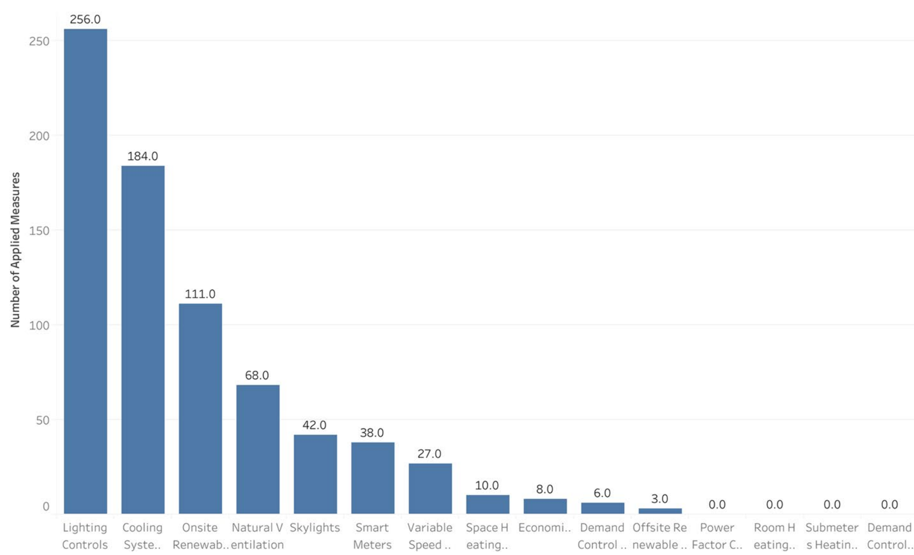

Fig. 3 Number of applied smart building technologies

were not used in any project such as power factor corrections, room heating controls with thermostatic valves, submeters for heating and/or cooling systems, and demand control ventilation for parking using CO sensors as shown in Fig. 3.

There was a tremendous increase in the application of smart building technologies from 2014 until 2021 as shown in Fig. 4 especially the cooling system efficiency, lighting control, and onsite renewable energy.

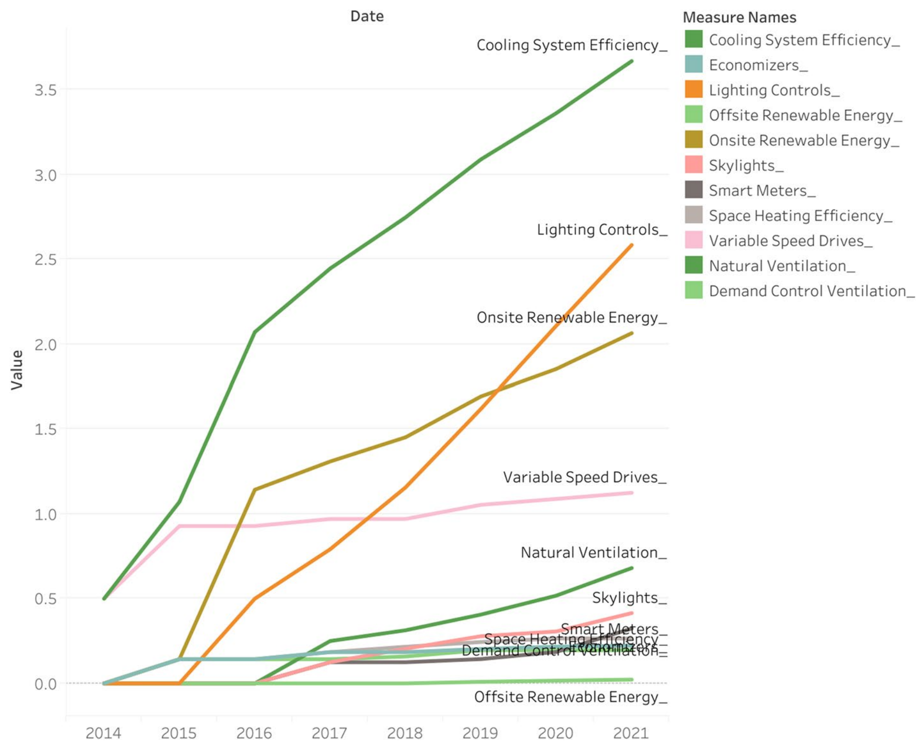

Fig. 4 The cumulative number of used smart building technologies from 2014 to 2021

Commonly used smart technologies in office buildings

This part of the research analyses the use of smart building technologies in the EDGE-certified office buildings. The use of passive measures was predominant as shown in Fig. 5. Same as the rest of the different buildings' typologies, cooling system efficiency, lighting controls, and onsite renewable energy were also the most common smart building technologies used in office buildings as shown in Figs. 5 and 6.

The research studies the relation between the use of smart building technologies in office buildings and the country's location. Obviously, Southeast Asian countries as China, India, and the Philippines apply multiple smart building technologies in their office building projects in order to minimize energy consumption as shown in Fig. 7.

Methods

The methods are divided into two main steps. The first step compromises the analysis of EDGE-certified green office buildings on EDGE website using the association rule. This analysis was undertaken to deduce the commonly used smart technologies in office buildings.

Based upon the identified commonly used smart technologies and using EDGE software, smart-orientated retrofitting scenarios were proposed. The second step quantitatively investigates the impact of applying these proposed scenarios on energy savings and incremental and running costs, in addition to the payback on an existing office building in Egypt. This part starts by a complete assessment of the energy performance of an existing office building in Egypt. This assessment was used as a reference point for a quantitative comparison of the different proposed

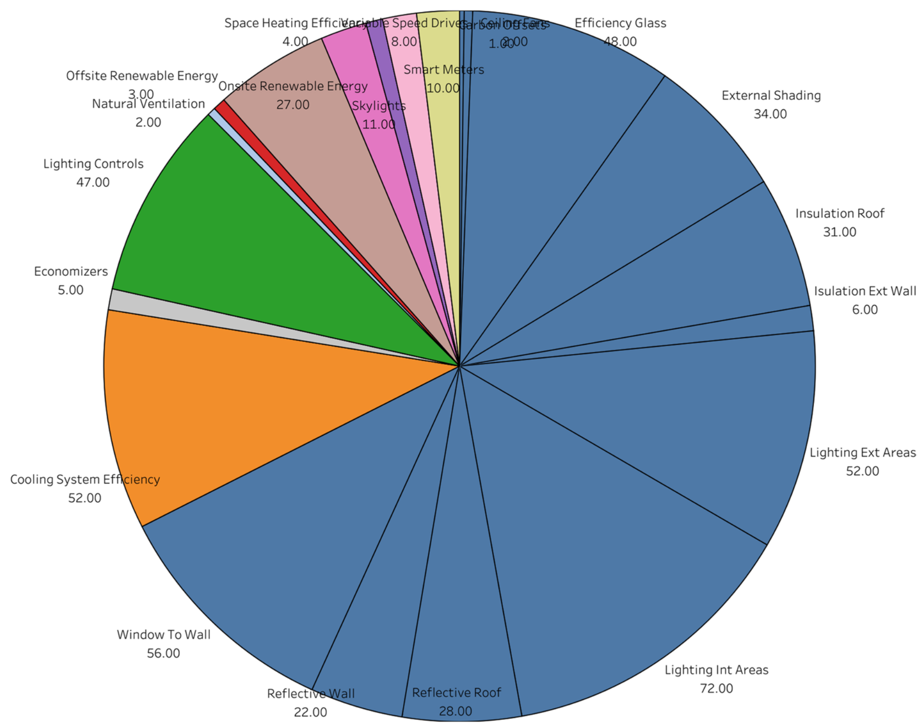

Fig. 5 Passive measures vs smart technology measures used in office buildings

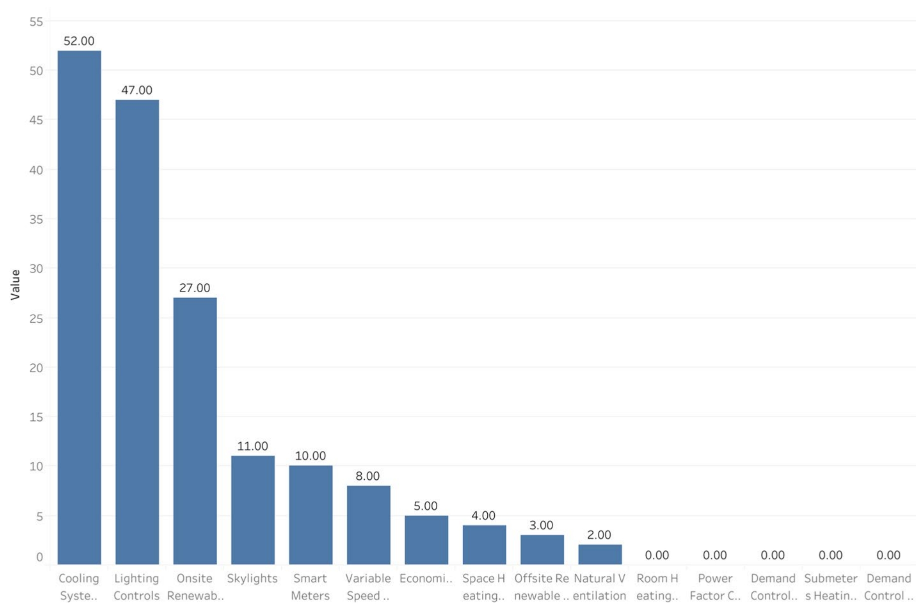

Fig. 6 Number of applied smart building technologies in office buildings

scenarios that could be applied for the retrofitting of this building. The main driver of this assessment is to identify the most cost-effective scenario to reduce energy consumption using smart technologies.

Fig. 7 The use of smart building technologies in office buildings by country

Identifying commonly used smart technologies in EDGE-certified office buildings using association rule

The association rule is used in this research to evaluate the interdependence between smart building technologies used in office buildings. An association rule has two parts: an antecedent (if) and a consequent (then). An antecedent is an item found within the data. A consequent is an item found in combination with the antecedent [21]. The item (A) represents a smart technology, and (B) represents other smart technologies. The Apriori Algorithm is applied for creating the association rule. Statistical analysis including the support and confidence is applied to identify the frequent items and their interdependency. Whereas the support of an association rule represents the percentage of groups that contain all of the items listed in that association rule (Eq. 1), it can be applied to a single item or pair of antecedents and consequents; support value ranges from 0 to 1 [22, 23], while confidence represents a percentage value that shows how frequently an item occurs among all the groups containing this item (Eq. 2); and confidence value ranges from 0 to 1 [22, 23].

The number of occurrences of smart technology (A) in the buildings database D as a percentage of the total buildings in D is called the support of smart technology (A). If the support of a smart technology exceeds the minimum support, it is called a frequent smart technology [14].

$$Support\ (A\ \rightarrow\ B) = P\ (A\ \cup\ B) = \sigma\ (A\ \cup\ B)\ /\ D \tag{1}$$

Support (A ➔ B): Support of association rule A ➔ B
A: Represents the selected smart technology
B: Represent other smart technology
P (A∪B): Probability of simultaneous occurrence of A and B
σ (A∪B): Number of simultaneous occurrences of A and B in all office buildings
D: Total number of all office buildings

$$Confidence\ (A \rightarrow B) = P\ (B\,|\,A) = \sigma\ (A \cup B)\ /\ \sigma\ (A) \tag{2}$$

Confidence (A ➔ B): Confidence of association rule A ➔ B
A: Represents the selected smart technology
B: Represent other smart technology
P (B | A): Probability of B when A appears
σ (A∪B): Probability of simultaneous occurrence of A and B
σ (A): Number of occurrences of A in all office buildings

Energy efficiency assessment for an existing office building in Egypt

A complete assessment of energy consumption for an existing office building in Egypt was performed using EDGE software. The existing office building is located in Cairo; it is comprised of ten aboveground floors of total project floor area 9892.00 m^2, open plan offices of 1448.87 m^2, and 5030.95 m^2 closed offices. The building has an air-conditioning system; the first two floors are served by 2 air-cooled chillers, the second three floors by 82 split air-conditioners, and the last five floors by 25 units of commercial air-conditioning split system. There is a power factor corrections installed in the building. Regarding lighting, all lamps used in the building are high-efficiency light emitting diode (LED). The main source of energy used is electricity.

An office building project was created in the EDGE software version 3.0.0 representing the existing office building. By entering all the required data of the building for energy, water, and embodied energy in materials, the software created a base case based on assumptions. The assumptions were made using national building codes, market studies, and data collection about actual buildings in Egypt. For the building to satisfy the EDGE standards, the difference in consumption between the base case and the entered case should be above the required value (20% less energy, water and embodied energy in materials consumption). Table 1 shows energy efficiency measures of the office building.

Table 1 Summarized energy-related technical solutions of existing office building

Number of energy efficiency measure in EDGE application	Energy efficiency measures	Existing case
EEM01	Window-to-wall ratio	34.06%
EEM02	Reflective roof	Solar reflectance index 76
EEM03	Reflective exterior walls	Solar reflectance index 83
EEM04	External shading devices	Annual average shading factor (AASF) 0.7
EEM05	Insulation of roof	U-value 0.43 W/m^2·K
EEM06	Insulation of ground/raised floor slab	U-value 1.61 W/m^2·K
EEM08	Insulation of exterior walls	U-value 1.29 W/m^2·K
EEM09	Efficiency of glass	U-value 1.98 W/m^2·K, SHGC 0.32, and VT 0.41
EEM13	Cooling system efficiency	COP (W/W) 6.44
EEM22	Efficient lighting for internal areas	105.3 L/W

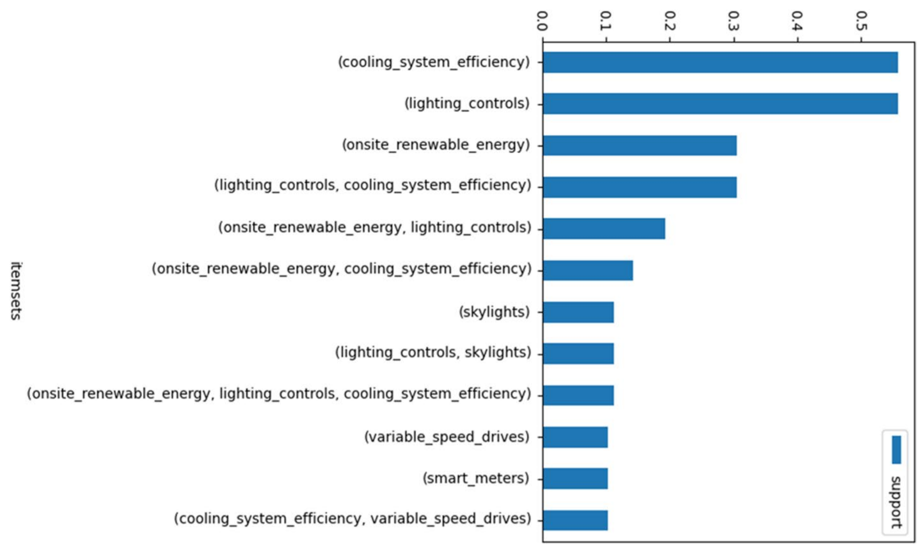

Fig. 8 The support of the association rule

Table 2 Association rules for smart building technologies

Antecedents	Consequents	Antecedent support	Consequent support	Confidence
(skylights)	(lighting_controls)	0.111111	0.555556	1
(onsite_renewable_energy)	(lighting_controls)	0.30303	0.555556	0.633333
(variable_speed_drives)	(cooling_system_efficiency)	0.10101	0.555556	1
(onsite_renewable_energy, cooling_system_efficiency)	(lighting_controls)	0.141414	0.555556	0.785714

The actual energy savings of the existing building were 11.74%. This value acts as a reference (benchmark) for evaluating the impacts of the identified smart technologies on the annual energy savings.

Results and discussion

The Apriori Algorithm is used to mine the association rules in the dataset that combines 99 office buildings on the EDGE Project Studies Archive website as case studies. This helps in identifying commonly used smart building technologies in office buildings and determining the smart technologies that are frequently used together in office buildings worldwide [15].

Selecting the appropriate minimum support and confidence is important and could affect the results. If minimum support and confidence are set too low, many invalid rules are mined; if the minimum support and confidence are set too high, some effective items will be lost. In this research, the minimum support and confidence are set based on multiple tests to select the values. The minimum support is set as 10%, and the confidence threshold is 60%. It can be deduced from the support and confidence results that more than the minimum selected threshold, there is no new combinations for smart building technologies.

Office buildings mainly apply six smart building technologies: cooling system efficiency, lighting controls, onsite renewable energy, skylights, variable speed drives, and smart meters as shown in Fig. 8. The commonly used smart technologies are lighting controls and cooling system efficiency as mentioned before. These findings are in line with the aforementioned literature review which argued that the lighting and HVAC systems have an important effect on energy efficiency in retrofitted office buildings [9, 10].

Lighting controls are usually used with skylights as well as onsite renewable energy as shown in Table 2. Meanwhile, variable speed drives are commonly used with cooling system efficiency. In addition, almost 80% of offices (that apply cooling system efficiency and onsite renewable energy) use with them lighting controls.

For the selected office building, it is important to mention that skylights were not used in the design of the building. In addition to many constrains that restrict the retrofitting process, among which the cooling system efficiency that cannot be modified as this requires the change of the whole system, in addition, economizers cannot be used with the existing air-conditioning (AC) systems. Moreover, the infrastructure is not suitable for installing smart meters.

Based upon the suitability of smart technologies to be used for the selected office building and the excluded smart technologies mentioned above, in addition to the identified groups of smart technologies that are commonly used together shown in Table 2, the research proposes five main smart-orientated retrofitting scenarios for different combinations of smart building technologies. The target was to at least reach 20% energy savings for fulfilling the minimum requirement to be EDGE certified, with the least incremental cost.

Each of the selected five scenarios combines different smart building technologies. Scenario 1 comprises the use of auto on-off lighting controls in all offices, bathrooms, kitchens, and mechanical rooms. Meanwhile, scenario 2 is for the use of solar photovoltaic that provides 10% of annual energy used in the office building. Scenario 3 focuses on the use of variable speed drives in the air handling unit. Scenario 4 comprises the use of solar photovoltaic that provides 10% of annual energy used in the office building and auto on-off lighting controls in all offices, bathrooms, kitchens, and mechanical rooms. Scenario 5 combines the above three technologies comprising the use of variable speed drives, solar photovoltaic that provides 5% of annual energy used in the office building, and auto on-off lighting controls in all offices, bathrooms, kitchens, and mechanical rooms.

EDGE software is used to calculate the percentage of energy savings, final energy use, final utility cost, utility cost savings, incremental costs, and payback periods for the five scenarios to determine the most cost-effective smart technologies by which the building could be EDGE certified with minimal cost as shown in Table 3.

It can be deduced that scenario 2 which comprises the onsite renewable energy is the second most effective scenario; it helps to achieve 20.56% energy saving, and the utility cost saving increases by US $8000/year than the existing case as shown in Table 3; in addition, the payback period will be less than the existing case by 2 years. This shows why the onsite renewable energy is one of the most common applied smart technologies worldwide, and its applications continue to grow as previously shown in Fig. 4.

Table 3 Smart building technologies applied for energy savings—EDGE App output

		Energy saving	Final energy use	Final utility cost	Energy savings	Utility cost savings	Incremental cost	Payback in years
		%	kWh/month	USD/month	MWh/year	USD/year	USD	years
Existing case		11.74	45,338	6631.5	65.29	14,690	125,623	8.6
Scenarios		The assessment output of each scenario when applied to the existing case						
1	Lighting controls	12.17	44,514	6562.8	67.27	14,855	131,876	8.9
2	Onsite renewable energy 10% of annual energy	20.56	40,805	5923.8	119.69	23,182	155,384	6.7
3	Variable speed drives	16.95	42,536	6397.7	98.92	17,496	125,452	7.20
4	Onsite renewable energy 10% of annual energy	20.96	40,063	5868.0	120.68	23,193	161,121.0	6.90
	Lighting controls							
5	Variable speed drives	21.58	39,650	5996.9	125.63	21,646	145,410	6.70
	Lighting controls							
	Onsite renewable energy 5% of annual energy							

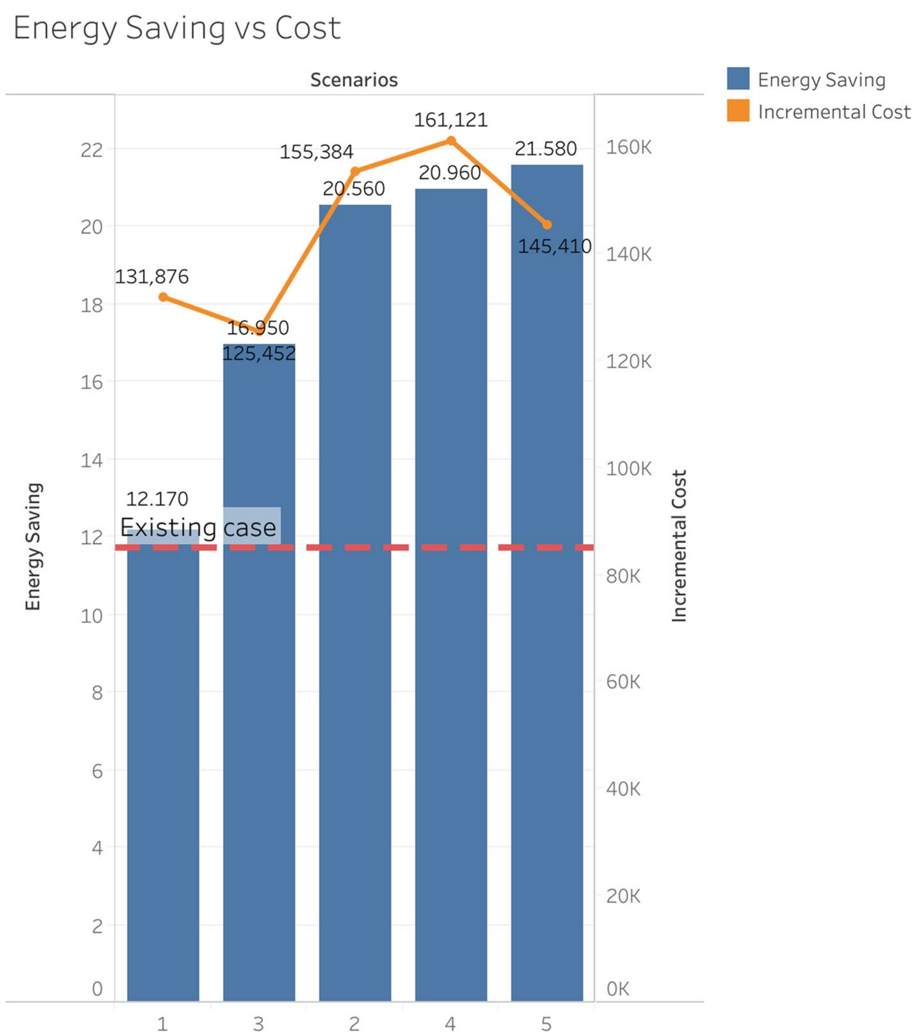

Fig. 9 Energy savings by applying the five scenarios

Meanwhile, scenario 3 shows that impact of variable speed drives on energy savings is very limited. But if a solar photovoltaic that provides 5% of annual energy is added as in scenario 5, this will increase energy savings to reach 21.58% with US $10,000 less incremental cost than scenario 2 as shown in Fig. 9. Regarding the use of lighting control as scenario 1, despite being one of commonly applied technology worldwide, it has a high initial cost in Egypt, and its impact on energy saving is very limited. The results show that renewable energy has a notable effect of energy savings in existing office building, as it could be integrated in the building with minimum intervention. At the end, it can be deduced that the investment in renewable energy will highly increase energy savings in existing office buildings.

Conclusions

Recently, energy savings became a crucial need in the building sector. The key driver of this research is the transformation of existing office buildings in Egypt to be sustainable and energy efficient in a cost-effective manner. There are many tools to minimize energy consumption worldwide, but up until now, the application of smart building technologies in existing building to minimize energy consumption is very limited. This is due to many reasons, such as the cost, the skilled labors, lack of investment in energy-efficient buildings, and lack of research in addition to other issues. Smart technologies that are commonly used worldwide are lighting controls, cooling system efficiency, and onsite renewable energy, respectively. For offices, cooling system efficiency comes in the first place. On the other hand, there are many smart technologies which were almost not used in any of the EDGE-certified projects such as power factor corrections, room heating controls with thermostatic valves, submeter for heating and cooling systems, and demand control ventilation for parking CO_2. This is due to their high initial cost compared with their effectiveness in saving energy.

The research uses the association rule to find the frequent used smart-orientated scenarios in EDGE-certified office buildings. Based on this analysis, the research proposes five smart-orientated retrofitting scenarios to increase energy savings of the selected office building. The potential use of some smart building technologies in retrofitting existing buildings could be restricted as a result of different constrains. These constrains could be the suitability of use with the existing building's systems, the availability and cost in the local market, and the need of upgrading of the building's infrastructure. Despite the high initial cost of smart technologies, it could be covered within around 3 years of operation. That is why it can be concluded that smart technologies could be the optimum solution for retrofitting existing buildings to safeguard our environment especially onsite renewable energy that could be integrated in existing office buildings with minimum intervention. This research addresses stakeholders in the industrial sector to encourage technology transfer of the know-how of these technologies, especially for onsite renewable energy, to be locally manufactured in Egypt; in addition, more investments should not only be directed towards the locally manufacturing of these smart building technologies to overcome the high initial cost of their application but also towards the retrofitting of existing office buildings to be energy efficient using smart technologies.

Suggestions for further work

Additional studies of the applications of smart technologies are necessary to gain a better understanding of their benefits especially relating to energy savings and their limitations in existing buildings. The potential of applying smart technologies in commercial buildings is enormous. Although the research focuses on existing office buildings, but many of the energy-saving benefits of smart buildings could be applied to other types of commercial buildings, including education, laboratory, healthcare, and hospitality. Further research and technology demonstrations are needed to address the benefits of smart technologies and the barriers to the market transformation. This would also help to take innovative approaches for the integration of smart building technologies into existing buildings.

Abbreviations

BAS Building automation system
BPIE Buildings Performance Institute Europe
DER Distributed energy resources
EDGE Excellence in Design for Greater Efficiencies
HVAC Heating, ventilation, and air-conditioning

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Not applicable.

Authors' contributions
The authors confirm contribution to the paper as follows: study conception, data collection, and draft manuscript preparation, MA and SE; data analysis, SE. Building analysis using EDGE, MA. Both authors reviewed the results and approved the final version of the manuscript.

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Availability of data and materials
The data is available in EDGE Project Archive website [15]. Regarding the data of the existing building in Egypt, it is available upon request.

Declarations

Competing interests
The authors declare that they have no competing interests.

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