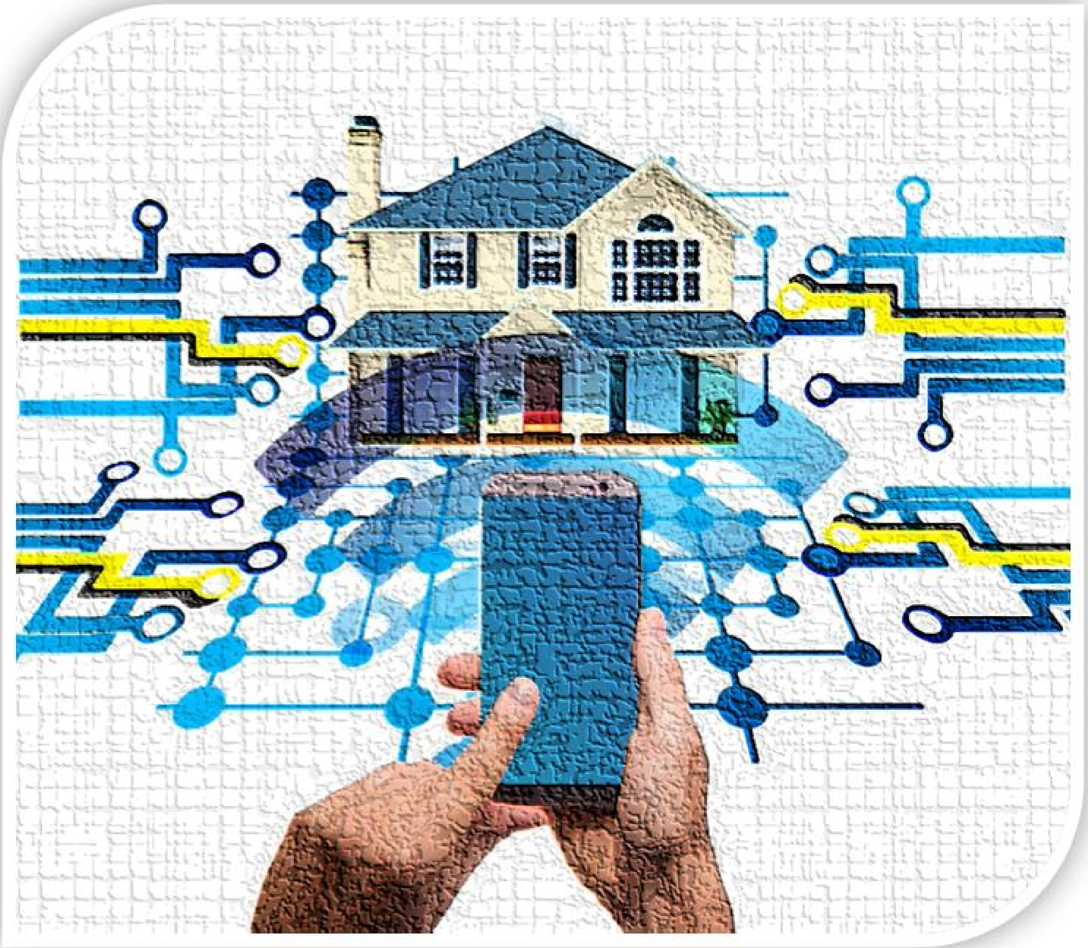

Artificial Intelligence & IoT for Energy Efficiency & Conservation (AIoT-EE&C) in Buildings

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1. Introduction

Digital transformation is changing several industries, including the energy industry, at an exceptional rate and scale. A mix of new technologies, data gathering, and its use are transforming the energy sector into an era of Energy 4.0. The concept of sustainable energy demands "smart solutions" across all stages of the overall energy system, from production and infrastructure to end-user devices. Artificial Intelligence (AI) and the Internet of Things (IoT) are being placed at the center of smart energy solutions. Smart energy solutions in ""energy network management", "bottleneck identification", "planning of network assets", "demand forecasting", "smart control of energy appliances", "optimal management of energy consumption through automated controllers", and "sensor-based appliance management" have shown very good results.

IoT has attracted a lot of attention for its potential to drive process automation and operational efficiency across many industries such as logistics, energy, manufacturing, etc. Industrial and commercial energy systems are increasingly reliant on the Internet of Things (IoT) to enable them to plan operations and supply chains in real time and identify energy usage patterns. IoT and AI complement each other and may collectively be called AIoT. AIoT manifests many real time applications in complex building control and energy management systems that combine data from smart sensors such as occupancy sensors, illumination sensors, temperature sensors, humidity sensors, and power distribution. This vast amount of building sensory data is then processed using machine learning and deep learning technologies for the better operation of the infrastructure and energy conservation.

AIoT can enable advanced occupant-centric control that optimizes building energy use while maintaining comfortable and productive indoor environments. Besides these advantages, there exist concerns about security, privacy, and algorithmic controls. To overcome these concerns, service providers needs to design human centric smart building systems to enhance human assistance and accept privacy-preserving feedback from people living in buildings.

In this backdrop, the government of Pakistan has also realized the importance of AI and its associated technologies and initiated a variety of initiatives to accelerate AI adoption, including the Presidential Initiative for Artificial Intelligence & Computing (PIAIC), the establishment of AI center of excellence and labs under CPEC. Through a comprehensive national R&D strategy, PIAIC will concentrate on creating an artificial intelligence (AI) ecosystem and link all stakeholders. Ministry of Information Technology and Telecommunication publishes Pakistan CloudFirst Policy (PCFP) to encourage cloud adoption across Pakistan. However, Pakistan’s progress in artificial intelligence and IoT has been a little slower. Certain fields, such as healthcare, energy, buildings, and agriculture, are in desperate need of technological breakthroughs. Pakistan must create a national AIoT policy as soon as possible to remain competitive in the global economy.

The National Energy Efficiency & Conservation Authority (NEECA) serves as a federal focal agency mandated for initiating, catalyzing and coordinating all Energy Conservation activities in different sectors of economy. NEECA commits to serve for establishment of institutions and enunciation of procedures to provide mechanisms for effective conservation and efficient use of energy. The establishment of Directorate of EI&F enabled NEECA to look into technological interventions for energy efficiency and conservations in different sectors of economy. That’s Why, AIoT is worked in this report.

Artificial Intelligence & IoT for Energy Efficiency & Conservation (AIoT-EE&C) in Buildings is the NEECA’s first thorough attempt to illustrate how AI & IoT could transform the building sector. AIoT-EE&C in Buildings is essential reading for policy makers and building operators, to be aware of AI’s potential for EE & C so that they can decide which technologies are appropriate to fit the individual building, institutional, or sector specific needs.

This report is designed to provide an overview of using AIoT in buildings. The report is structured around theory, working and outcomes of three categories of AIoT smart energy-saving technologies:

1. Smart light, temperature, air condition control
2. Energy management systems

The rest of the report is organized in a systematic manner. Section 2 describes Internet of Things (IoT), the use of Artificial Intelligence in energy sector is reported in Section 3. Section 4 defines AIoT. In section 5 few use use cases and applications of AIoT are described. Section 6 includes, different AIoT technologies for smart buildings. Section 7 provides overview of Smart Home market, and general considerations for smart home deployments in Pakistan. Finally, Section 8 describes barriers to adoption / challenges for AIoT.

2. Internet of Things (IoT)

The "Internet of things" (IoT) is a phrase used to describe physical objects (or collections of such objects) that are equipped with sensors, processing power, software, and other technologies that may exchange data with one another through the Internet or other communications networks. The Internet of Things (IoT) is now widely used in a variety of real-life situations, including homes, workplaces, factories, cars (particularly mobile ones), cities, and regions. IoT devices, for instance, are a component of the broader idea of smart buildings, which may also incorporate lighting, heating, and air conditioning, media and security systems, and video systems. Long-term advantages might include energy savings by ensuring that lights and devices are switched off automatically or by alerting the occupants about energy consumption.

There are four stages in any IOT architecture namely data collection, data aggregation and conversion, data pre- processing and data management which is described in the figure 1.

a. **Data collection:** The first stage of IoT architecture is data collection. The IoT application component responsible for this stage are connected or "smart" objects. These components can be wireless sensors or actuators. They interact with the environment and make the data they collect available for analysis. For example, the smart home will contain PIR motion and environmental sensors to measure humidity and temperature in the home and the presence of a person in it. The power of actuators lies in their intelligence and ability to control or alter the environment. For instance, they can be used to simply turn off valves when the water reaches a certain level.
b. **Data aggregation and Conversion:** The second stage of IoT architecture is data aggregation and Conversion. IoT application component responsible for this stage are internet gateways and Data Acquisition System (DAS). DAS connects to the sensors and actuators, compiles all their data, and then converts it into digital form. Later, this compiled data can be routed over the network by the internet gateways (Wi-Fi, Wired LAN).
c. **Data Preprocessing:** The third stage of an IoT architecture entails preprocessing and improved analytics of the data. These operations are performed by edge IT systems. Edge devices are equipped with data processing capabilities and are normally located close to sensors and actuators (or may reside remotely in datacenter). IoT Edge devices use machine learning and visualization technologies to process data in real time. IoT Edge devices typically reduce the burden on their servers, reduce bandwidth utilization, and provide savings in costs and energy.
d. **Data Management:** The 4^{th} stage of IoT architecture needs powerful IT systems to analyze, manage, and securely store the data. The massive amount of data needs to be stored for further in-depth analysis and Cloud storage is the preferred storage method in IoT implementations. Stage 4 processing may execute precise analysis by combining data from other sources, both in the digital and physical worlds. These sources can be analyzed to identify significant trends and patterns. The Cloud analytics platform provides AI based analytics and visualization tools for in-depth analysis and processing of the data.

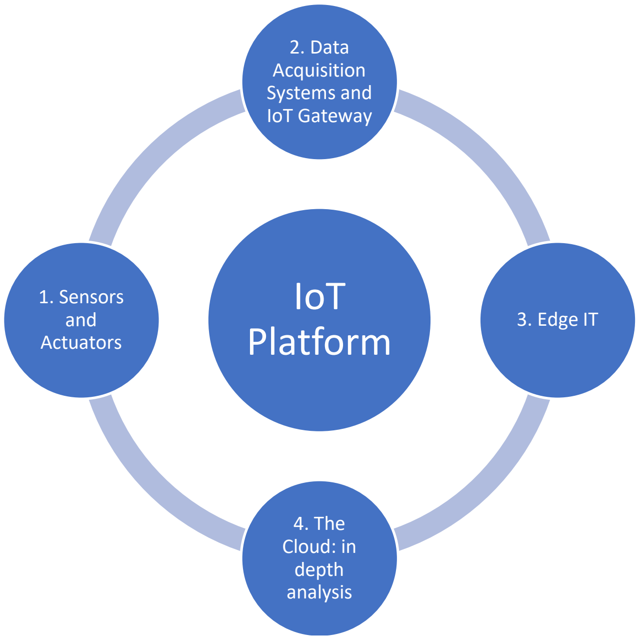

Figure 1: Stages of IoT architecture

IoT has various applications in energy planning, management, and supply chain, in the following we discuss the role of IoT in the energy planning, management, and supply chain.

Figure 2: Applications of IoT in energy Supply Chain

a) **IoT Applications in Energy Trade:** IoT is crucial to the democratization of energy and the consolidation of tiny prosumers. Energy industry undergoes a transformation from centralized to distributed, intelligent, and integrated energy systems with the aid of IoT. This is a crucial prerequisite for the deployment of regionally dispersed RESs like wind and solar energy, as well as for converting many small-scale energy consumers into prosumers by pooling their supply and streamlining their demand whenever it benefits the grid. **Peer-to-peer (P2P)** energy trading is a decentralized model that provides an interconnected marketplace where consumers and producers "meet" to trade electricity directly without the need for an intermediary. P2P empowers prosumers and consumers, leading to increased renewable energy deployment and flexibility in the grid. A **virtual power plant (VPP)** is a cloud-based control center that uses Internet of Things (IoT) devices to aggregate the capacities of heterogeneous distributed energy resources (DERs). The participants in the virtual power plant supply renewable energy, and a pool of energy is available to them through demand-side management techniques. Ultimately, VPPs form "a coalition of heterogeneous DERs" for energy trading on wholesale electricity markets.

b) **IoT applications for Energy Supply:** The monitoring of distant energy assets may be where IoT has the most potential for preventive fault maintenance. Upstream energy companies may utilize static and mobile sensors or cameras to monitor their pipelines. Monitoring data helps to Identify the failures and problems in energy networks and possibly fixing them virtually. The big data collected through IoT sensors can be used to predict the faults, leakages and fatigue in the energy network. Hence, preventive maintenance of infrastructure results in reducing the risk of failure, production loss and maintenance downtime. The overall spending on O&M are reduced. The growing emphasis on energy conservation is driving the worldwide intelligent energy storage systems market. The Internet of Things acts as the central nervous system for intelligent energy storage systems (ESS). For example ESS systems can easily catch fires if temperatures of lithium batteries increases, by means of IoT technology, the equipment manufacturers or ESS operators can remotely monitor, manage, troubleshoot, and improve the safety of these systems. Energy producers today have to take into account things like global warming and dwindling fuel supplies while producing energy. In this regard, implementing IoT in energy generation, particularly in the generation of renewable fuels, may be very beneficial. For instance, sensors allow Internet of Things (IoT) devices to capture and share data during the various phases of solar energy production. IoT-powered actuators in power plants convert energy into motion. IoT-enabled power plant hardware systems could be instructed to arrange solar panels that capture sunlight as efficiently as possible in order to enhance energy production. The numerous activities and systems in a solar power generating facility are generally held together by the Internet of Things (IoT), which acts as a kind of digital glue. It can also be applied to data analytics and precise forecasting for the production of energy.

c) **IoT Applications in Energy transmission and Distribution**: Typically, energy distribution companies are responsible for distributing electricity from the transmission system to residential and commercial customers. Transmission and distribution (T & D) equipment often refers to things like electrical generators, transformers, switchgear, transmission, and distribution lines, etc. These pieces of equipment are prone to faults and failures due to factors like overloading, vandalism, etc. Thanks to the internet of things, they can be remotely monitored with a variety of sensors. Security breaches and fallen utility poles can be timely detected before they pose a safety risk. The efficiency of repair teams is increased, and costs are decreased due to the sensors' capacity to detect problems and their origins before they become serious. The systems developed through AIoT may also be integrated with the existing information systems of the networks like Geographic Information Systems (GIS), Analytical Software and monitoring systems. Energy Management /Distributed Energy System: Sensors placed at various substations and along distribution lines deliver real-time data on power usage in various places, allowing utilities to make automatic and intelligent choices about voltage control, network layout, and load switching, among other things. Trends in the data might be utilized to guide infrastructure construction and improvement. Moreover, real-time data can be used to efficiently manage load on Transmission and distribution lines. One of the recent phenomena in electricity generation is the contribution of regular homes to the energy grid. Solar panels on the roofs of multiple residences create excess electricity, which is contributed/sold to the grid. The Internet of Things (IoT) is one of the fundamental technologies that will drive this transition. When renewable energy-based generation plants with varying production levels are connected to the grid, voltages at different nodes on the grid will vary, causing changes in power flow. However, all of this can be managed using real-time data provided by IoT solutions, auto adjusting the grid to maintain stability.

d) **IoT applications on demand Side:** Domestic energy use accounts for a significant portion of total energy consumption, contributing to global climate change. Therefore, improving building sustainability and energy efficiency is essential to achieving global climate targets. Energy usage can be improved with the use of IoT-driven metering systems. Traditional methods of tracking electricity have been replaced by smart metering systems. This IoT system monitors energy use, gives customers information about usage patterns and peak times, forecasts electricity demand, and optimizes energy pricing and delivery. Energy optimization technology is receiving billions of dollars in investment from businesses like General Electric, Siemens, and IBM. There are countless opportunities to implement connected infrastructure from the start as the developing world urbanizes. Cities like Barcelona, London, New York, and Dubai are putting "smart" systems in place to save energy. Energy suppliers are working with cities to digitally manage their resources, including EDF in France, E. ON in Germany, and Enel in Italy.

3. Artificial Intelligence

Artificial intelligence (AI) attempts to make the computer act like the human mind. For this, AI simulates human behavioral and cognitive intelligence in machines. In order to generate artificial intelligence, AI systems address the real-world problem through an interdisciplinary stance by integrating deep learning, big data analytics, statistics, machine intelligence and others in a single platform to ensure intelligent decision-making. Learning is the expected outcome of an AI system. In conventional computer science, the solutions are programmed to provide a fixed behavior that won't improve with time. The evolution of behavior is guaranteed through learning that in today's systems is done through artificial intelligence.

Artificial intelligence systems work in multiple sub-domains including but not limited to big data analytics, machine learning, deep learning and natural language processing. Pattern recognition Machine learning/ big data analytics refers to the process by which computers find the patterns hidden inside the datasets. These domains provide systems the ability to continuously learn from and make predictions based on data and can make adjustments without being specifically programmed to do so. Machine learning, a type of artificial intelligence, effectively automates the process of developing analytic models and enables devices to independently adapt to novel situations.

Deep learning is a branch of machine learning that has been proven to perform significantly better than some older machine learning techniques. Deep learning, inspired by our most recent understanding of human brain behaviour, employs a combination of multi-layer artificial neural networks and data- and compute-intensive training. This strategy has become so successful that it has even started to outperform human capabilities in several domains, including speech and image recognition and natural language processing.

AI is one of the digital technologies that is increasingly being used in the energy sector. Its widespread use in the energy sector is for a variety of purposes, including energy demand forecasting, energy generation and conservation, energy price forecasting, and the incorporation of more renewable energy sources. Artificial intelligence collects information, evaluates, and manages energy consumption in buildings and reduces energy usage during peak hours.

The application of artificial intelligence (AI) in energy saving has been widely studied. A recent study surveyed the domains of application and energy-saving effects of AI. Survey identified 113 technological developments in AI related to energy saving in eight different fields, namely

- AI assisted Building Energy Management System (BEMS)
- AI-assisted Heating Ventilation and Air Conditioning System control (HVAC)
- Industrial energy saving
- Information and communication technology (ICT)
- Artificial lighting system (LS)
- Power systems and electric power grids, renewable energy system (RES)
- Transportation.

Table 1: AI technologies in energy saving

Field of Application	Category	Technologies	Energy Saving by AI
	Learning	DNN, MLP, RNN, SVM, BPNN, DT, …	
	Optimization	GA, ANFIS, ARIMA, Wavelet, …	6.80%-47.50%
	Control	Fuzzy, MPC, MFPC, MACS, …	
	Learning	MLP, FNN, DT, …	
	Optimization	GA, ANFIS, LM, …	9.12%-60%
	Control	Fuzzy+, MFPC, MPC, …	
	Learning	RNN, SON, LSTM, RF, RNN, …	
	Optimization	Self-Optimization, …	50%-70%
	Control	Fuzzy+, ...	
	Learning	CNN, RNN, FNN, …	
	Optimization	Adaptive	21.90%-68%
	Control	MPC, MACS, …	
	Learning	MLP/FNN, SVM, BPNN, DT, …	
	Optimization	GA, PSO, Q-Learning, EP, ARIMA, FIS, …	25%-50%
	Control	Fuzzy+. MPC, MFPC, …	

Quantitative energy-saving data (quantified in %) and major technologies have been summarized in table 1. AI technologies for eight fields can be divided into three groups, namely learning technology, Optimization technology, and Control technology.

Commercial AI energy saving applications are becoming popular, Following are few relevant real world examples of deploying AI in energy sector:

a. Smart thermostats monitor locations in real-time and turn the heating on and off accordingly. They rely on ML algorithms to personalize home temperature to one's preferences and showed ~13% energy savings for heating and 16% and 14% energy savings for cooling compared to the baseline homes.

b. Google applied its DeepMind AI technology and achieved the forecasting of electricity generation by a wind farm. With a trained neural network on the available weather forecasting and turbine data, they managed to predict wind power output 36 hours ahead of its actual generation. Based on the results, the wind farm could deliver precise electricity generation at a particular time. These results are consistent and Google data centers managed to reduce the amount of energy for cooling by up to 40 %.

c. Power company Jamaica Public Service Company, Ltd. (JPS) has installed advanced metering infrastructure (AMI) meters for almost 6,000 of its biggest clients. From the AMI meter data, JPS developed a collection of predicted variables and built a machine-learning model that assigned each account a risk score based on the possibility that an inspection would find nontechnical losses. In the past, 5 to 7 percent of abnormalities were found during JPS inspections. The method more than doubled the accuracy of finding anomalies when it was tested on the ground by the JPS detection team. An excellent step forward for the utility.

d. For industrial and commercial organizations in India, Equilibrium Energy is a top provider of energy analytics. Their analytics platform SmartSense utilizes advance machine learning algorithms to converts energy data into intelligence. Equilibriums has customer base of more than 450 active industrial / enterprise customers. SmartSense monitors more than 1,400 nodes in real time, and analyses over 100 million data points on a daily basis. This has helped save, on an average, of 5 to 25 percent of power consumption to their customers.

e. The U.S. Department of Defense was able to find potential energy savings of $4 billion because to remote large-scale building assessments provided by FirstFuel (USA). Comparing this data-driven method to the leading on-site audit conducted by an independent third-party building auditor, savings increased by 16 to 37%.

4. Artificially Intelligent Internet of Things (AIoT)

Artificial intelligence (AI) and internet of things (IoT) can be merged together to form artificially intelligent internet of things (AIoT). This synergy has great potential in which the IoT serves as central nervous system that is used as a channel to deliver information to the artificially intelligent brain. A conventional IoT system is used to collect, store, and process data, whereas an AIoT embed analytical and control functions in IoT to facilitate real/ unreal time data to aid decision making. This enables reaching an intelligent network of everything. The standards developed for IoTs are about data transmission technologies, whereas the standards needed for AIoT will facilitate intelligent algorithm based services and IoT-oriented backend processing. AI and IoT complement each other in which huge amounts of data for deep learning, and scenario-based interconnection of IoT provides a basis for fast implementation of AI. AI converts data into value through analysis and decision-making.

An IoT lifecycle consist of the five key functions:

Collect - Telemetry data from a massive number of sensors is collected at central location

Store - Telemetry data is kept in scalable storage systems like data lakes.

Process - To process and analyse the telemetry datasets, Big Data platforms are used.

Analyze - Big Data systems insights presented through visualizations

Control - Technicians or Engineers control the devices based on Big Data system recommendations

Figure 3: Difference between Capabilities of IoT and AIoT

AIoT supplements an important ability to connected systems – "**Act".** AI goes beyond visualizations by introducing the new capability "Act." Instead of simply presenting facts to humans in order for them to act, AI closes the loop by taking action automatically. It essentially becomes the connected systems' brain.

Figure 4: Key Benefits of AIOT

The data gathered through IoT systems are of no use unless it reveals hidden patterns inside it. The revealed patterns will aid the decision maker to utilize the said data in a meaningful manner. The outcome produced by IoT devices can better be enhanced by:

1. Real Time Decisions
   Real-time decisions is one of the main outcomes that is obtained after embedding AI into the IoT systems. The evolution of artificial intelligence algorithms made it possible to have fast algorithms that produce results in negligible time. For instance, an AI-powered surveillance system with object detection technology can instantly notice an occupational or environmental hazard like sparks from machinery. Such advanced systems are further enhanced to initiate actions on the stimuli at their own.
2. Optimized Decisions
   Recommender systems and pattern-oriented systems are also capable of initiating actions based on the usage history of a certain appliance. Personal preferences are used by smart home appliances to enhance the performance of a machine learning model. In the concept of federated learning, AIoTs can help in decisions by mining the user preferences.
3. Minimized Costs for data transfer: The centralization of AI systems results in large data transfers between edge devices and central servers. AIOT systems reduce data transfer by moving analytics to edge devices.
4. Effective Data Interoperability
   Similar to how a lack of data results in no appropriate results from modules, siloed data produces similar results. Data silos are causing problems for stakeholders. These are datasets that are kept separate. These may be critical datasets that enable game-changing business decisions. With the rise of AIoT, siloed data is gradually being dealt with in the best possible ways by implementing adequate interoperability measures. Devices and AI modules are being programmed to send and process the precise dataset required to carry out their intended tasks.

5. Applications of AIoT

Despite the fact that many AIoT applications concentrate on integrating cognitive computing into home appliances, the following lists many instances of the use of AIoT in more general applications:

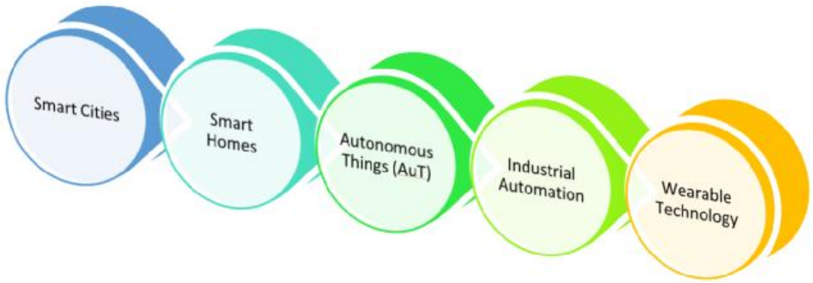

Figure 5: AIoT Use Cases

5.1 Smart Cities

There are expected to be 43 megacities with more than 10 million residents around the world by 2050, according to the United Nations. One-third of the world's population is expected to live in urban areas by 2050, and one in eight people lives in a megacity today. These developments are going to provide several issues in terms of managing cities in a sustainable and smart manner.

The development of smart cities is the one of application area where AIoT has enough potential to contribute, though these are large-scale projects that necessitate a massive amount of data and infrastructure. Only AIoT could accomplish such a feat. Everything, from public safety and energy efficiency power grids to agriculture to traffic signals, could be linked and controlled through smart infrastructure.

ET City Brain, developed by Alibaba Cloud, is an AIoT solution that optimizes the use of metropolitan public resources. The system processes logs, videos, and data streams acquired from various systems and sensors across the city using big data and deep neural networks. A pilot project in Hangzhou, China, resulted in a 3 minute reduction in the average daily commute and a 15% improvement in transit speed. The accuracy rate for incident identification has grown to 92 percent, and ambulance arrival times have been cut in half, allowing them to get at their destination 7 minutes quicker. Similarly, a pilot project in Suzhou city is efficiently managing its bus networks and increase passenger volumes by 17% on pilot bus routes.

5.2 Smart Homes

Even though smart homes are not a new phenomenon, their capabilities are expanding due to the sophisticated incorporation of AI into the technology. Smart appliances such as refrigerators, microwaves, heating and cooling systems, faucets, and even window blinds can now be controlled by a single device thanks to AIoT. However, AI takes it a step further by storing and learning data in order to understand user habits and provide tailored support and operations (i.e. homeowners can set the gauges to their desires once and AI will learn to repeat the processes each time they are used). AIoT solutions can address both the need for premises security and efficient energy consumption. They can provide users with the insights they need to conserve energy through visualized representations of individual power consumptions while also taking charge of protecting homes and properties through smart locks, automated lighting systems, sirens, and other devices.

5.3 Autonomous Things (AuT)

Autonomous Things (AuT) are AIoT devices that execute specified functions without the need for human involvement. Robotics, automobiles, drones, and other autonomous software are among the most prevalent AuT technologies. ADRs (Autonomous Delivery Robots) are commonly used in manufacturing, assembly, and storage. They are already being used for package delivery in various institutions and cities. Autonomous vehicles are one of the most talked-about AuT gadgets. In 2025, it is expected that 8 million units will be shipped. An AI-based computing platform, computer vision/sensor fusion, and high-definition maps are necessary for autonomous cars to be effective.

Tesla Autopilot is a cutting-edge driver assistance technology used in self-driving automobiles. To collect data, the cars are outfitted with external cameras, ultrasonic sensors, and a sophisticated onboard computer. The data is then processed using a deep neural network model to predict what the automobile will do next. Tesla is developing its self-driving capabilities by deploying autopilot and gathering data. Similarly, hands-free driving is viewed as an unavoidable next step in the industry, bringing a safer and worry-free driving experience. With nations like Germany permitting self-driving cars on the road, this is one of the most promising areas for AIoT growth.

5.4 Industrial Automation

The Industrial Internet of Things (IIoT) is a technology that deals with the automation and optimization of industrial machinery and equipment, ensuring that no human intervention is required in the execution of specific tasks in a manufacturing unit.

This could be accomplished using complex predictive analytics systems, deep learning models, RPMs, robots, and other technologies.

5.5 Precision Farming

The AIoT has the capability to revolutionize every sector. Agriculture is one field where AIoT-based solutions have the potential to tackle significant challenges. Pakistan is an agricultural country, with the majority of the population still relying on agriculture for a living. In this country, technology to improve farming efficiency has become even more important. Precision farming, often known as smart farming, is a method of improving agricultural product quality and quantity by utilizing cutting-edge modern technologies. Sensors based on the Internet of Things capture geographical and temporal data and send it to a cloud server. Deep learning techniques are used by AI-based models to interpret data, detect patterns, and create autonomous analysis and forecasts. There are several promising AIoT applications in agriculture, such as pest monitoring and forecasting, green house management, livestock monitoring, etc.

FarmBeats is an AIoT solution made specifically for farmers to increase farm productivity while lowering overall maintenance costs and labor inputs. Microsoft Research developed and tested FarmBeats in several locations around the globe. Microsoft and Seed Studio are currently collaborating on the Sensor Box, a piece of specialized hardware. The first version of sensor box consists of a lithium-ion battery pack and a wirelessly networked sensor unit that can track three different parameters: electric current, air temperature, and ground temperature.

6. AIoT in Smart Buildings

Figure 6: AIoT in Smart Buildings

The term smart building usually refers to commercial buildings, while the term smart home usually refers to private residences. Smart building can be seen as a smart home but on an industrial scale. Smart buildings usually employ the Industrial Internet of Things (IIoT) to make large units energy-efficient, simple to operate, and highly convenient. Both smart homes and smart buildings use sensors and actuators, but the level of their usage is different.

Although both smart homes and smart building networks have the overall goal of reducing energy consumption, there are considerable differences in implementation. Moreover, the smart building use case matrix is much more complex. Applications for smart buildings that are used in commercial settings include space management, asset tracking, centralized control of the structure's water and electricity, waste management, ventilation, security, intelligent parking.

A smart building technology stack uses connectivity technologies such as cellular or Low Power Wide Area Network (LPWAN) and standard communication protocols such as Message Queuing Telemetry Transport (MQTT). LoRaWAN, a long-range wireless communication technology, has emerged as a viable IoT connectivity option for commercial buildings due to its better penetration of walls and resilience to interference. LoRa networks are easy to deploy, scalable and offer low-cost connectivity.

Commercial IoT applications deployed at supermarkets, malls, hotels, healthcare facilities, museums, exhibitions, and leisure complexes aim to create an enjoyable consumer experience outside people's home environments. To create a comfortable environment, sensors monitor and automatically adjust air quality, lighting, and temperature in public buildings. Commercial IoT applications manage access control and security, monitor inventory in retail stores, gather data about people's behavior in public places, and provide location services for visitors to hospitality venues.

Smart subsystems in these buildings may include smart Energy Management Information System (EMIS) / Building Management System, HVAC, Smart Lighting, Communication System, & Window Shading. The purchase cost, energy savings, and payback of smart technologies varies widely across technology types. For technologies that cover the whole building in one application, such as an advanced BAS, installation costs are lower for larger buildings than for smaller ones, due to the square footage covered by the application. There are different subcategories of Commercial buildings: Education, Office, Hotel, Health Care facilities, Supermarkets, malls, Museums, exhibitions, and Leisure complexes. The IoT devices used in these subsectors may differ, but they do overlap.

To get started with a basic energy efficient Smart building we have listed some of the product categories, recommended devices and estimated cost based on ACEEE analysis in table 2 below.

ACEEE analysis (based on US market data) of Retail costs and savings estimates for Smart building sub-systems is as follows:

Table 2: Recommended Devices with Estimated Cost

Category	**Technology**	**Components**	**Cost**	**Energy Savings**	**Simple payback**	**Measure Life**
Building automation	Traditional BAS	Sensors, controllers, automation software	\$1.50–7.00/ sf	10–25% whole building	3–5 Years	10–12 years
Analytics Cloud-based	EIS	Sensors, communication systems, web-based software	\$0.01–0.77/ sf + service contract	5–10% whole building	1–2 years	Length of Contract
Shading	Smart glass	Thermochromic Electrochromic	\$40/sf \$61/sf	20–30%	21 years 33 years	30 years 50 years
Lighting	Advanced lighting controls	Occupancy/vacancy, daylighting, task tuning, lumen maintenance, dimming, daylighting	\$2–4/sf	45%	3–6 years	10–20 years
HVAC	Variable frequency drive	Variable frequency drive (pumps and motors)	\$125–250/ hp	15–50% pump or motor energy	1–2 years	7–10 years

The systems given in table 2 are analyzed in detail in the following segment. The devices which are used in these systems are also reviewed. The cost, market trends and performance parameters of these devices are also discussed in the following section.

6.1 HVAC SYSTEM

Heating, ventilation and air conditioning (HVAC) equipment typically consume at least 40% of a commercial building's energy. Using controls to properly manage HVAC operations is an essential part of saving energy in a building. Smart HVAC systems have the potential to greatly reduce energy consumption while maintaining or even improving occupant comfort. Smart HVAC systems control different variable values through sensor devices. A custom-built software is used to collect and interpret information from the sensors that is then used to optimize the values of different HVAC variables. HVAC systems with smart controls gave very good results in limiting the energy consumption especially in the unoccupied and unattended zones. It further facilitates intelligent management of HVAC operations based on occupancy and usage.

Figure 7: HVAC Control System

6.2 PLUG LOADS

A device that is plugged in consumes a small amount of energy even when it is switched off. Plug load is the amount of energy drawn by a device plugged into an electrical outlet. According to NREL 2015, such loads constitute a substantial portion of electrical demand in commercial buildings. These phantom loads are optimized in the recent years by optimizing the design of plugs that are now able to run in low power mode. In existing buildings, smart plug load controls consist of auto controlled receptacles and power strips that rely on time scheduling, motion sensing, or load detection to completely cut off power to equipment that is not in use. Some smart power strips can sense the primary load, such as a computer, and operate peripheral devices accordingly. For centralized control, plug load schedules can be programmed into lighting and building management systems (BMS).

Figure 8: Power Plugs

6.3 WINDOWS SHADING

Heat gains and losses from windows is one of the major consumption area of HVAC energy. About one-third of commercial building HVAC energy use is due to heat gains and losses from windows. The windows shades are usually controlled manually, through motors, analog timers or glass films. All these measures are taken to reduce heat gain and glare. Smart window systems consist of windows glazing and films that are tuned with the changes in climate, e.g. sunlight and temperature. These systems controls the amount of heat that enters a building. These shading technologies are effective both in new builts and retrofits.

Figure 9: Windows Shading System

6.4 LIGHTING

Lighting accounts for roughly 350 terawatt-hours (TWh) of energy usage in all current commercial buildings in the United States. While LED retrofits can save up to 30% on energy, adding smart lighting controls can save up to 44% on energy with a payback time of less than five years. Completely integrated smart lighting systems might save up to 90% of energy by installing LED luminaires and linking sensors and controllers to a centralised management system with data analytics and learning capabilities. Advanced lighting controls on the market today might save around 100 TWh of energy if deployed in every current commercial building in the United States, representing a $10.4 billion yearly savings.

Smart lighting includes enhanced controls that combine daylighting as well as advanced occupancy and dimming capabilities to prevent overlit environments. Light level controllers for lighting systems are fast evolving and gaining industry traction. Demand-response programs encourage the use of step and continuous dimming controls. Smart lighting solutions may be operated remotely and scheduling into lighting management systems is also possible. Wireless controllers make retrofitting easier, while lighting management technologies provide control via web-based dashboards.

The energy saving potential of smart lights isn't entirely clear. Smart bulbs are LEDs, they are highly efficient and use much less energy than incandescent bulbs so they do save considerable energy. However, smart bulbs cost considerably more than regular LED bulbs and outweigh the money saving one get from switching to LEDs. Plus, they're a vampire appliance, meaning they suck energy when the lights are off. Additional efficiency and cost benefits of smart lights may arise through more tightly control use of lighting that better matches room occupancy with lighting needs, eliminating over-illumination and unnecessary usage.

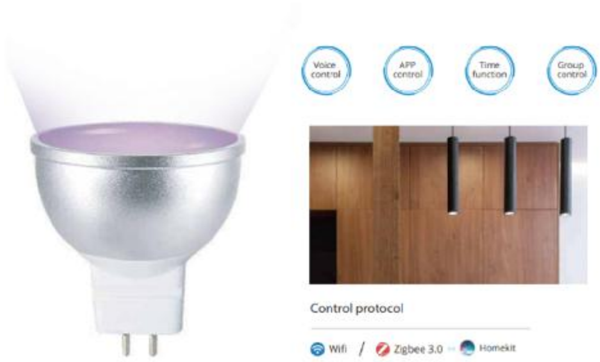

Figure 10: Smart LED Control

6.5 ENERGY MANAGEMENT INFORMATION SYSTEM (EnMS)

EnMS (energy management and information systems) refer to a broad variety of hardware and software used to control energy use in commercial buildings. EnMS is frequently used interchangeably with other names such as building automation systems (BAS) and building management systems (BMS) (BMS). Whereas a standard BAS focuses on preset programs and set points for building operations, EnMS relies on real-time input and leverages ICT to gather and analyse technical and energy performance metrics from building systems and make predictive adjustments in operations depending on external factors such as occupancy patterns, weather predictions, and utility bills. Cloud-based remote building monitoring is becoming increasingly common. Through web-based energy management solutions, building operators (or third-party energy service suppliers) may monitor building performance.

Figure 11: Sense Energy Monitor

7. AIoT in smart homes

Statista is one of the world's largest online statistics databases. Its Digital Market Outlook products provide forecast, detailed market insights, and key indicators on over 90 digital markets. According to Statista the Smart Homes Market is segmented by Product Types Comfort and Lighting, Control and Connectivity, Energy Management, Home Entertainment, Security, and Smart Appliances. Table 1 give a smart home device market overview for year 2021 in Pakistan. This data is basically about the size and value of market for smart home devices. The total number of homes with smart home devices are 840,000 with total annual worth of $53 million. The given picture clearly depicts the values of rest of the attributes.

Table 3: Smart Homes Market Insights for Pakistan

Pakistan	Statistics
Number of homes with smart home devices	840 thousand
Total annual value of smart home devices market	53.62 million $
Smart home penetration rate	2.5 %
Value of smart home control & connectivity devices market	5.90 million $
Value of smart home appliances market	27.28 million $
Value of smart home security devices market	8.34 million $
Value of smart home entertainment device market	6.05 million $
Value of smart home comfort & lighting market	2.78 million $
Value of smart home energy management market	3.27 million $

The global smart home appliance market is dominated by a few key tech companies like Google, Amazon, Apple, and Samsung. Google is the industry leader, controlling 24% of the market for smart home appliances worldwide, followed by Amazon with 12% and Apple with 10%. Now, these companies are focusing on extending their customer base in developing countries by making strategic alliances with local companies to promote their appliance ecosystem. In this section, we explore the energy-saving smart home and building technologies available in Pakistan. Therefore, we specifically concentrate on hardware that is available for purchase and use in Pakistan and that gathers data on energy use or enables control of energy-consuming processes, provides information or control capabilities to users, and does so.

7.1. Smart Bulbs

Traditional lights are transformed into "smart" lights by adding sensors, microprocessors, and remotely programmable switches or relays. This allows users to control the lights remotely or automatically. Almost every smart light available on the market uses an Edison screw base (E27) LED bulb, which is a simple replacement for existing plug sockets. All connected apps for smart lights enable remote control and provide dimming and color-changing options.

Several brands are available in Pakistani market, among them the most notable smart lighting brand is Philips Hue, starter kits of Philips Hue are costly and ranging between Rs 3500-11000The Philips Hue family of products includes outdoor and indoor LED lighting that adjusts to people’s preferences and routines. Philips Hue devices are a reliable option to try out. For smart bulbs, which operate off a home Wi-Fi network, Tuya and Xiaomi provide excellent smart bulb options, and they are slightly more affordable. Both Tuya and Xiaomi offer cheap products ranging between Rs 1000-3000.

Figure 12: Philips Hue

Figure 13: Mi Smart LED

7.2. Smart plugs and switches

Many non-smart appliances are now controllable through home networking, thanks to the increasing popularity of smart plugs and switches. Smart plugs and switches come in two flavors: either they are portable devices (Smart strips, portable plug sockets) or they are fixed wall mounted switch/socket. Wall mounted smart switch /sockets are easy to install and can be used both as traditional wall mounted switches or can be controlled from a mobile app. Similarly, smart strips include on/off buttons and smart displays that are used to control lights and other household appliances. Switch controllers allows remote management and control of appliances and monitor home energy usage. These switches allow to keep track of 99% accurate real-time current, voltage and power on mobile app. The power switch can protect appliances from overload. The mobile app provides recorded electricity usage data, which you can export to your phone storage. You can keep track of how much energy your appliances are consuming and estimate your running costs. These tools are adaptable and enable users to control the behavior of their electrical appliances from any location in the home. If used properly, these devices provide a chance to conserve energy by automatically turning off devices when they are not in use or by controlling devices to lower their use during peak hours.

 (a) Power strip (Price range Rs 4000-6000)	 (b) Switch Controller (Price range Rs 1500-3000)
 (c) Touch Wall Switch (Price range Rs 8000-12000)	 (d) Wall Socket (Price range 5000-9000)
 (e) Light Dimmer (Price range 1500-2500)	 (f) Smart Plug (Price range 1500-2500)

Figure 14: Smart Plugs and Switches

Sonoff, Goodlife, orvibo, Tuya, ABB and okasahsmart are the most notable brands for smart plugs and switches in Pakistani market. These brands offer plugs and switches those work with existing home WiFi networks, control outputs using manual touch control or smart control via app. Moreover, these brands partner with Google and Amazon, one can control home appliances hands free with voice commands e.g., “Ok Google, turn on light” or “Alexa, turn off fan” and voice assistant will fulfil commands.

7.3. Controlling Devices:

Smart home consumers can easily end up with 100s of smart devices (and so dozens of phone apps), also likely to have various different company’s products. It becomes very hard to manage all these devices and applications. Another, challenging issue in this scenario is the problem of cross-compatibility – the ability of smart machines to communicate and work with each other and safely share data. This is the major obstacle to successful home automation. Home automation hardware producers solve this problem differently.

The most popular solution to the cross-compatibility challenge is voice assistants. Connected to Alexa or Google Home, different home automation tools can be controlled and configured from one place. This solution also solves the problem of multiple controls – too many apps to control every single smart object. Basic Smart home speakers price ranges between Rs 6000-25000 and more advance variants ranges between Rs 50000-80000.

Smart home touchscreen control panel (smart screen) is another option to control a multitude of smart devices. Smart screens integrate the functions of different devices: smart gateways, smart switches, air conditioning panels, background music panels, AI voice speakers, etc., which can replace multiple smart single products. In addition to voice interaction, music playback, making to-do lists, setting alarms, streaming podcasts, and playing audiobooks, one can access complete house controls like switches, appliances, lighting, cameras security etc. Can program scenarios and create scenes to enjoy a fully Automated Home or Building. Most notable brands of touch screen control panel available in Pakistan are Amazon Echo Show, Google Nest hub, Orvibo, and Crest. Price range between Rs 12000-100,000.

Smart Hub (gateway) is the least expensive solution to tackle the problem of cross compatibility of smart devices. In recent years, these solutions have gained popularity due to the lack of standard communications protocols in the domain of IoT. A Smart Hub offers a variety of communication protocols to setup a network with a variety of different smart devices. Hubs support multiple communication protocols like Zigbee, Wifi, Bluetooth & Bluetooth Mesh. Most notable smart hub brands are Mi, ovribo, Sonoff and Tuya. Price range between Rs 2000-12000.

		
Smart Speakers (Price range Rs 6000-30000)	Smart panels (Price range Rs 12000-100,000)	Smart Hub (Price range Rs 2000-12000)

Figure 15: Controlling Devices

7.4. SMART HVAC:

If you want to have a smart HVAC system in your home, the best and easiest way to do that is to start with a smart thermostat. Smart thermostats are used to control and manage the home temperature, most notable smart wifi thermostats available in market are Nest Learning thermostat, ecobee smart thermostat, Amazon smart thermostat, Sensibo and Tado smart AC controls. Price range for these products are between Rs 14000-70000. Other parts that a smart HVAC system consists of smart vents, smart humidifier, smart air purifiers and smart wifi air conditioners. To sum up, in Pakistan, many brands are manufacturing these appliances. Smart wifi air conditioners of Gree and Haier are at the top of the list in Pakistan. Other notable brands are Kenwood and Orient.

General Considerations: Basic Smart Home

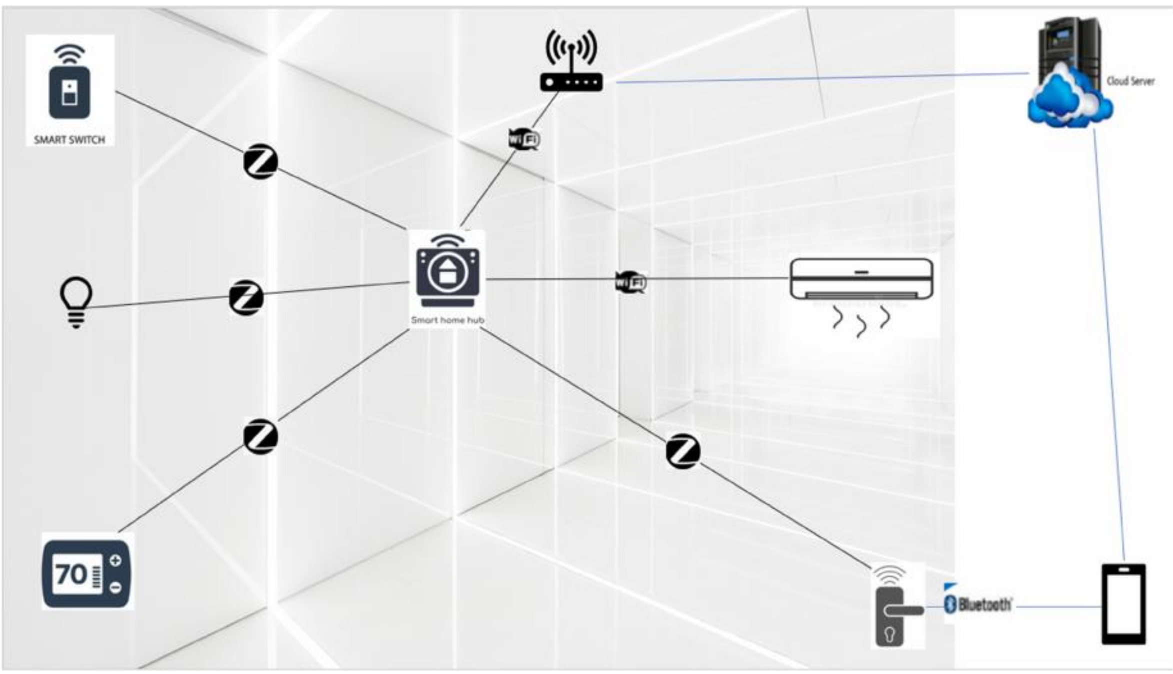

Figure 16: SMART Home

General Considerations:

- Any good smart home starts with strong Wi-Fi
- Choose a single ecosystem of smart devices.
- When starting with a Smart home project, we recommend starting with the main lights
- The best place to start is with smart switches that can manage large groups of recessed lights, fixtures, etc.

- In general, we advise using smart bulbs in lamps and any other non-switchable location
- Air-conditioning (HVAC) is great place to explore for energy saving
- Zigbee Home Automation system is better than a Wi-Fi Smart Home System and core of ZigBee home automation is a hub
- Zigbee is similar to WiFi because it also uses a 2.4 GHz frequency, it has a better range and security and doesn't require the internet to operate
- Smart speaker is single most important device in a smart home that can execute complex tasks through single voice command
- A Basic single room Smart Home costs PKR. 15000-20000
- A moderate single room smart home costs PKR 35000-40000.

To get started with a smart home some of the product categories, recommended devices and estimated cost are given in table 4.

Table 4: SMART Home Devices and estimated prices

Component	Recommendation	Cost (PKR)	Remarks
Wifi Router	TP-Link Tenda	3000	Extend Wi-Fi coverage using Tenda range extender
Device management App for controlling smart home appliances	Google Home Tuya Smart Life	Free	Use Android Smart devices from Google / Tuya Eco System
Smart plugs / power strips	Sonoff Okasha Smart	9000	power non-smart devices Smart switches for light fixtures and fans
Smart Bulb	Mi LED Smart Bulb	2500	power must always be on for bulb to respond
Smart plug	Sonoff Okasha smart	4000	To power up non smart devices e.g. split AC
Smart Speaker	Amazon	6000	Advance Optional
Smart Thermostat		9000	Advance Optional
Smart Motion Sensor (Zigbee)		5000	Advance Optional

8. Barriers to Adoption / Challenges

Even though home buildings and Internet of Things technology have been around for a while, many solutions are infant or in test regime, and there's always a huge room for improvement. Even though home automation and Internet of Things technology have been around for a while, adoption of smart technologies is slow for several reasons as mentioned below.

- The initial purchase cost of the energy technologies is found to be one of the leading concerns in large buildings. Smart technologies are expensive in one-time investments. The buildings are very commonly upgraded with time. Such an upfront cost can constrain the retrofitting or upgradation as and when needed. Small and medium size building owners lack the affordability to make such investments and if done they are restricted to plan to retrofit.

- Technological obsolescence and steep learning curves for smart building technologies are the two primary concerns that have a negative impact on adoption of smart building technologies.

- Building management systems, AIoTs and intelligent logging technologies need specific knowledge and expertise not only to operate them but also to analyze their outcomes. The tasks of building management are usually undertaken by operators who do not have the requisite skill. They are even not capable of differentiating the performance obtained by incorporating smart systems in the buildings.

- The diffusion of smart technologies in the mainstream is low for which the standards for their communication protocols are yet to finalize. A uniformity and collectivity can only be ensured once the standards will be finalized.

- In smart AIoTs IT systems including IoTs and AI are used that are algorithm-based. All these systems are exposed to cyberthreats. A complete information security infrastructure is needed to ensure the security of the systems.

- The spread of smart technology is also hampered by a lack of consumer awareness and skill shortages within the workforce. For instance, even though a sizable majority of consumers are aware of smart home gadgets like thermostats and smart lighting systems (44 percent and 42 percent, respectively), awareness of security issues with smart devices is notably lower. Industry is also facing trouble in finding skilled personnel and decision-makers to create, integrate, and use smart technology.