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Improving Energy Performance in Smart Buildings Through Information and Communication Technology: A State-of-The-Art Review

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Abstract

Buildings have become the primary energy consumer due to increased outdoor temperature rates due to global warming and climate change. Building Management Systems (BMS) are considered a key tool in improving energy management through automation, which relies on Information and Communications Technology (ICT) applications, leading to the emergence of smart buildings as an effective solution. However, a proper theoretical framework for integrating solutions at various levels remains lacking. This research aims to clarify the integrative relationship and its role in building automation to achieve optimal interaction between occupants and the building, focusing on using BMS to attain energy efficiency. Recent literature on integrating ICT with BMS has been reviewed to classify different variables and factors impacting the work topic. An overview of the current state of knowledge has been provided, and a comprehensive table of all potential factors, parameters, technologies, and tools at various levels (such as sensor level, device level, communication level, occupant comfort level, and communication with occupants) has been developed. This facilitates the development of a theoretical framework, which can serve as a basis for a practical decision-making tool to help designers make the best design decisions.

Keywords: Building Automation, Building Management Systems, Energy and Building, Feedback Loops, Information and Communication Technology.

1. Introduction

The global building sector consumes approximately 40% of the total energy produced. In Iraq, the residential building sector consumes 48% of the total energy generated, and 69% of this share is used for cooling and heating [1],[3]. Iraq's power plants were severely affected by the wars since 1990 and deteriorated further during the war in 2003. Basra is considered one of the cities most affected by energy shortages in Iraq. Moreover, excessive hot weather due to the desert climate in Iraq leads to high energy consumption for heating, ventilation, and air conditioning (HVAC) purposes [4] .In addition, most buildings do not meet the minimum requirements of energy efficiency standards. Subsequently, a large amount of energy consumption for cooling and heating has become a significant issue[5].

In Iraq, approximately 60% of buildings fail to meet the minimum energy efficiency standards of the International Energy Agency (IEA). This highlights significant challenges the country faces in improving energy efficiency and reducing overall energy consumption across various sectors, including the residential sector [6],[8]. Thus, the need for effective solutions to solve this situation has emerged. Information and Communication Technology (ICT) is one solution that profoundly impacts most aspects of daily life. One of the applications of ICT is smart architecture, which was first linked to safety and security. This concept has also risen with the endurance of architecture. Smart buildings adhere to environmental responsibility by addressing environmental repercussions, striving for justice in intergenerational energy consumption, and achieving social security [9]. Since research into the energy efficiency of smart buildings is an important topic in the current era, the concept has become that environmentally intelligent design seeks to contribute to the regional and international effort to reduce the carbon footprints of buildings, thus contributing to mitigating the impact of Climate Change. About 80% of the energy consumption is due to providing indoor comfort. This energy can be hugely reduced if automation is integrated into the building and its systems are smart-controlled, in addition to minimizing heating and cooling costs [10].

Fig. 1 illustrates the interrelationship between Information and Communication Technology (ICT) and energy within smart grids and network management. It also shows the role of ICT in buildings at the level of design, planning, monitoring, control, and information exchange tools throughout the design and construction phases, utilizing ICT technologies in this field.

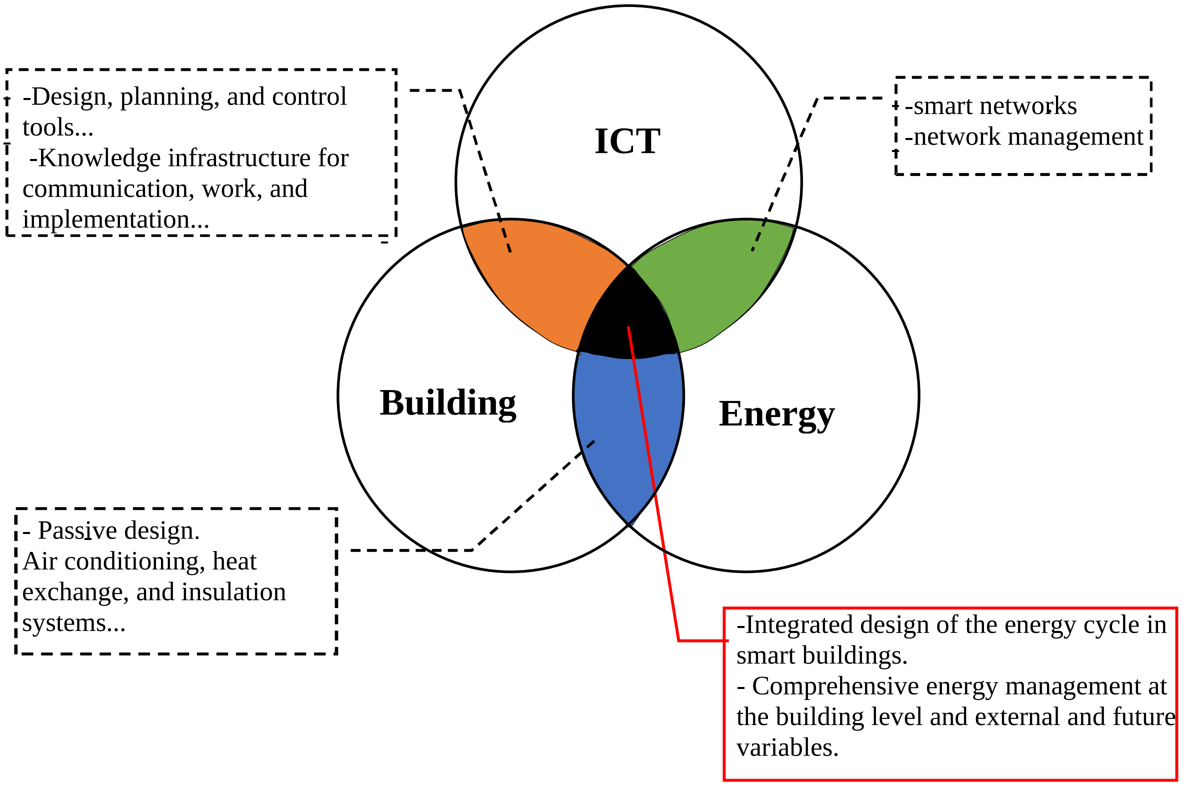

Figure .1 (The interrelationship between energy, building, and information and communications technology) - researcher source

When energy criteria are applied to buildings without relying on ICT, the application is limited to passive treatments and energy efficiency at the level of air conditioning systems, insulation, and heat exchange. This type of building is unsuitable for our present era, given the rapid technological advances in various fields and energy solutions that rely on ICT for their operation.

Therefore, most current research focuses on the intersection of ICT, energy, and buildings, indicated by the black area, to produce integrated designs that feature intelligence in operation and maintenance, energy efficiency, occupant comfort, and minimal environmental impact. Such buildings are unavailable in the local context, and there is an urgent need for them in light of climate changes that have affected the region, particularly Iraq, leading to high energy consumption [11].

A critical comparative analysis method has been followed to review 57 papers to gain insights into the topic. This systematic process categorizes the reviewed literature's themes, parameters, and information. This is paramount to achieving a model that includes the smartest technological systems with control and automation integrated into local buildings and contributes to energy efficiency.

1.1 Limitation

1. No specific and comprehensive theoretical model for ICT can be integrated into buildings to achieve energy-efficient smart buildings relying on control and operation, especially at the local level.
2. The research lacks field studies focusing on how ICT solutions are practically applied in smart buildings, emphasizing deployment, management, and operational challenges.
3. Difficulty accessing some important information due to restricted access to databases and scientific journals.
4. The challenge is collecting homogeneous data from different sources due to the various standards and methods used to measure and analyze data.

2. Methodology

The work is based on a review of 57 papers related to Information and Communication Technology (ICT) and its applications in architecture, focusing on building automation. The selection of these papers was justified based on relevance to the topic, impact factor of the journals, and geographic diversity to cover various climates. The search strategy involved identifying relevant keywords and synonyms, such as "ICT in architecture," "building automation," "smart buildings," "energy efficiency," and "occupant engagement," which were used in major databases like Scopus, Web of Science, and ProQuest. Inclusion criteria were studies that explicitly discussed ICT applications in architecture and building automation, covered different periods to track the temporal progress of technologies, and examined mechanisms of smart building applications across all climates. Exclusion criteria eliminated papers not directly related to the integration of ICT in architecture and studies with a focus outside of building automation or energy efficiency. This review extracted the main parameters, variables, and potential values by examining the relationship between ICT and its role in automating smart buildings and involving occupants in building management. This contributes to achieving energy efficiency in buildings post-occupancy. A model for ICT applications in smart buildings was developed to enhance local designs towards energy efficiency.

3. Information and communications technology (ICT).

Information and Communications Technology (ICT) encompasses all technologies used in communications, broadcast media, smart BMS, and audio-visual processing and transmission systems [12]. According to the Merriam-Webster Dictionary, ICT involves developing, maintaining, and using computer systems, programs, and networks to process and distribute data [13]. Rubin defines it as any machine, technology, or special means that produces, stores, retrieves, distributes, receives, or displays information [14]. Known as the information revolution, ICT is associated with manufacturing, marketing, storing, retrieving, displaying, and distributing information through modern, advanced, and fast technical means involving the joint use of modern computers and communication systems [15]. Thus, ICT can be summarized as a collection of modern and advanced technical tools that collect, store, process, retrieve, and communicate information using contemporary communication technologies.

3.1. ICT components

ICT technologies have been used and applied since the 1990s. The data and communications technology system includes computers, laptops, tablets, mobile and fixed phone systems, communications networking software, and wearable devices. Companies flocked to the ICT system to request improvement features such as reducing cost, increasing effectiveness and decision-making, and increasing competition in the market [16]. To facilitate the understanding of how ICT works, it can be divided into six main components:

• Devices and networks

It includes all devices in the information technology system, such as computers and their accessories, such as keyboards, disk drives, routers, or smartphones. These devices work to receive and transmit information over the Internet [17].

• Software

Information technology systems contain software divided into two types: 'system programs' that help manage devices, files, and other programs and 'application programs' specialized in implementing a specific task. Application programs are a standard means of dealing with information systems, such as spreadsheet programs and processors, texts, accounting programs, design, etc. [18].

• Telecommunications

It is the tool that connects devices to form a system network. Communications can be by wires, such as optical fibers or cables, or by wireless communications, such as *WIFI*. Networks are also divided into local networks and wide-area networks based on the area in which they are located. The Internet can also be considered a network of networks [14].

• Data warehouse rules

It is the basic material and the most important part of systems. It is a collection of interconnected data that is stored in a protected manner. Databases and data warehouses have gained greater importance in information systems with the emergence of the concept of “Big Data” [19].

• Human Resources (HR)

The system is operated and managed by people who follow the procedures that transform knowledge into large databases and data warehouses. The system also includes programmers, data entry users, designers, business analysts, information security officials, and others, as all employees must be trained to maximize the information system's capabilities [19].

• Means of communication

Books, films, and individual means of communication, such as letters, conversations, and audio communications, such as programs broadcast over the Internet or radio, store, analyze, process, and transmit data. In addition, computers store, analyze, process, and transmit data.

3.2. Characteristics of ICT

ICT is distinguished from other technologies by several characteristics [20]:

- **Immaterial:** It generates intangible information that can be transferred transparently and quickly to any place.
- **Interaction:** This technology's user can simultaneously be a receiver and a sender. Participants in the communication process can exchange roles, which creates an interactive feature.
- **Interconnection:** It is about creating new possibilities by connecting two technologies. An example of interconnectedness is telecommunication, which results from the union between information and communication technologies.
- **Immediacy:** This feature refers to the ability of information and communication technologies to transmit information over long distances and quickly.

- **Digital:** Information is represented in a unique, universal format that allows sounds, text, images, etc., to be transmitted by the same means.
- **A broad scope covering cultural, economic, and educational fields, among others:**
- ICT has significantly impacted one area or a specific group of individuals and expanded and penetrated important global areas such as economics, education, medicine, and others.
- **Impact on processes is greater than on products:** ICTs give individuals access to a large amount of information from which to build knowledge and associate them with other networked users so that individuals have a greater role in creating knowledge collectively.
- **Innovation:** The ICT field has generated the need for innovation, especially in the social field, which has created new means of enhancing communications.
- **Diversity:** ICTs do not fulfill a single purpose. On the contrary, they are very useful for carrying out multiple functions by building connections between people to create new information and manage processes simultaneously.

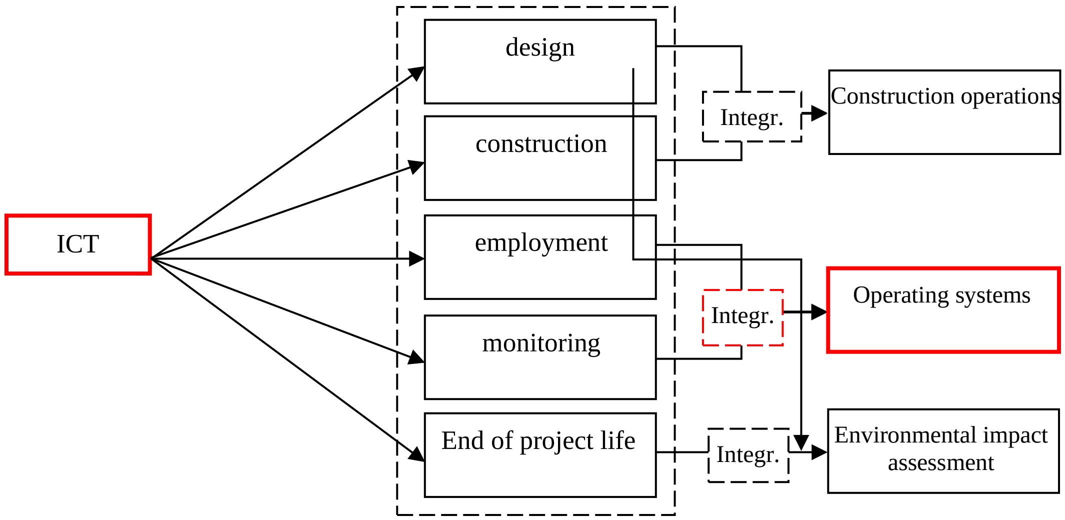

Figure. 2 Stages of ICT interference in the building life cycle - researcher source

Information and Communication Technology (ICT) enhances access to and the rapid exchange of information, increasing efficiency and productivity while enabling the provision of services over the Internet. ICT plays a fundamental role in developing societies and improving daily life by enhancing the security and privacy of data and information. Measures such as strong encryption, access control, anonymization, regular security audits, and strict privacy policies are adopted to achieve this. Additionally, residents are educated on the importance of security, and incident response plans are established to ensure a safe and reliable environment in smart buildings.

3.3. The Role of ICT in Architecture

ICT is crucial for achieving and maintaining energy-efficient buildings throughout the life cycle of a smart building. It enables the creation of smart buildings across neighborhoods, campuses, districts, cities, and countries, providing a sustainable built environment [21].

The diagram illustrates the integration of Information and Communication Technology (ICT) across different stages of a building's lifecycle and its impact on construction operations, operating systems, and environmental impact assessment. The influence begins at the design phase, where ICT enhances design plans. ICT improves operational efficiency during construction, leading to more precise and faster implementation. In the operational phase, ICT manages the building's systems, such as heating, cooling, and lighting, enhancing operational efficiency and saving energy. ICT is also used to monitor building performance and ensure efficiency.

At the end of the work's lifecycle, ICT contributes to the building's environmental impact assessment, aiding in making sustainable decisions regarding renovation or repurposing. The diagram also highlights integration points where ICT intersects with specific stages of the building's lifecycle, ensuring effective management and comprehensive assessment throughout the building's usage period (Fig. 2).

The environmental impact is calculated at the end of the project and during the design stages, where the external and internal environment, controlling the building's interaction with variables, and taking appropriate action is considered [12]**.**

ICT enables the integration of various building systems (mechanical, electrical, etc.) with local energy networks and energy sources to achieve efficient energy performance from economic and environmental perspectives. This integration also includes information technology infrastructure, which is crucial for smart buildings. Achieving this integration is essential for ensuring the Sustainability of the building throughout its life. Additionally, ICT helps manage building operations, activities, and devices in an integrated and efficient manner, reducing the energy required for operation. To fully and comprehensively understand the technicalities of this integration, Smart Building as a concept will be further investigated through the relevant literature in the following section.

4. The concept of smart buildings

Smart buildings have integrated systems to manage their components and equipment accurately, quickly, and efficiently [22]. This concept evolved with the information and communications technology revolution, enhancing operation, control, and monitoring performance, providing increased user comfort, and reducing energy and resource consumption [23]. A smart building optimizes its structures, systems, services, and management, including their interrelationships, to create a productive and cost-effective environment [24]. Smart Building technology is defined in four important calculations: intelligence, project type, control, materials, and construction, which must be adaptable to the surrounding environment to meet building developments in energy efficiency, comfort, satisfaction, and longevity (life cycle[21], [25],[26]. They specify the Building Smart Alliance, the council of the National Institute of Building Sciences, defines a smart building as follows: "A smart building, with its four components: systems, structures, services, and management, as well as their interactions, creates an efficient, cost-effective environment ."The one common feature of all smart buildings is that they are designed to respond to the changing environment at a low cost and effectively [27].

Processes in smart buildings can be summarized as systems that start with an input system receiving information from sensors. This information is processed, and the output system determines the reaction based on the available data, sensor inputs, and timing standards [28] see Fig 3.

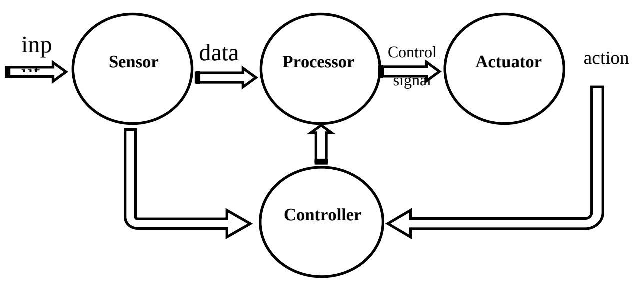

Figure. 3 Smart building working system

It was recently developed by introducing Artificial Intelligence (AI) so that the building can learn and be updated to suit changing and emerging conditions [29]. These processes that take place inside the smart building, and whose work depends on the information it gathers through sensors or the behavior of the occupants to give the appropriate action or change to the type of data entered, need the speed provided by the modern communications environment and the type of smart information processors, that depends on ICT. That is the building's transmitting, processing, and operating medium to comfort the occupants, conserve resources, and achieve a suitable indoor environment

with efficient energy management that has little impact on the external environment [30]. The technological systems integrated into the smart building that manage these important features will be explained to reach an automated system for efficient energy management.

Suppose all the above considerations are taken into account in smart building processors and their important features. In that case, they cannot be achieved without systems capable of meeting the performance requirements, which are known as Smart Systems. Smart or automatic systems are intelligent because they are built on superior connectivity for every part of the building while contributing primarily to developing its performance.

Intelligent systems refer to the physical part (hardware), including control switches and communication channels (wires, input means, etc.), which play an important role in the building's economy. Accordingly, the modern requirements for systems in buildings require the provision of some specific requirements (function diversity) such as lighting, heating, etc., economic operation, convenience, flexibility, and safety factors [27],[31].

In a technological context, Intelligent Systems use ICT to improve performance by adapting to changing conditions in a dynamic environment. The AI embedded in such systems imitates human intelligence, which allows the system to make the necessary decisions [30].

In light of the scope of this research, which focuses on ICT and its role in Smart Buildings, this research will shed some light on the employment of systems technologies and automatic control (Automated buildings), which are part of the technological systems integrated into Smart Buildings due to their impact on the automation of the whole building and their role in energy optimization processes.

5. The Concept of Building an Automated System (BAS)

Building automation system. (BAS) is a system for automatic central control of heating, ventilation, air conditioning, lighting, and other systems through a BMS. The role of ICT has emerged by linking systems and stakeholders through the BAS, especially in improving its performance, interacting with the environment, and embodying sustainability [32]. Since buildings represent about 40% of global energy consumption [33], governments have introduced global energy reduction targets for the current climate emergency. BAS was first introduced in the 1970s to control HVAC systems and lighting, which is considered part of the solution to reducing carbon dioxide emissions [8]. The basic function of the smart building automation system is as follows [34] :

- Climate control within a specific space.
- Reducing energy consumption and operating costs.
- Turn on the lighting based on room occupancy.
- Monitoring the performance of all systems inside the building.

• Improving the life cycle of building facilities.

• Sending alerts (usually via email or letter). Text the maintenance crew in the building.

Fig. 4 represents a miniature diagram of building automation systems and their associated activities 35]them.

6. ICT levels in BAS

ICT plays a crucial role in the development and operation of BAS. Modern BAS systems rely on advanced communications technologies, software applications, and data processing capabilities, all of which fall under the ICT umbrella. ICT integration with BAS allows building systems to be monitored, controlled, and managed remotely. This integration contributes to more efficient and sustainable building operations and easy access to real-time data for analysis and decision-making [36], [37]. BAS has developed as an essential working system for the building's operations, devices and equipment control systems, cooperation, communication, and working with high levels of harmony between these components. An essential factor for the success of the building is to achieve integration between these systems and make their integration easier, simplify handling, and achieve a permanent degree of security at a lower cost [38].

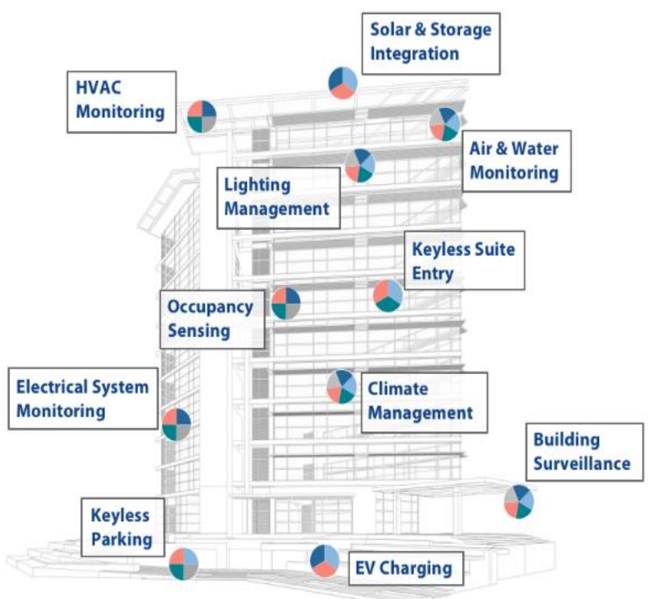

Figure. 4 Miniature structure system of BAS building automation system [35].

Several levels are concluded based on the relevant literature as follows:

6.1 Component level

Sensors are responsible for transmitting data to control units and are the first level of the automation system group. These components (sensors) are crucial inputs for decision-making in automation systems to save energy. It reports information in an important time frame according to the priorities prepared. The most important sensors and their uses will be explained:

•Motion detection sensors

Uses passive infrared sensors (PIR-Passive infrared) To detect occupancy movement in rooms and places of little use, where they are deployed to reduce the energy consumption of lighting, heating, ventilation, and air conditioning in toilets, employee rooms, and some classrooms, as studies have shown that their use reduces 7% of the total energy, and 1.2 % of the heating, ventilation, and air conditioning energy [39]-[41]. Some problems that appeared during the use of sensors negatively affected energy consumption, such as line-of-sight problems, immobile occupants, and false readings that lead to energy activation without occupancy [42]**.**To overcome these problems, peripheral sensors were used, such as a magnetic door socket that records movement entering the room to confirm actual occupancy [43], as well as making use of motion sensors in the corridors leading to the room to confirm the occupancy status [44], or adding actual occupancy times and interrupting them with internal movement sensors, where the system recognizes the time of occupancy to open lighting, ventilation, and air conditioning[45]**.**

• Light sensors

Lighting levels are crucial for BAS to provide optimal conditions for occupants by integrating natural and artificial lights to minimize energy usage [46]**.** The light intensity in the building is managed and monitored by extracting data from photoelectric sensors to maintain the level of lighting and glare. This is suitable inside the building [47]. Light sensors are the easiest way to assess light levels in multi-use office environments because they work in a feedback loop to tell the control unit if electrical lighting needs to be turned on or off [48].

• Thermostats

Thermostats measure and control air temperature and reduce the energy consumption of heating, ventilation, and cooling units, which are the largest energy consumers. Air conditioning units rely heavily on the information provided by thermostats, so it is important to calibrate and locate them correctly [44]**.**

Sensors, thermostats, and lighting sensors are essential to building control systems (BAS) and improving energy efficiency. Working Sensors detect environmental changes and inform the control system to adjust systems intelligently. Thermostats help implement energy-saving strategies, such as turning off unnecessary equipment. These devices are part of a feedback cycle, contributing to achieving energy savings and maximizing efficiency in building operations.

6.2 Device level

Reducing energy use and greenhouse gas emissions requires rapid energy efficiency improvements in existing structures. [49]. Technology businesses must offer devices to incorporate energy-efficient building solutions into existing structures. [50]. The main devices controlled by BAS will be presented, and their use, connection, and benefits will be explained.

• Blinds and louvres

Curtains and shutters prevent heat gain most often. Closed curtains limit solar heat gain by 40% from high-performance windows and 50% from ordinary windows compared to unshaded windows [51]. Window shade coverings now save energy, improve comfort, and improve views [33]**.** The use of curtains with dynamically moving inclined shapes helps reduce the demand for artificial lighting and eliminate the discomfort resulting from solar glare by changing the angles of the blade according to the movement of solar radiation throughout the day based on the data entered into the control system [52], **[**53]. The blind system efficiently lets in a measured quantity of solar radiation, avoiding heat in the morning and preventing the usage of lights when the room is at a specific lighting level.

• Lighting

Lighting has always been a large consumer of energy in traditional buildings. However, the availability of LED lamps has led to a decrease in lighting energy consumption by 47% in recent years [54]. Currently, lighting represents between 19-20% of the total global electricity consumption in buildings, and studies indicate that Maximum energy efficiency becomes possible when HVAC systems are connected to lighting in a BAS system [55]. Lighting control solutions to save energy depending on time scheduling, daylight harvesting, occupancy control, and sensing, or a combination of all three [56]**,**[57] . Time scheduling works to stop lights being left on during daylight hours. It includes appropriately harvesting daylight to compensate for the amount of electrical lighting needed to illuminate the space through electrical dimming control systems. Occupancy can be controlled by detecting the presence in the room via sensor information [56]. The analysis results of these methods vary according to the size of the building. However, they all reduce the energy consumption of artificial lighting by 50-80**%** [55]**.**

• HVAC equipment

Control of heating, ventilation, refrigeration, and air conditioning (HVAC) systems remains the major challenge for BAS, and methods must be explored to reduce the energy consumption of HVAC systems simultaneously with increasing temperatures as a direct result of greenhouse gas emissions [58]. Passive building treatments are important for reducing energy consumption for space heating and cooling. Changing the set point on thermostats by 1-1.5°C results in a 6-13% reduction in energy without any significant impact on occupant comfort[59]. She came to Time scheduling of HVAC temperature setpoints in two schools, resulting in energy savings of 16-20% [39]**,** [60]. BAS systems in controlling HVAC are important in reducing energy consumption, better than human interaction, which is a small percentage of research, despite the desire of some occupants to manually control air conditioning and ventilation devices.

The Device level emphasizes the importance of addressing energy efficiency in existing buildings, focusing on specific devices controlled by BAS, such as blinds, lighting, and HVAC systems. The integration of these technologies aims to improve energy consumption, enhance occupant comfort, and contribute to global efforts to reduce greenhouse gas emissions.

6.3 Process and Communication Level

The operations and communications level is described in BAS as the connection between hardware and software that monitors and controls the built environment [61] and is also considered a basic requirement for building an automation network in a building to achieve energy efficiency. It must be reliable (delivery of data with error rate Low), scalability (the network can grow without incurring excessive overhead), and safety and privacy (the systems are immune to malicious attacks) [62]. It is divided into four parts:

• Communication systems and protocols

Running cabling to install sensor networks represents 50-90% of the installation cost, and wiring techniques require complex cabling from the management layers to the sensor and operator levels. Therefore, WSNs (Wireless sensor networks) have become preferred with the advancement of technology [63], **[**64]. Wireless sensors also provide low maintenance costs, making them a suitable candidate for advanced [62]. This has been demonstrated by the paucity of research in the past 10 years using the original form of wired communication system, which does not report on the status of the device (sensor) [8]**.**

• Bus systems

International unified communications systems such as Lon Works, BACnet, and KNX are important for communicating and implementing messaging between devices. These systems provide effective means of control and monitoring in various systems, contributing to effective communication and integration between system components. This allows users to manage and monitor facilities better and more efficiently [65]**.**

• Wireless communication systems (Bluetooth, ZigBee, Wi-Fi)

Bluetooth is suitable for short-range personal device communications without a line of sight, Zigbee is designed for low-power and low-data-rate applications in sensor networks, and Wi-Fi provides high-speed, medium-to-long-range wireless connectivity for local area networks and Internet service. Each technology has its advantages and is selected based on the specific requirements of the intended application [45]**.**

• Middleware

Middleware is the bridge between the network application and the underlying data acquisition equipment [66]. It was developed to enable existing BAS integration to communicate with optimized applications to increase energy efficiency in existing buildings [56]**.** This middleware simplifies system components' communication and interaction, improving integration and better system management.

The level of operations and communications in the BAS system is one of the basic requirements for building automation networks, which is characterized by reliability, mobility, scalability, safety, and privacy, which is the main principle of system efficiency. This level depends on wireless sensor networks characterized by high technology, low bandwidth, and advanced communications systems such as Lon Works, BACnet, and KNX. And wireless transmission systems. Relying on wireless technologies provides flexibility in operating and connecting systems to existing buildings without extending wires that require corridors during construction and high implementation costs.

6.4 Macro level

In most research, the processing level of the building, sensor-rich modeling scenarios, is useful for reducing energy use through decision-making techniques controlled by fuzzy logic based on several variables. The overall energy level is improved by integrating inputs from lighting and curtains with heating, ventilation, and air conditioning control, which positively impacts energy consumption in buildings[67]**.** The control algorithm presented by Adhikari and his colleagues [68] improves energy efficiency, reduces overhead costs, and enhances user comfort by applying smart management based on historical and actual data to create accurate and effective control of the HVAC system, as it is characterized by relying on space occupancy and not just on thermostats.

6.5 level of occupants

Modeling energy use in buildings without considering human interaction has two adverse effects: first, it does not consider the random actions of human interaction; Second, it risks non-adoption and dissatisfaction with technology by neglecting occupiers in the decision-making process [60]. People spend more than 90% of their lives in buildings, making occupant behavior one of the main influences on energy consumption in buildings [69]**.** Therefore, occupant behavior and practices are of great importance in reducing energy consumption in buildings, and a lack of understanding of BAS can lead to increased consumption. Information, choice, and predictability are the three most prominent factors influencing the control level [51]. The smart built environment depends on the people occupying the space. There is a delicate balance between reducing costs and enabling building occupant comfort while BAS maintains control over the surrounding environment [2]. Fig. 5 represents a summary of the processes and how they are connected within the automated parts and activities of the building to achieve the best results in energy management, control energy reduction, and achieve occupant comfort. Starting from the design stage to the operation and building evaluation stage. The arrows show the methods of correlation and back-review between sensors, components, and devices to achieve the best performance of the BMS**.**

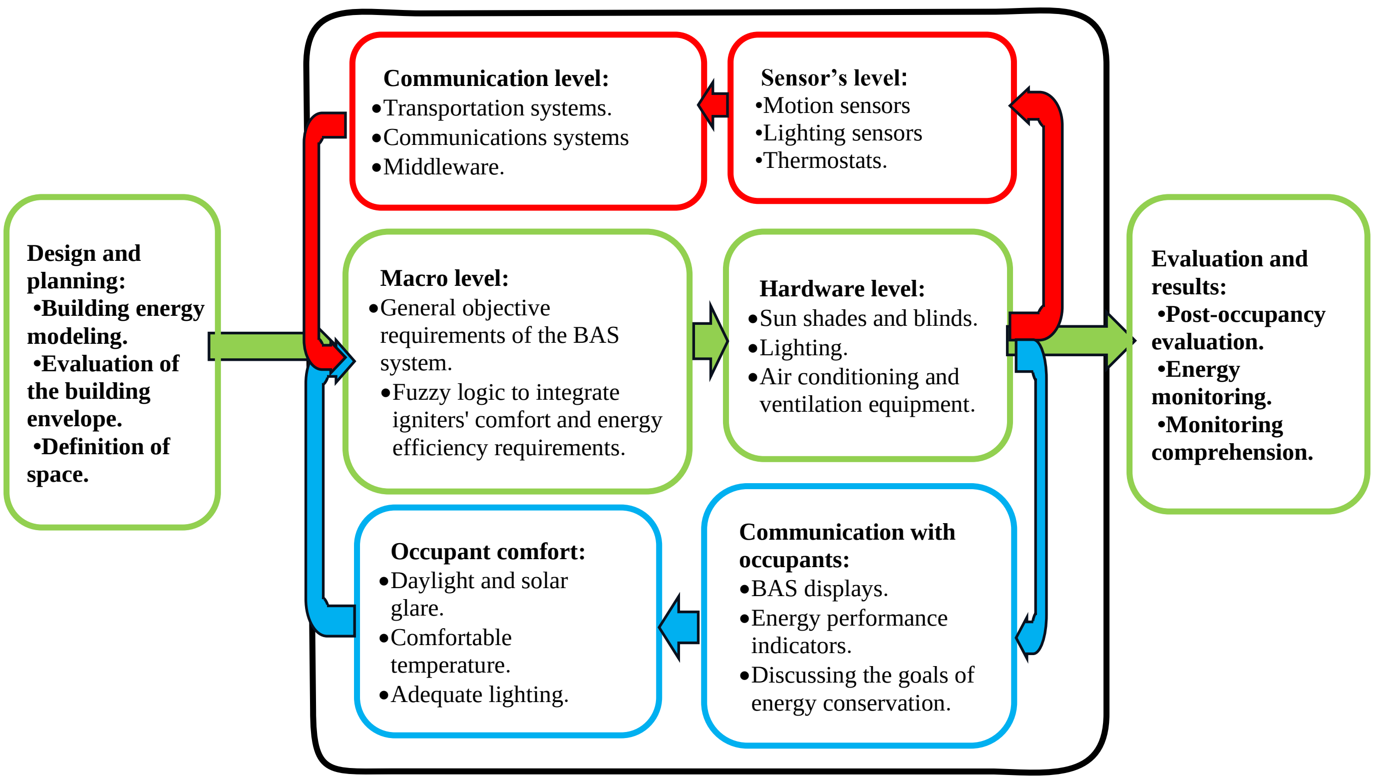

Figure 5 Explaining the feedback for automated control in the building to assign work to users (researcher source)

7. Discussion

Since people spend more than 90% of their lives inside buildings, occupant behavior significantly impacts energy consumption in buildings. Therefore, discussing the results obtained from previous studies involves finding the relationship between occupant interaction with various BMS, such as lighting, heating, cooling, and ventilation[69]. Additionally, decision-making and predictability are fundamental factors that influence the level of control within the building. The smart built environment relies on the people who occupy the space, and it is essential to strike a balance between energy reductions and occupant comfort. Imposing technology on building occupants can lead to dissatisfaction, which can be avoided by enabling adequate feedback loops through occupant input.

Additionally, integrating smart technologies into traditional buildings achieves various goals at the economic level (reducing energy consumption, lowering operating and maintenance costs, increasing return on investment, and enhancing property value), environmental level (providing clean energy, reducing water consumption, and recycling waste), and social level (maintaining public health, increasing safety, improving performance and productivity, and advancing societal progress with the enhanced concept of smart buildings). Any smart technology at the component or communication level within building parts requires data, a means to transmit data, a decision-making center, and a process to execute decisions. The entire process is facilitated by information and communication technology, which enables smart management and automation of the building.

In reality, energy efficiency in buildings is often addressed in a highly fragmented manner. This paper introduces an approach to bridge the gaps between these fragmented aspects by developing a framework that outlines the operational levels of an automated building. This framework aims to assist building decision-makers, architects, and others in selecting the critical mechanisms or technologies that should be available in a smart building to reduce energy consumption while ensuring occupant comfort.

This framework is considered a theoretical basis for applying technologies practically to benefit from ICT; it is a field that can be developed as technologies develop. A program for ICT applications in the building will be created in detail in a master's thesis that is being prepared in the form of a program with a variable interface, with a statement of the percentages of the impact of each technology on energy efficiency, based on a study conducted on several global projects that have an essential effect on energy efficiency and achieved results and evaluations.

International technical development at the level of communications and technology and also the human passion for these technologies to be used in all aspects of life highlighted the fact that there is a need for transforming traditional buildings into buildings that contain smart systems, as the building's smart systems have become more like the human nervous system that we cannot do without. These systems facilitate managing buildings to reduce energy and water consumption without monitoring them constantly. In addition to the other positive influences previously mentioned, all of which contribute to reducing the impact of climate change, which is currently the main concern worldwide.

Doing so requires a set of strategies that will be formulated in the form of a theoretical framework for the most important technologies that help transform the traditional building into a smart, automated building that contributes to reducing energy consumption after the traditional building system has become an energy consumer [6] [1]. It is a major cause of carbon emission due to relying on burning fossil fuels to produce electricity, which contributes to increasing the problem of climate change.

For these conclusions to be applied practically by the architectural designer, they will be clarified in the form of two stages:

7.1. The first stage (collecting data and setting the goal)

1- Determine the functional program of the building, the nature of its work, and the services it provides.

2-Relying on design standards and adopting an open design that offers open spaces helps control, monitor, and diversity.

3-Study the external environment of the building, maximize the benefit from the external location of the building, and determine the strengths that must be exploited and the weaknesses that must be avoided.

4-The designer must be fully aware of smart architecture's systems, means, materials, and technological development. This helps achieve the principle of optimal exploitation of available resources and saving the most significant amount of energy.

7.2. The second stage:(design and implementation)

1. Use a central control system for the building.
2. Providing wired and wireless means of communication and linking all subsystems together.
3. Adopting a design that exploits natural lighting as much as possible.
4. Use energy-efficient lighting.
5. Movement, occupancy, temperature, and lighting sensors are used, and they are linked to the central administration.
6. Exploiting renewable solar energy in the design to obtain the most significant amount of energy savings.
7. Using simulation programs to reach the best design solutions.
8. Activate the role of smart maintenance.

8. Results

In light of the review of previous works on ICT and its role in the Smart Building to achieve efficient energy management through building automation, the most important aspects of research and the relevant studies in the development of smart building management and its impact on the comfort of occupants to achieve efficient energy performance are presented in Table.1. Where main values and several sub-values and secondary values were extracted, which represent most of the means, techniques and technological systems that are integrated into smart buildings; and are described as a cornerstone and reference to be relied upon in the case of constructing and designing a smart building.

Table 1 Aspects of research and studies in the development of smart building management

T	Key values	Sub-values	Secondary vocabulary
1	Macro level	Level of work execution	detect location Guidance the account standardization
		Control level	Organizing business flow control Improve efficiency Centralized operation
		Management level	Display data .Save and record information
2	Occupant level	Occupant interaction	Touch screen controls Digital applications Voice recognition methods Consistent with the behavior of the occupants
		Communication with occupants	screens Mobile applications Discuss energy goals
3	Operations and communications level	Transportation systems	Color Works BACnet KNX
		Communications systems	Bluetooth, ZigBee Wi-Fi
		Middleware	
4	Safety and Security	Monitoring	Cameras Sensors
		Protection	Remote control systems Alarm systems
5	Hardware-level	Room automation	Control of breakers and curtains Lighting and air conditioning sensors Motion sensors External environmental novae Smart maintenance
		Device automation	Controlling the operation of air conditioning and ventilation devices Monitoring the efficiency of devices
6	Flexibility and convenience		Adaptability Flexibility of control Dynamics of change

The overall level refers to the general framework for building automation represented by (the implementation of work, control, and management). These processes are considered the first stages of implementing building automation to determine the locations of devices and sensors and direct them...etc. Among the requirements for starting the project, in addition to the control systems, reviewing and recording data, most of these works are not visible to the occupants because they are carried out within the central administration of the project.

As the level of occupants is considered an important part of the functions of the smart building, the occupants have a role in managing and operating the smart building by studying their behavior, achieving their desires in the building, and reviewing their decisions that affect the energy efficiency of the building.

The operations level represents data transfer protocols and means of communication that must be considered to establish communication between devices, sensors, and central management.

The level of security and safety in which the occupants have no role in its management and operation, as the work is self-organized and organized at the highest levels of monitoring, protection, and warning because it relates to the lives of the occupants and the building. Data Monitoring and Protection

The level of devices refers to the various sensors and devices that must be provided to complete the automation system for all parts of the building and the related maintenance, operation, and data.

Flexibility and suitability refer to choosing devices and equipment that can be added to and changed without affecting the completed building's infrastructure.

The building envelope is considered the first point of defense against environmental variables. Its purpose must be determined based on which project will work and how its systems will be integrated with the central administration.

The works will address the conclusions about how to benefit from these levels and how they will work in the future, and the architectural designer will apply them.

9. Conclusions

This paper reviews the state-of-the-art literature on integrating ICT in Smart Buildings to provide an overview of current knowledge about this topic and suggests directions for future research. It has synthesized how the main characteristics have changed to enhance the current understanding. Hence, a framework with all possible values related to the topic at different levels was developed and presented as a table with their relevant literature. A critical comparative analysis method was used, and literature related to this topic was reviewed. In doing so, a thematic approach was adopted so that the research could be used as a reference for such integrations to be justified.

The results of this paper indicate that Information and Communication Technology (ICT) plays a vital role in improving energy efficiency in buildings by providing smart, integrated systems based on data analysis and intelligent decision-making. These smart systems and automation enhance the management of heating, cooling, and lighting, allowing for optimal energy distribution and determining the best times for appliance operation. This leads to reduced operational costs and increased resource efficiency in modern buildings. Additionally, effective communication between components of the building automation system and increasing user awareness about energy consumption is essential for achieving efficient integration and improving user behavior regarding energy usage, contributing to more sustainable environments and reducing energy waste.

Analyzing the large volumes of data collected from automation systems enhances the ability to understand patterns and trends in energy consumption, helping to identify opportunities for improving energy efficiency and optimizing daily operations in smart buildings. Smart energy management systems improve a building's ability to use energy effectively by monitoring and enhancing the performance of devices through sensor technology and real-time data collection.

Integrating heating, cooling, lighting, and security systems maximize energy efficiency, enhancing user comfort and safety while achieving significant energy savings. Overall, ICT significantly impacts Sustainability in buildings and reduces environmental impact by improving the effectiveness of resource use through automation systems. This helps achieve smart, sustainable buildings and reduces the carbon footprint.

In future work, the theoretical framework developed in this research, with its concepts, features, and components of smart buildings, and the effective role of ICT in the progress and development of smart systems in the management and operation of buildings can be adopted to provide comfort for the occupants, achieve effective energy performance, low environmental impact, and mitigate the impact of climate change.

In addition, it is recommended that:

1. The table of technologies developed in this study can be adopted as a theoretical basis for a software application that may help the architectural designer determine the best technologies based on their percentage impact on the building. This will be applied in the next paper.
2. The building can achieve the maximum possible design flexibility, relying on sustainable architecture and benefiting from developing information and communications systems in all aspects due to their importance in developing local construction.
3. The inclusion of building technologies and intelligent control and management systems in the curricula of Architectural Engineering departments is of paramount importance due to their impact on the design, configurations, and shape of the building.
4. Increasing awareness and advertising about ICT means and systems at the state level through its media channels and specialized international exhibitions will contribute to achieving a new vision for the state towards energy conservation and Sustainability.
5. The research recommends creating an Iraqi code for smart buildings with automated control and operation, which would complement the Iraqi Code for Green Architecture outputs.
6. ICT applications in energy management face challenges, including system integration difficulties, data security issues, high initial costs, and user acceptance, requiring comprehensive training and awareness.

So, the future work:

- Application of ICT Solutions in Smart Buildings: This section reviews deployment methods, management, and operational challenges associated with implementing ICT solutions in smart buildings, along with case studies illustrating real-world applications and challenges.
- Adapting ICT Technologies to the Local Context in Iraq: Consider cultural, social, and economic factors to adapt these technologies to meet the needs of the Iraqi society.
- Analyzing the Economic Impact of Smart Building Technologies in the Iraqi Market: Explore opportunities for return on investment and available funding options to assess the economic feasibility of these technologies.
- Assessing the Long-Term Impact of ICT Integration on Energy Performance: Study the effects of ICT integration on energy efficiency under different climatic conditions.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Khalid A. Karoon proposed the research problem and investigated and reviewed the relevant literature.

Yahya Ibraheem, Poorang Piroozfar: verified the analytical methods and supervised the findings of this work.

Khalid A. Karoon, Yahya Ibraheem, Poorang Piroozfar**:** They developed the theory and set the research aim, plan, and methodology, discussed the results, and contributed to the final manuscript.

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