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Smart Buildings as Smart Loads: A Real-World Methodology for Demand Management in the Smart Grid

M.Nasrallah[1,], **Ahmed Abdelaleem[1]**, **Tarek Amer[1]**, **Ahmed Abdelmoniem[1]**, **Omar Nagy[1]**, **Omar M.Abdo[1]**, **Ali okasha[1]**, **Mohamed Nagar[1]**, **Abdallh Abied[1]**, **Hussein El Sayed[1]**, **Youssef Abdelzaher[1]**, **Ibrahim Mohamed[1]**, **Soad Shams Eldien[1]**, **Hossam Hassan[1]**, **Ibraheem Mabrouk[1]**, **Muhammad Abdullhameed[1]**, **Michael Khalaf[1]**, **Fatma Mahmoud[1]**

Abstract In recent times, energy demand on the grid has significantly increased, impacting its stability, reliability, and service continuity. One contributing factor is that many buildings—both old and new—lack modern electrical equipment, devices, and control technologies. To address this, the paper presents two case studies: the transformation of an existing traditional building (the Faculty of Engineering in Qena) into a smart building, and the design of a new two-level smart office building in Qena. Both cases involve replacing outdated electrical systems with smart devices and implementing advanced control technologies, such as KNX. Additionally, both buildings are powered by on-grid Photovoltaic (PV) systems. The methodology section outlines the detailed steps for converting a traditional building into a smart one and designing a new smart office building. The smart loads (i.e., smart buildings) improve the load efficiency and the grid performance by reducing demand, and are the first step toward making the grid a smart grid with its benefits. This paper offers a comprehensive view of smart building development. Theoretical results, supported by real data, validate the proposed approach and confirm the effectiveness of the smart building methodology.

Keywords: Smart building; Smart grid; KNX; BMS, PV.

1 Introduction

Loads such as residential, educational, office, healthcare, and industrial buildings account for a significant portion of electrical grid consumption. As a result, considerable research has focused on Building Energy Management Systems (BEMS) to optimize energy use and reduce consumption across these sectors [1–5]. For example, [1] presented a comprehensive review of research on BEMS dating back to 1982. In [2], a building information management system proposed using a 3D grid-based building model, while [3] introduced an energy control strategy for office buildings. Reference [4] presented a big-data-based architecture for efficient building management, and [5] proposed an optimal BEMS based on the Active Target Grey Wolf Optimization algorithm. Additionally, extensive research has been conducted on integrating PV renewable energy systems into buildings [6–10]. For instance, [6] proposed a method to extend the battery life of PV systems, and [7] studied a grid-connected PV system with battery storage for residential buildings. Reference [8] introduced a load management strategy for building-integrated PV systems, while [9] investigated rooftop PV implementation on academic buildings with smart monitoring. Furthermore, [10] examined PV use in office buildings, considering seasonal variations. The use of Internet of Things (IoT) technologies for building energy management has also received considerable attention [11–15]. Reference [11] reviewed various IoT-based methods for reducing building energy consumption. In [12], an IoT-based energy management system integrated human detection and prepaid metering. Similarly, [13] presented a smart home energy management system for automatic energy optimization and billing. Reference [14] proposed a multi-objective IoT-based energy management system for residential microgrids with renewable integration, while [15] focused on energy conservation in buildings with multiple appliances using IoT. Smart grid development has also been a major research focus [16–20]. Reference [16] offered a general review of smart grids, emphasizing the role of renewable energy. In [17], an automatic crowbar was used to protect transmission and distribution lines from faults. Reference [18] explored the use of Electric Vehicle (EV) charging stations as smart loads in the grid. Additionally, [19] proposed an adaptive protection method using electronic relays. As mentioned above, the previous literature mentioned one of the methods to reduce or manage the demand to improve the

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Corresponding Author: Mahmoud Nasrallah,
nasrallah_1@yahoo.com
1. Electrical Engineering Department, Faculty of Engineering, South Valley University, Qena 83523, Egypt

grid performance, this paper proposes a comprehensive methodology to make the load as smart as a step to make the traditional grid a smart grid. And this methodology can be applied to any building to make it smart. Except, the PV part can be replaced by a fuel cell as a renewable energy source, according to the location of the building.

In this paper, implementation of a practical methodology for converting a traditional building (the Faculty of Engineering in Qena) into a smart building and designing a new two-floors smart office building is proposed. These implementations aim to reduce grid consumption by transforming passive loads into smart, manageable ones, aligning with the broader objectives of smart grid development. The paper also demonstrates how smart buildings can contribute to improve both grid performance and load efficiency.

The motivation from this paper is to reduce the demand from the grid, and improve both grid performance and load efficiency by improving the load behavior through smart conversion, and the contribution from this paper is how to make the load a smart load supported by two studies, traditional building and new building, and making them as smart loads.

This paper is structured into eight sections:

1. Institution under Study – Describes the buildings selected for the case studies.
2. New Smart Building Methodology – Presents the proposed methodology for achieving smart building functionality.
3. Upgrading Electrical Devices – Details the replacement of outdated devices with modern smart equipment in the existing building, and the selection of smart devices in the new design.
4. Design of Operation Sequences – Proposes operation sequences for all electrical devices based on their functional requirements.
5. Integration of PV Systems – Describes the use of photovoltaic panels to reduce energy demand and support smart grid goals.
6. IoT Implementation Using KNX – Demonstrates the application of the KNX protocol as an IoT solution for smart control.
7. Results and Analysis – Presents theoretical and real-world data that validate the effectiveness of the proposed methodology.
8. Conclusion – Summarizes the key findings and implications of the study.

2 Institutions under Study

This paper examines two case studies. The first involves retrofitting a traditional building—the Faculty of Engineering in Qena, Egypt—into a smart building. The second focuses on the design of a new smart office building from the ground up, also located in Qena, Egypt.

2.1 Description of the faculty of engineering building in Qena

As shown in **Fig. 1**, the floor plan illustrates the layout of the Faculty of Engineering building, which consists of three floors. **Figure 2**, **Figure 3**, and **Figure 4** show the distribution of electrical loads on the first, second, and third floors, respectively.

- First Floor: Includes two auditoriums, two teaching break rooms, two storage rooms, two classrooms, three corridors, two bathrooms, and two exam halls.
- Second Floor: Comprises two auditoriums, two teaching break rooms, two storage rooms, six classrooms, three corridors, and two bathrooms.
- Third Floor: Contains two teaching break rooms, two storage rooms, six classrooms, one corridor, and two bathrooms.

Fig. 1 Top view for Qena Faculty of Engineering

Table 1, **Table 2**, and **Table 3** list the location, type, quantity, and rating of electrical loads on the first, second, and third floors, respectively. Each table also provides the total electrical load for the floor before any improvements were implemented.

2.2 Description of the New Smart Office Building

A conceptual image of the proposed new smart office building is shown in **Fig. 5**, **Fig. 6** and **Fig. 7** detail the layout of each floor:

- **First Floor:** Includes eleven offices, one open space, four rooms, one pantry, one stairwell, and one exterior area (car parking).
- **Second Floor:** Includes nine offices, two rooms, two toilets, one pantry, one open space, one lounge, and one stairwell.

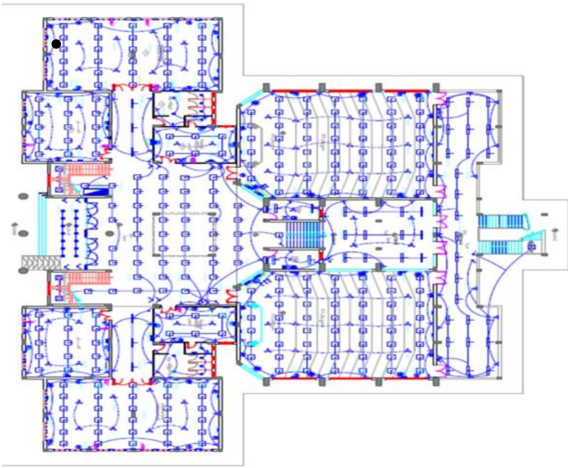

Fig. 2 Electrical loads of the first floor

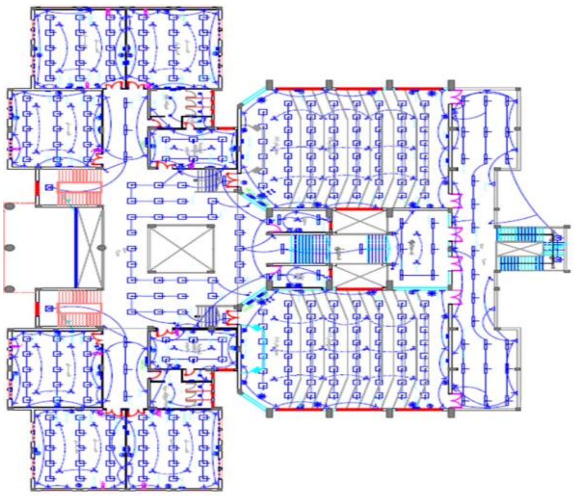

Fig. 3 Electrical loads of the second floor

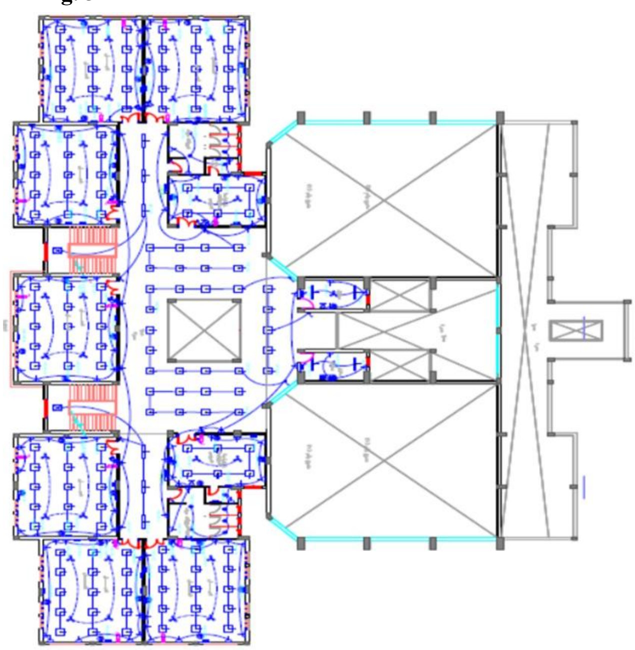

Fig. 4 Electrical loads of the third floor

Fig. 5 A new smart office building proposed

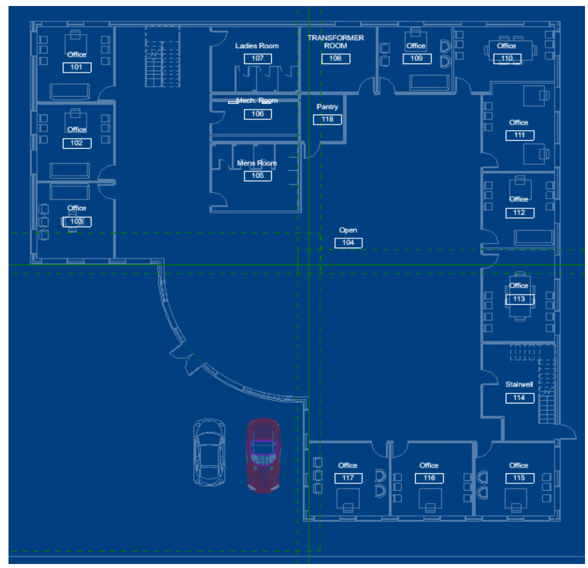

Fig. 6 First floor of a new smart office building proposed

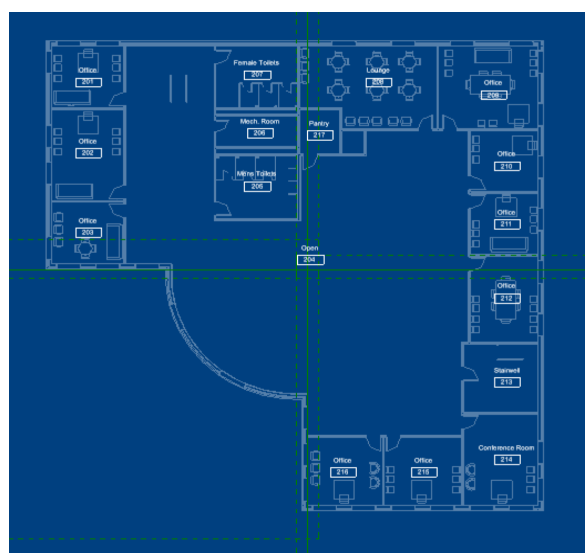

Fig. 7 Second floor of a new smart office building proposed

Table 1 Electrical loads of the first-floor before replacing

PLACES	ELECTRICAL DEVICES	NUMBER	OLD POWER (W)	TOTAL OLD POWER (W)
Front	Spotlight	16	11	176
First Auditorin	60*60 LED Panel	63	24	1512
	120 cm Luminaires	2	49	98
	Conditioner	4	6830	27320
	Fan	12	80	960
	Microphone & speaker	6	60	360
Second Auditorin	60*60 LED Panel	63	24	1512
	120 cm Luminaires	2	49	98
	Fan	12	80	960
	Microphone & speaker	6	60	360
First Teaching break	60*60 LED Panel	6	24	144
	Fan	2	80	160
Second Teaching break	60*60 LED Panel	6	24	144
	Fan	2	80	160
First store	120 cm Luminaires	2	49	98
	Fan	1	80	80
Second store	120 cm Luminaires	2	49	98
	Fan	1	80	80
Classroom 1	60*60 LED Panel	15	24	360
	120 cm Luminaires	2	49	98
	Fan	4	80	320
Classroom 2	60*60 LED Panel	15	24	360
	120 cm Luminaires	2	49	98
	Fan	4	80	320
Corridor 1	60*60 LED Panel	25	24	600
Corridor 2	60*60 LED Panel	8	24	192
	Fan	3	80	240
Corridor 3	60*60 LED Panel	44	24	1056
	TV screen	1	75	75
Bathroom 1	spiral bulb	5	24	120
	Water chiller	1	370	370
Bathroom 2	spiral bulb	5	24	120
	Water chiller	1	370	370
exam hall 1	60*60 LED Panel	25	24	600
	Fan	8	80	640
	Conditioner	5	6830	34150
exam hall 1	60*60 LED Panel	25	24	600
	Fan	8	80	640
	Conditioner	5	6830	34150
Total				109799

Table 2 Electrical loads of the second-floor before replacing

PLACES	ELECTRICAL DEVICES	NUMBER	OLD POWER (W)	TOTAL OLD POWER (W)
First Auditorin	60*60 LED Panel	63	24	1512
	120 cm Luminaires	2	49	98
	Conditioner	4	6830	27320
	Fan	12	80	960
	Microphone & speaker	6	60	360
Second Auditorin	60*60 LED Panel	63	24	1512
	120 cm Luminaires	2	49	98
	Fan	12	80	960
	Microphone & speaker	6	60	360
Corridor 1	60*60 LED Panel	25	24	600
Corridor 2	60*60 LED Panel	8	24	192
	TV screen	1	75	75
	Fan	3	80	240
Corridor 3	60*60 LED Panel	38	24	912
First Teaching break	60*60 LED Panel	6	24	144
	Fan	2	80	160
Second Teaching break	60*60 LED Panel	6	24	144
	Fan	2	80	160
	Conditioner	1	6830	6830
	heater	1	3750	3750
Bathroom 1	spiral bulb	5	24	120
	Water chiller	1	370	370
Bathroom 2	spiral bulb	5	24	120
Classroom 1	60*60 LED Panel	15	24	360
	120 cm Luminaires	2	49	98
	Fan	4	80	320
Classroom 2	60*60 LED Panel	15	24	360
	120 cm Luminaires	2	49	98
	Fan	4	80	320
Classroom 3	60*60 LED Panel	15	24	360
	120 cm Luminaires	2	49	98
	Fan	4	80	320
Classroom 4	60*60 LED Panel	15	24	360
	120 cm Luminaires	2	49	98
	Fan	4	80	320
Classroom 5	60*60 LED Panel	15	24	360
	120 cm Luminaires	2	49	98
	Fan	4	80	320
Classroom 6	60*60 LED Panel	15	24	360
	120 cm Luminaires	2	49	98
	Fan	4	80	320
First store	120 cm Luminaires	2	49	98
	Fan	1	80	80
Second store	120 cm Luminaires	2	49	98
	Fan	1	80	80
Total				52021

3. New Smart Building Methodology

The proposed smart building methodology is derived from the literature reviewed in the introduction and consists of the following key steps:

A. Upgrading Electrical Equipment: Replacing outdated electrical equipment with modern, smart devices in the case of retrofitting an existing building, or incorporating smart devices from the outset in the case of a new building design.

B. Designing Device Operation Sequences: Defining the operation sequences for all electrical devices based on their intended function and usage patterns.

C. Integrating Renewable Energy: Installing PV panels in both cases to reduce dependency on the grid and support renewable energy integration.

D. Implementing IoT Solutions: Applying IoT technology, specifically using the KNX protocol, to enable intelligent control and monitoring. Each of these methodology components is explained in detail in the following section

4. Replacing Old Electrical Devices with Smart Devices

4.1 Retrofitting a Traditional Building

In this step, each outdated electrical device in the Faculty of Engineering building is replaced with a modern smart equivalent. **Table 4**, **Table 5**, and **Table 6** show the power ratings of the devices before and after the replacement, as well as the resulting energy savings per floor. These savings are visualized in **Fig. 8** and **Fig. 9**.
Table 7 summarizes the total savings achieved on each floor:

- First Floor: 58,476 W
- Second Floor: 26,142.8 W
- Third Floor: 10,694 W

In total, the upgrade results in an overall energy saving of 95,312.8 W for the entire building.

Table 3 Electrical loads of the third-floor before replacing

PLACES	ELECTRICAL DEVICES	NUMBER	OLD POWER (W)	TOTAL OLD POWER (W)
Classroom 1	60*60 LED Panel	15	24	360
	120 cm Luminaires	2	49	98
	Fan	4	80	320
Classroom 2	60*60 LED Panel	15	24	360
	120 cm Luminaires	2	49	98
	Fan	4	80	320
Classroom 3	60*60 LED Panel	15	24	360
	120 cm Luminaires	2	49	98
	Fan	4	80	320
Classroom 4	60*60 LED Panel	15	24	360
	120 cm Luminaires	2	49	98
	Fan	4	80	320
Classroom 5	60*60 LED Panel	15	24	360
	120 cm Luminaires	2	49	98
	Fan	4	80	320
Classroom 6	60*60 LED Panel	15	24	360
	120 cm Luminaires	2	49	98
	Fan	4	80	320
First Teaching break	60*60 LED Panel	6	24	144
	Fan	2	80	160
	heater	1	3750	3750
Second Teaching break	60*60 LED Panel	6	24	144
	Fan	2	80	160
	Conditioner	1	6830	6830
	heater	1	3750	3750
First store	120 cm Luminaires	2	49	98
	Fan	1	80	80
Second store	120 cm Luminaires	2	49	98
	Fan	1	80	80
Bathroom 1	spiral bulb	5	24	120
Bathroom 2	spiral bulb	5	24	120
Corridor 1	60*60 LED Panel	38	24	912
stairs	60*60 LED Panel	8	24	192
Total				21306

Table 4 Electrical loads of the first-floor after replacing

PLACES	ELECTRICAL DEVICES	NUMBER	NEW Power (W)	TOTAL NEW POWER (W)
Front	Spotlight	16	5	80
First Auditorin	60*60 LED Panel	63	19.8	1247.4
	120 cm Luminaires	2	18	36
	Conditioner	4	3000	12000
	Fan	12	40	480
	Microphone & speaker	6	40	240
Second Auditorin	60*60 LED Panel	63	19.8	1247.4
	120 cm Luminaires	2	18	36
	Fan	12	40	480
	Microphone & speaker	6	40	240
First Teaching break	60*60 LED Panel	6	19.8	118.8
	Fan	2	40	80
Second Teaching break	60*60 LED Panel	6	19.8	118.8
	Fan	2	40	80
First store	120 cm Luminaires	2	18	36
	Fan	1	40	40
Second store	120 cm Luminaires	2	18	36
	Fan	1	40	40
Classroom 1	60*60 LED Panel	15	19.8	297
	120 cm Luminaires	2	18	36
	Fan	4	40	160
Classroom 2	60*60 LED Panel	15	19.8	297
	120 cm Luminaires	2	18	36
	Fan	4	40	160
Corridor 1	60*60 LED Panel	25	19.8	495
Corridor 2	60*60 LED Panel	8	19.8	158.4
	Fan	3	40	120
Corridor 3	60*60 LED Panel	44	19.8	871.2
	TV screen	1	50	50
Bathroom 1	spiral bulb	5	20	100
	Water chiller	1	88	88
Bathroom 2	spiral bulb	5	20	100
	Water chiller	1	88	88
exam hall 1	60*60 LED Panel	25	19.8	495
	Fan	8	40	320
	Conditioner	5	3000	15000
exam hall 1	60*60 LED Panel	25	19.8	495
	Fan	8	40	320
	Conditioner	5	3000	15000
Total				51323

4.2 Using modern electrical devices for a new building

In this case, modern smart electrical devices are used for a new building, as illustrated in **Table 8** and **Table 9**. The electrical load is 9603 W on the first floor and 17763.5 W on the second floor.

Table 5 Electrical loads of the second-floor after replacing

PLACES	ELECTRICAL DEVICES	NUMBER	NEW Power (W)	TOTAL NEW POWER (W)
First Auditorin	60*60 LED Panel	63	19.8	1247.4
	120 cm Luminaires	2	18	36
	Conditioner	4	3000	12000
	Fan	12	40	480
	Microphone & speaker	6	40	240
Second Auditorin	60*60 LED Panel	63	19.8	1247.4
	120 cm Luminaires	2	18	36
	Fan	12	40	480
	Microphone & speaker	6	40	240
Corridor 1	60*60 LED Panel	25	19.8	495
Corridor 2	60*60 LED Panel	8	19.8	158.4
	TV screen	1	50	50
	Fan	3	40	120
Corridor 3	60*60 LED Panel	38	19.8	752.4
First Teaching break	60*60 LED Panel	6	19.8	118.8
	Fan	2	40	80
Second Teaching break	60*60 LED Panel	6	19.8	118.8
	Fan	2	40	80
	Conditioner	1	3000	3000
	heater	1	1500	1500
Bathroom 1	spiral bulb	5	20	100
	Water chiller	1	88	88
Bathroom 2	spiral bulb	5	20	100
Classroom 1	60*60 LED Panel	15	19.8	297
	120 cm Luminaires	2	18	36
	Fan	4	40	160
Classroom 2	60*60 LED Panel	15	19.8	297
	120 cm Luminaires	2	18	36
	Fan	4	40	160
Classroom 3	60*60 LED Panel	15	19.8	297
	120 cm Luminaires	2	18	36
	Fan	4	40	160
Classroom 4	60*60 LED Panel	15	19.8	297
	120 cm Luminaires	2	18	36
	Fan	4	40	160
Classroom 5	60*60 LED Panel	15	19.8	297
	120 cm Luminaires	2	18	36
	Fan	4	40	160
Classroom 6	60*60 LED Panel	15	19.8	297
	120 cm Luminaires	2	18	36
	Fan	4	40	160
First store	120 cm Luminaires	2	18	36
	Fan	1	40	40
Second store	120 cm Luminaires	2	18	36
	Fan	1	40	40
Total				25878.2

Table 7 Total power in each floor before and after replacing

Floor	Old power (W)	New power (W)
First floor	109799	51323
Second floor	52021	25878.2
Third floor	21306	10612

Table 6 Electrical loads of the third floor after replacing

PLACES	ELECTRICAL DEVICES	NUMBER	NEW Power (W)	TOTAL NEW POWER (W)
Classroom 1	60*60 LED Panel	15	19.8	297
	120 cm Luminaires	2	18	36
	Fan	4	40	160
Classroom 2	60*60 LED Panel	15	19.8	297
	120 cm Luminaires	2	18	36
	Fan	4	40	160
Classroom 3	60*60 LED Panel	15	19.8	297
	120 cm Luminaires	2	18	36
	Fan	4	40	160
Classroom4	60*60 LED Panel	15	19.8	297
	120 cm Luminaires	2	18	36
	Fan	4	40	160
Classroom 5	60*60 LED Panel	15	19.8	297
	120 cm Luminaires	2	18	36
	Fan	4	40	160
Classroom 6	60*60 LED Panel	15	19.8	297
	120 cm Luminaires	2	18	36
	Fan	4	40	160
First Teaching break	60*60 LED Panel	6	19.8	118.8
	Fan	2	40	80
	heater	1	1500	1500
Second Teaching break	60*60 LED Panel	6	19.8	118.8
	Fan	2	40	80
	Conditioner	1	3000	3000
	heater	1	1500	1500
First store	120 cm Luminaires	2	18	36
	Fan	1	40	40
Second store	120 cm Luminaires	2	18	36
	Fan	1	40	40
Bathroom 1	spiral bulb	5	20	100
Bathroom 2	spiral bulb	5	20	100
Corridor 1	60*60 LED Panel	38	19.8	752.4
stairs	60*60 LED Panel	8	19	152
Total				10612

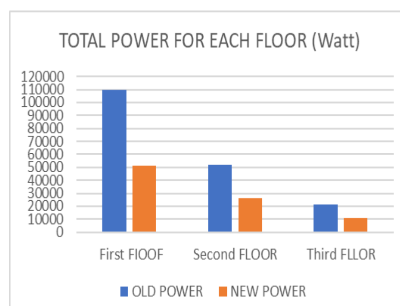

Fig. 8 Total power for each floor of the faculty building before and after replacing step

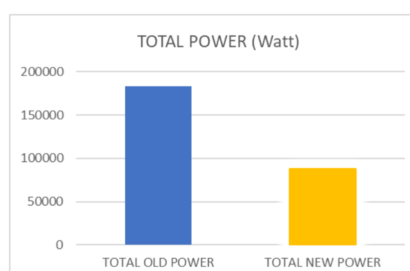

Fig. 9 Total power for the faculty building before and after replacing step

Table 8 Electrical load for first floor

PLACES	ELECTRICAL DEVICES	NUMBER	Power (W)	TOTAL POWER (W)
Office 101	60*60 LED Panel	6	23	138
	TV screen	1	75	75
	FCU	1	320	320
	Computer	1	200	200
Office 102	60*60 LED Panel	6	23	138
	TV screen	1	75	75
	FCU	1	320	320
	Computer	1	200	200
Office 103	60*60 LED Panel	6	23	138
	TV screen	1	75	75
	FCU	1	320	320
	Computer	1	200	200
Open 104	SPOT	23	22.5	517.5
	TV screen	2	75	150
Mens Room 105	SPOT	8	22.5	180
	Water chiller	1	88	88
Mech Room 106	120 cm Luminaires	2	26	52
Ladies Room 107	SPOT	8	22.5	180
	Water chiller	1	88	88
Transformer Room 108	120 cm Luminaires	4	26	104
Office 109	60*60 LED Panel	4	23	92
	FCU	1	320	320
	TV screen	1	75	75
	Computer	1	200	200
Office 110	60*60 LED Panel	6	23	138
	FCU	1	320	320
	TV screen	1	75	75
	Microphone & speaker	4	40	160
	Computer	1	200	200
Office 111	60*60 LED Panel	6	23	138
	FCU	1	320	320
	TV screen	1	75	75
	Computer	1	200	200
Office 112	60*60 LED Panel	4	23	92
	FCU	1	320	320
	TV screen	1	75	75
	Computer	1	200	200
Office 113	60*60 LED Panel	6	23	138
	FCU	1	320	320
	TV screen	1	75	75
	Computer	1	200	200
Stairwell 114	SPOT	5	22.5	112.5
Office 115	60*60 LED Panel	6	23	138
	FCU	1	320	320
	TV screen	1	75	75
	Computer	1	200	200
Office 116	60*60 LED Panel	6	23	138
	FCU	1	320	320
	TV screen	1	75	75
	Computer	1	200	200
Office 117	60*60 LED Panel	6	23	138
	FCU	1	320	320
	TV screen	1	75	75
	Computer	1	200	200
Total				9603

Table 9 Electrical load for second floor

PLACES	ELECTRICAL DEVICES	NUMBER	Power (W)	TOTAL POWER (W)
Office 201	60*60 LED Panel	6	23	138
	FCU	1	320	320
	TV screen	1	75	75
	Computer	1	200	200
Office 202	60*60 LED Panel	6	23	138
	FCU	1	320	320
	TV screen	1	75	75
	Computer	1	200	200
Office 203	60*60 LED Panel	6	23	138
	FCU	1	320	320
	TV screen	1	75	75
	Computer	1	200	200
Open 204	Spot	23	22.5	517.5
	TV screen	2	75	150
Men Toilets 205	Spot	6	22.5	135
	Water chiller	1	88	88
Mech Room 206	120 cm Luminaires	2	26	52
Female Toilets 207	Spot	6	22.5	135
	Water chiller	1	88	88
Lounge 208	60*60 LED Panel	5	23	115
	TV screen	2	75	150
	FCU	2	320	640
Office 209	60*60 LED Panel	6	23	138
	FCU	1	320	320
	TV screen	1	75	75
	Microphone & speaker	4	40	160
	Computer	1	200	200
Office 210	60*60 LED Panel	4	23	92
	FCU	1	320	320
	TV screen	1	75	75
	Computer	1	200	200
Office 211	60*60 LED Panel	4	23	92
	FCU	1	320	320
	TV screen	1	75	75
	Computer	1	200	200
Office 212	60*60 LED Panel	6	23	138
	FCU	1	320	320
	TV screen	1	75	75
	Computer	1	200	200
Office 209	60*60 LED Panel	6	23	138
Office 210	FCU	1	320	320
	TV screen	1	75	75
	Microphone & speaker	4	40	160
	Computer	1	200	200
	60*60 LED Panel	4	23	92
Office 211	FCU	1	320	320
	TV screen	1	75	75
	Computer	1	200	200
	60*60 LED Panel	4	23	92
Office 212	FCU	1	320	320
	TV screen	1	75	75
	Computer	1	200	200
	60*60 LED Panel	6	23	138
Open Place	HVAC	1	8000	8000
Pantry 217	Spot	4	22.5	90
Total				17763.5

5 Operation Sequence Design for Electrical Devices

The operation and shutdown schedules of electrical devices within a building are optimized to enhance energy efficiency while maintaining user comfort. These schedules are based on working hours, occupancy patterns, and energy-saving strategies. The main objective of this step is to eliminate energy waste caused by human error.

Furthermore, these schedules can be implemented using KNX-based IoT control circuits, as discussed in Section 6. The terms (ON–OFF) in this context indicate the capability of the devices to be automatically controlled via KNX, not their actual operating status at any given time.

5.1 Operation Sequence for the Traditional Building (After Retrofitting)

- Front Lights: Operate daily from 5:00 PM to 6:00 AM.
- First, Second, and Third Floors: Lighting and other devices are ON from Sunday to Thursday between 7:30 AM and 8:30 PM.

5.2 Operation Sequence for the New Smart Office Building

- Lighting: Operate daily from Sunday to Thursday, operating 12 hours daily from 6:30 AM to 6:30 PM.
- HVAC (Air Conditioning): Operate daily from Sunday to Thursday, operating 10.5 hours daily from 7:00 AM to 5:30 PM.

6 Integration of PV Panels as a Renewable Energy Source

In this step, on-grid PV panels are installed to generate electricity from solar energy, thereby reducing the building's reliance on the utility grid. The number of required panels and the system configuration for each case are calculated as follows:

6.1 The Faculty of Engineering Building

Following the replacement of traditional devices with smart alternatives, the total electrical load is approximately 88 kW. Assuming each panel generates 600 W, the number of panels required is calculated as:

Number of panels= (88 kW*1.03)/600 W=150 panels

These 150 panels are configured into 25 series and 6 parallel strings to ensure the system operates within the maximum allowable system voltage and the optimal Maximum Power Point (MPP) voltage range. This configuration was validated using PVsyst simulation software, with the results are summarized in **Table 10**.

Table 10 PVsyst simulation software results for the faculty building

PV panel data	Magnitude
Planed power	90 kW
Power of each plane	600 W
inverter	105 kW 600-1500 V
No. of modules and strings	25 series- 6 parallel
No. of panels	150
Modules area	419 m^2

6.2 The New Smart Office Building

After the integration of smart devices, the total load is approximately 27.4 kW. Assuming each panel generates 600 W, the number of panels required is:

Number of panels= (27.4 kW*1.03)/600 W=48 panels

The 48 panels are arranged in 12 series-connected strings and 4 parallel branches to ensure the system operates within the maximum allowable system voltage and the optimal MPP voltage range. This configuration was validated using PVsyst simulation software, with the results summarized in **Table 11**.

Table 11 PVsyst simulation software results for the new office building

PV panel data	Magnitude
Planed power	28.8 kW
Power of each plane	600 W
Inverter	33.3 kW 200-1000V
No. of modules and strings	12 series- 4 parallel
No. of panels	48
Modules area	134 m^2

7 Implementing IoT Using the KNX Protocol

As mentioned in papers [11-15], IoT has been used in building to make it smart. KNX is one of the most widely adopted protocols in Building Management Systems (BMS) (KNX protocol applies IoT on buildings). It is an open international standard (EN 50090, ISO/IEC 14543) for home and building automation. KNX systems can manage lighting, blinds, HVAC, security, energy use, audiovisual systems, appliances, and more.
KNX system components overview

1. Sensors (Input Devices): Push buttons, motion detectors, temperature sensors, light sensors, weather stations, window/door contacts.
2. Actuators (Output Devices): Relay actuators, dimming actuators, shutter/blind actuators, valve drives, HVAC controllers.
3. System Devices: KNX power supplies with choke, line/area couplers, KNX IP routers, KNX/IP interfaces, KNX RF devices, KNX PL devices, KNX Data Secure devices.
4. Control Devices: KNX touch panels, room controllers, visualization systems (e.g., GIRA Homeserver), voice control gateways, logic modules.
5. Bus Media: KNX TP (twisted pair), KNX PL (power line), KNX RF (radio frequency), KNX IP (Ethernet).
6. Additional Components: KNX Data Secure devices, backup power supplies, DALI gateways, HVAC controllers, logic modules.

Note: All KNX components communicate via the standardized KNX bus, enabling interoperability among devices from different manufacturers.

7.1 Application to the Faculty of Engineering Building

The KNX system was deployed in the Faculty of Engineering building in Qena. Quantities of components used on each floor are summarized below:

First Floor:

67 KNX lighting circuits, 2 heaters, 52 low-current devices, 20 air conditioning units, 10 presence sensors, 9 touch screens, 2 keypads (2G), 6 keypads (3G), 6 keypads (4G).

Second Floor:

68 KNX lighting circuits, 2 heaters, 45 low-current devices, 22 air conditioning units, 10 presence sensors, 10 touch screens, 2 keypads (2G), 8 keypads (3G), 4 keypads (4G).

Third Floor:

39 KNX lighting circuits, 2 heaters, 26 low-current devices, 14 air conditioning units, 4 presence sensors, 8 touch screens, 2 keypads (2G), 8 keypads (3G), 2 keypads (4G).

Table 12 presents the total quantities of each KNX component used throughout the building.

Table 12 Total quantity of the final components of the KNX protocol

Module	Part No.	Description
Power Supply	10	Power Supply 640mA
Line Couplers	20	To Connect 2 Lines
Switch/Shutter Actuator	10	Switch/Shutter Actuator 16A, 20/10 Fold
Universal Dimmer	-	Universal Dimmer 230V, 4 Fold
A/C IR	56	Universal IR Air Conditioner to Home Automation Interface - 1 unit
Ceiling Motion Sensor	-	Ceiling Sensor IP20, 2.5m Height, 7m Coverage Range
Presence Sensor	24	PIR Sensor IP20, 2.5m Height, 7m Coverage Range
Touch Screen 7"	27	Touch Screen 7", with Back Box (10cm * 6cm)
Server	3	To Connect KNX via internet and mobile application
2G Keypad	6	4 Buttons
3G Keypad	22	6 Buttons
4G Keypad	12	8 Buttons
KNX Electrical Panel	11	96 Raws Electrical Panels

7.2 The New Office Building

The KNX protocol was implemented in the new office building, and the quantities of components were calculated as follows.

7.2.1 First Floor

17 KNX lighting circuits, 27 dimming units, 28 shutters, 4 motion sensors, 11 outdoor light sensors, 15 indoor light sensors, 12 air conditioning units, 12 presence sensors, 2 touch screens, and 11 keypads.

7.2.2 Second Floor:

4 KNX lighting circuits, 27 dimming units, 28 shutters, 4 motion sensors, 11 outdoor light sensors, 15 indoor light sensors, 12 air conditioning units, 12 presence sensors, 2 touch screens, and 12 keypads.

Table 13 presents the total quantities of KNX components installed in the entire building.

Table 13 Total quantity of the final components of the KNX protocol

Module	Part No.	Description
Power Supply	10	Power Supply 640mA
Line Couplers	20	To Connect 2 Lines
Switch/Shutter Actuator	10	Switch/Shutter Actuator 16A, 20/10 Fold
Universal Dimmer	-	Universal Dimmer 230V, 4 Fold
A/C IR	56	Universal IR Air Conditioner to Home Automation Interface - 1 unit
Ceiling Motion Sensor	-	Ceiling Sensor IP20, 2.5m Height, 7m Coverage Range
Presence Sensor	24	PIR Sensor IP20, 2.5m Height, 7m Coverage Range
Touch Screen 7"	27	Touch Screen 7", with Back Box (10cm * 6cm)
Server	3	To Connect KNX via internet and mobile application
2G Keypad	6	4 Buttons
3G Keypad	22	6 Buttons
4G Keypad	12	8 Buttons
KNX Electrical Panel	11	96 Raws Electrical Panels

8 Conclusion and Theoretical Results from Real Data

As mentioned above, this paper proposes a complete methodology to make the load as smart as a step to make the traditional grid a smart grid. And this methodology can be applied to any building to make it smart. However, the PV part can be replaced by a fuel cell as a renewable energy source, according to the location of the building.

As demonstrated in both case studies, the Faculty of Engineering building and the new office building, the proposed smart building methodology for managing energy demand has yielded promising results. The approach began with replacing outdated electrical devices with smart alternatives (or incorporating them from the design phase in the new building). This was followed by implementing optimized operation sequences encoded within the KNX protocol to eliminate user-related errors. Additionally, integrating PV panels as a renewable energy source significantly reduced energy demand. Finally, applying the KNX protocol as an example of IoT-based control facilitated efficient building automation and transformed both buildings into intelligent, easily manageable systems.

9 Future Work

The limitations and the economic view will be studied to apply the proposed complete methodology to make building smart for a smart grid.

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