Application of IoT-Based System for Monitoring Energy Consumption

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Abstract Energy conditions in Indonesia are not balanced so there is an overlap between energy demand and availability. Energy demand will continue to increase with population and industry growth, but the availability of energy will continue to decrease. Uncontrolled energy consumption will certainly increase damage to the environment which in turn worsens global warming. Energy management is a best practice so that the use of energy is well managed. Technological developments can also support energy management by utilizing IoT technology. This study conducted a systematic literature review related to the application of IoT in energy management systems. The results of the literature review conducted are that IoT which was built for energy management consists of several components, such as microcontrollers, sensors, modules, communication protocols, and cloud-based systems. Microcontrollers often used in building IoT systems are Arduino and NodeMCU. The sensor is varies depending on the measurement requirements, usually using the current sensor and voltage sensor.

***Index of Terms*— Energy Management, Energy Monitoring, Internet of Things, Microcontroller, Sensor.**

I. Introduction

Population growth and rapid industrialization result in an imbalance in energy demand and supply, leading to the depletion of large amounts of energy reserves. The main energy sources that are drained are fossil energy (petroleum, natural gas, and coal). In this condition with high energy demand, it will certainly encourage economic and industrial growth. Indonesia, which is a country that seeks to increase economic growth rates, is also affected by energy conditions. In recent years, the position of Indonesia's energy security has declined due to an imbalance in energy availability with demand. Based on The Indonesia Energy Outlook Report 2019, state that total fossil energy production and renewable energy reached 411.6 MTOE in 2018. Indonesia also imported energy, especially crude oil and fuel products, amounting to 43.2 MTOE and several high-calorie coals needed to meet industrial sector needs. In 2018, total final energy consumption without traditional biomass consists of the transportation sector by 40%, industry by 36%, households by 16%, commercial and others respectively 6% and 2%. Coal production in Indonesia is expected to continue to increase, especially in meeting domestic needs, such as for electricity generation and industry [1].

The installed capacity of power plants in Indonesia is still dominated by fossil energy, especially coal. In 2018, the capacity of power plants reached 64.5 GW, an increase of 3% compared to 2017, where most use fossil energy, especially coal by 50%, natural gas by 29%, fuel by 7%, and renewable energy by 14%. Power plants in Indonesia are mostly managed by PLN. PLN manages electricity by 43.2 GW or 67%. Besides PLN, the power plant is also managed by an IPP (Independent Power Producer) of 14.9 GM or 23%, Private Power Utility (PPU) of 2.4 GW or 4%, and an Operating Permit (IO) of 4.1 GW or 6%. Electricity is distributed to consumers, including household consumers of 97.8 thousand GWh or 42%, industrial sector 76.9 thousand GWh or 33% and commercial amounting to 59.5 thousand GWh or 25%, while electricity consumption in the transportation sector is used for the operation of commuter trains whose consumption is 274 GWh or 0.12% [1].

Increased energy demand has an impact on the high rate of growth of CO_2 emissions. The release of CO_2 emissions resulting from the combustion of energy in power plants, the transportation sector, industry, commercial, household, and other sectors into the atmosphere in a certain amount will have an impact on global warming [2]. To minimize global warming can be done through energy savings and energy efficiency improvements. Energy savings in question is to use energy wisely, efficiently, and not use energy for something that is not useful. The benefit of saving energy is that it can reduce energy use costs, increase environmental value, and comfort.

Energy management is one solution to improve energy control to achieve effective, efficient, and sustainable energy use. The steps in energy management are monitoring, controlling, conserving energy, and evaluating energy use in a building or company, taking into account several parameters such as cost, environmental impact, availability, and so on [3]. The fundamental goal of energy management is to produce strategies and minimize energy consumption, costs, and effects on the environment, without reducing the comfort of people who carry out activities in the building or room. Energy management requires a careful balance between efforts to save energy to be efficient and meet the quality requirements of life [4]. Energy management is the main step that must be done to be able to control CO_2 emissions, if CO_2 emissions can be managed properly through energy management it will automatically affect the environment [5].

Energy management is the right solution for creating a smart and sustainable environment and supporting the Sustainable Development Goals (SDGs). The implementation of this energy management system strongly supports the objectives of SDG 12 and SDG 13. SDG 12 talks about reducing the environmental impact caused by the earth through appropriate production and consumption patterns, specifically the management of consumption and production of energy that can have an impact on increasing carbon emissions. SDG 13 relates to how to deal with global warming, one of which is to increase public awareness of the impact of uncontrolled energy use or consumption that can cause global warming [6].

The energy management system is an automation system that collects energy measurement data from the field and makes it available in the form of visualization/graphics so that it is easily understood by users in monitoring, analyzing, and managing energy resources. The availability of historical measurement information can be analyzed and utilized to develop strategies and decisions to optimize energy use. The first step in implementing an energy management system is to determine monitoring points/measurement points. An electric power monitoring system is installed to enable monitoring at each measurement point of the electricity network. This process is carried out by establishing a data acquisition system, where monitoring devices are distributed throughout the electricity network to send electricity usage data at each measurement point to the control center through a communication system [7].

Research on monitoring electrical energy consumption has been carried out with various methods. In line with technological developments, methods of monitoring electrical energy are also experiencing developments, from monitoring that is done directly/conventionally, using cable or indirectly, or through wireless technology. This highly developed technology and can be used to monitor electricity consumption is the Internet of Things (IoT) Technology. IoT technology is a physical cyber system or network of networks consisting of many objects/things and sensors/actuators that are interconnected in a very large internet network and is used as a means to stream data generated by sensors/things. Through IoT, data will be collected, exchanged, and analyzed to obtain valuable information related to the relationship between things [8]. IoT technology enables remote object control across existing network infrastructure and can create opportunities for integration between the physical world and cyber-based digital systems to increase efficiency, accuracy, and economic benefits. Each object/thing can be identified through an embedded computing system and can operate within the existing internet infrastructure [9].

This article reviews the development of IoT Technology-based Applications and research in energy management that so far has been in Indonesia. The purpose of this research is to get insight into how IoT has been developed or studied to support energy management

II. Literature Review

A. Energy Management

Energy is a very important resource for life and increasing social welfare, this means that a sufficient and reliable supply of energy is needed to ensure sustainable development, but the use and conversion of primary energy mostly produce emissions. The increasing level of environmental problems related to energy use has led to a growing interest in the problem of sustainable development. Therefore, to overcome these problems requires the use of resources, technology, appropriate incentives, and strategic policy planning.

Energy management is the best solution for managing energy use. The definition of energy management has been suggested by several experts and researchers. According to Ates and Durakbasa [10], Energy Management is a combination of activities to carry out energy efficiency, engineering, and related process management to produce energy costs and lower CO2 emissions. According to the German Federal Environment Agency [11], Energy Management is an action planned and implemented to ensure minimum energy input to achieve a predetermined/targeted performance. Based on research conducted by Bunse et al [12], energy management is defined as an activity of controlling, monitoring, and improving energy efficiency. According to Abdelaziz et al [13], energy management is a strategy to meet energy demand when and where it is needed, by optimizing energy-using systems and procedures to reduce demand and constantly reduce production costs. Based on the definitions of several researchers, it can be concluded that the goal of energy management is to carry out energy efficiency with certain strategies so that it can affect several aspects such as costs and carbon emissions.

Industrial growth contributes to Indonesia's economic growth, but on the other hand, the industry uses energy as well as being a significant greenhouse gas-producing sector. There is an energy dilemma in the industry, increasing the economy while consuming so much energy. The industrial sector consumes the largest energy in Indonesia. Therefore, we need an energy management system for better energy management. Energy Management System (EMS) is a system that was built to assist and automate the energy management process. EMS offers many benefits such as efficient energy consumption, reducing costs incurred, improving the company's image, and reducing negative impacts on the environment, specifically reducing greenhouse gas production [14][15]. EMS begins by formulating energy use policies, determining energy goals, strategies to achieve these goals, developing a system to monitor energy use, and implementing procedures to improve sustainable energy performance [16].

According to Segatto et al [7], EMS is an automation system that can collect energy measurement data from a place or building, and compile these data in a visualization form that can be understood by users. According to Shamseldein et al [17], the EMS is a computer system used by users to monitor, control, and carry out optimal energy management. According to Robin Kent [18], an EMS is needed to identify, plan and complete projects to produce energy savings, without a system the energy management activities will not be properly accommodated and eventually become damaged. EMS unites and handles the main electricity and energy systems. EMS is the heart of smart green buildings that provide benefits for consumers and utilities.

One of the developments of the EMS is the Energy Management Information System (EMIS) which is a system that provides relevant information about energy performance for users so that it is seen by various levels, both organizations, individuals, and departments. This information is used to plan, make decisions, and take effective actions in energy management. This leads to increased productivity through continuous monitoring of energy performance, and opportunities to save energy. Performance information generated by EMIS enables organizations/individuals to take preventive actions that can reduce financial costs through energy management and control. Fig 1 shows the EMIS components and various business processes that can be supported in an organization. The Fig shows that EMIS requires effective communication, integration, and commitment to continuous improvement in producing optimal performance [19].

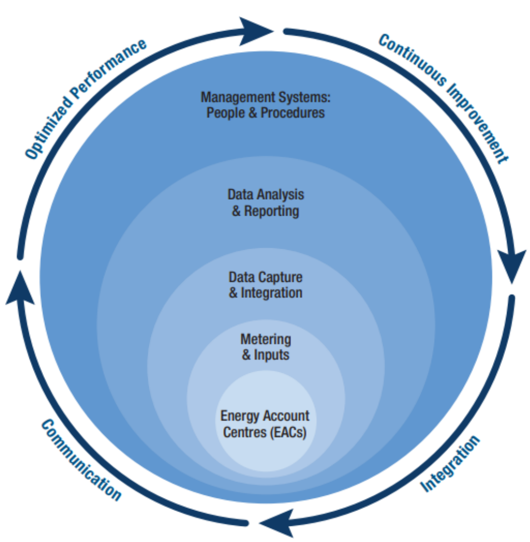

Fig 1. Operational of EMIS [19]

The EMIS components shown in Fig 1 include Energy Account Centers (EACs), Metering & Inputs, Data Capture & Integration, Data Analysis & Reporting, and Management Systems which consist of People & Procedure. EACs are the organizational level where energy performance must be managed that reflects the organization's processes and responsibilities. Metering is a measurement of data needed for EMIS such as energy consumption data derived from energy meters or submeters. Data Capture & Integration is the hardware, software, and/or procedure used to collect measurement results data. Data Analysis is the process of comparing energy performance or the processing of measurement data into management information. This Management System shows organizations such as peoples, processes, procedures, and how to translate insights gained from the analysis and reporting of data into energy performance measures [19].

International Standard Organization (ISO) is an international standard-setting organization consisting of representatives from national standardization organizations of each country. ISO 50001 Energy Management System is an international standard on energy management. ISO 50001 is a standard designed to manage energy in all commercial sectors or organizations, such as energy use, energy monitoring, and other activities [20]. The aim of ISO 50001 as an Energy Management System standard is to be a reference for organizations in building a system or process to improve energy performance and energy consumption efficiency. The application of ISO 50001 is to reduce greenhouse gas emissions and environmental impacts through systematic energy management. The concept of ISO 50001 adopts the management cycle of the Deming Cycle. The Deming Cycle is an iterative four-step management method used in business processes to control and continuously improve the processes and products introduced by W. Edwards Deming in the 50s. These four steps can be seen in Fig 2 [21].

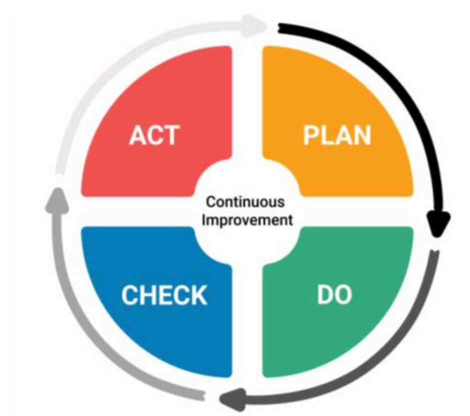

Fig 2. Deming Cycle [21]

The ISO 50001 energy management standard is intended to provide a framework for companies to integrate energy efficiency in their companies into the practical management of the company, in general, the objectives of ISO 50001 are as follows [16].

- Guide companies in using energy better.

- Guide in benchmarking, measuring, documenting, reporting energy intensity, and the benefits of implementing energy projects to reduce the impact of greenhouse gas emissions.
- Establishing open communication between cross-divisions in energy management.
- Promote successful cases in energy management and encourage good energy management behavior.
- Guide companies to evaluate and implement new technologies in energy efficiency.
- Provide a framework for promoting energy efficiency in all available utilization lines in the company
- Facilitating the improvement of energy management to reducing the carbon emissions produced.

Energy efficiency is an activity to use less energy for the same or even increase output. Energy efficiency is identified as the efficiency scale of the ratio between energy input and output [22]. Galvin researched energy efficiency by using monetary and physical indicators, according to him the ratio between energy input and energy output as monetary values were considered as a monetary indicator [23]. Ganda and Ngwakwe stated that energy efficiency was increasingly recognized as one of the most cost-effective solutions, policies, technologies, and strategies in reducing greenhouse gas emissions resulting from burning fuels [24]. An energy audit is a systematic approach in determining decisions/strategies in carrying out energy efficiency, by balancing the total energy input with its use, and serves to identify all energy flows in a building/facility. Energy audits refer to examinations and analysis of the activity process, company finances, and energy use per relevant energy-saving standards [25].

Research on energy audits has been carried out in various fields. Yudiyana et al [26] have researched electrical energy management studies at the Klungkung Hospital. The parameter that influences energy use in hospitals is the fluctuation in inpatient visits. Based on an Audit conducted at the Klungkung Hospital which refers to the 1990 ASEAN Database Office standard, the energy consumption in the Klungkung Hospital is categorized as a bit wasteful. In addition to the visitor factor, the cause of energy waste is that the building envelope is still not optimal, air conditioners and lamps are still using old technology. The recommended improvement recommendation is the maintenance and operation of the building to consider energy conservation.

Energy audits at hospitals were also conducted by Setyawan et al [27] who conducted energy management research at Surya Husadha Hospital Denpasar. In that study, an analysis was conducted based on electrical energy usage data, where the energy conservation carried out was focused on AC and lamps because AC energy consumption reached 43% and lamps 13%. The energy management plan prepared refers to the energy management matrix. The results of the energy management matrix show that the hospital's energy management is still not well-managed because the hospital does not yet have a reference in the preparation of energy management, but the efficiency of AC and lamp consumption can be used as best practice.

Putra et al [28] conducted a study on the management of electrical energy in the Faculty of Medicine Building Udayana University, located in Denpasar. The intensity of electricity consumption in the building is based on payment accounts per building area of 82.94 kWh/m2/year which is included in the highly efficient category. The recommended program for saving energy is to arrange the usage schedule and lamp replacement.

Pratama et al [29] conducted a study of electrical energy management in the Meat Processing Company named PT. Soejasch Bali. In this study, an electrical energy audit was conducted and the interview was conducted using a questionnaire to determine the intensity of energy consumption in buildings. The results of the study after an energy audit are that energy savings can be made by setting operating hours to produce a 5% savings in energy consumed.

Putra et al [30] conducted a study of energy conservation at the Sewaka Dharma Building in Denpasar by applying the Green Building concept, which is by taking several actions such as building more windows or ventilation using vertical ventilation systems, green environments and the use of solar cells for lighting lamps. The results of this study are the work environment and employees are not too comfortable and adapt to the Green Building concept because the temperature and humidity are too high so that the installation of air conditioners in each room is carried out.

Rachmat et al [31] conducted a study of energy management at Prima Medika Hospital Denpasar. Electricity consumption in the hospital per year is 2,299,077 kWh / year. Electricity load comes from lighting equipment, air conditioning system equipment, medical equipment, office equipment, and utility equipment. Based on the energy audit conducted, it can be categorized as a hospital that uses wasteful energy. The recommendation that must be done is to conserve energy, especially in the air arrangement system equipment that absorbs the largest energy that is equal to 56.12%, draws assumptions about the operating hours of the equipment, and other measures that enable energy efficiency.

Based on some of these studies, managing energy needs to be identified several parameters such as the number of people in the building, the area of the building, electronic devices used in the building, and so on. The results of these studies indicate that the equipment that consumes a lot of energy in a building/room is air conditioning, further review is needed on how to save air conditioning system equipment.

B. Internet of Things (IoT)

Topics about IoT have been in the spotlight over the past decade. The concept of IoT has evolved from the 1800s, where there is machine vision communicating with each other. The electromagnetic telegraph was invented by Baron Schilling in Russia in the 1830s, which allowed machines to communicate. The first radio voice transmission took place in 1900 [32]. In 1926, Nikola Tesla predicts that smart devices will be realized through wireless networks. The group of programmers at Carnegie Mellon University designed a sensor system to track the status of the vending machine and send the information through ARPANET in the

1980s. Shortly after, Tim Berners-Lee proposed the World Wide Web (WWW) in 1989. John Romkey created an intelligent toaster connected to the internet. In 1999, IoT was finally introduced by Kevin Ashton in his presentation on RFID technology, which coincided with the time when the IoT revolution was starting to gain momentum. Since then, technology institutions, businesses, researchers, and communities have gradually changed their minds towards IoT ideas and began to apply them in various fields and activities. The emergence of connectivity standards such as Bluetooth or Wi-fi, smart hardware, and the growth of cloud computing triggered the development of IoT technology [33].

Internet of Things is a concept that combines the fields of computer science and electronics. Through IoT technology, one or several objects can communicate with each other through the internet network. IoT objects are equipped with microcontrollers and sensor devices that are connected and integrated with software applications/systems that allow communicating and interacting with other objects. Objects in IoT can be any device, animal, person, building, vehicle, or physical object that is part of daily life. IoT combines smart devices with smart services, such as smart cities, smart transportation, smart homes, smart buildings, smart agriculture, and so on [34]. The main challenge of IoT is to bridge the gap between the physical world and the world of information, such as how to process data collected from electronic equipment through an interface or visualization that can be easily understood by users because sensors produce data that is still unprocessed and must first be converted into a machine format so that it can simplify the data exchange process [35]. The IoT supported by embedded system technology, RFID, wireless networks, and web services [8].

According to Burange and Misalkar [36], IoT is a concept where an object can transfer data through a network without requiring two-way interactions, from human to human or human to computer interactions. Keoh et al [37] stated that the Internet of Things is a scientific development that is very promising to optimize life based on smart sensors and smart devices that work together through the Internet network. Examples of its application in objects in the real world are for processing food, electronics, and various other machines or technologies that are all connected to local and global networks through embedded sensors and always on. This IoT refers to a machine or device that can be identified as a virtual representation in its Internet-based structure.

The way the IoT works utilizes a programming argument, where each of the command's arguments can produce an interaction between machines that have been connected automatically without human intervention and without being limited by great distances. The internet is the link between the two machine interactions. Humans in the IoT job is only to be the regulator and supervisor of the machines that work directly. The basic constituent elements of IoT are as follows.

1) Artificial Intelligence (AI), IoT makes almost all existing machines become "Smart". This means that IoT can improve all aspects of life by developing technology-based on AI. The development of existing technology is done by collecting data, artificial intelligence algorithms, and available networks.
2) In IoT connectivity, it is possible to create or open new networks, and IoT-specific networks. This network is no longer tied only to the main provider. The network does not have to be large-scale and expensive; it can be available on a much smaller and cheaper scale. IoT can create a small network between system devices.
3) The sensor is the differentiator that makes the IoT unique compared to other sophisticated machines. This sensor can define instruments, which change IoT from standard networks and tend to be passive in the device so that it becomes an active system that can be integrated into the real world in everyday life.
4) Active Engagement, IoT introduces a new paradigm for active content, products, and service involvement.
5) Small Size Device. IoT utilizes small devices that are tailor-made to produce accuracy, scalability, and good flexibility.

IoT has the power to change the way people interact with things around them. In an industry/company, IoT can change the way business is run. IoT architecture can also be called a phenomenon-driven model. Fig 3 shows an overview of the IoT architecture that illustrates the building blocks of IoT technology and how each component is connected to interact to do the process, data transfer, data storage, analysis, data processing, data visualization, and so on [38].

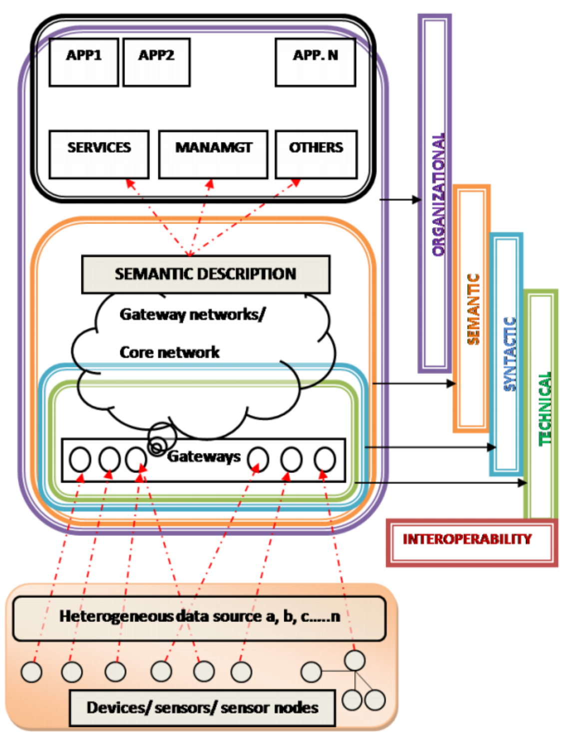

Fig 3. IoT Architecture [39]

IoT devices can connect with other devices or systems and exchange information as desired. Interoperability between devices and IoT systems occurs in various layers of communication protocols between devices. Technical interoperability ensures a mechanism for establishing physical and logical connections between systems, network interoperability for exchanging data between multiple systems on various networks. Syntactic interoperability ensures an understanding of data structures in the exchange of data between systems. While semantics ensures understanding of the concepts contained in data structures. IoT systems need to handle high-level interoperability, where the industry currently uses different standards to support applications with various heterogeneous data sources and devices, the use of standard interfaces between diverse entities is very important, especially applications that support cross-organization and various system boundaries [39].

III. Material and Methods

In this research, a systematic literature study method is used by identifying, assessing, and interpreting databases [40] related to IoT-based applications for monitoring energy consumption. This literature study begins by collecting documents using keywords such as energy management systems, IoT applications, and energy monitoring systems. The database search uses several platforms, such as Google Scholar, Research Gate, and ScienceDirect. The schematic methodology of the research is shown in Fig 4.

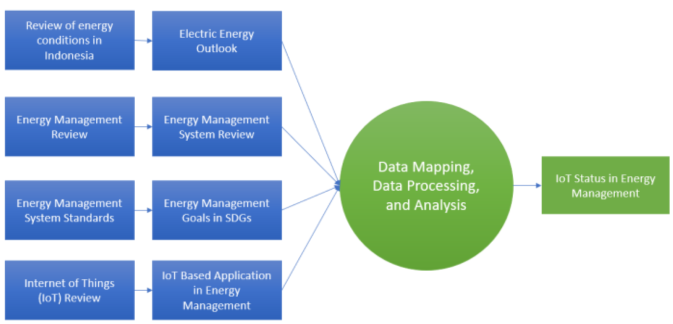

Fig 4. Schematic Research

The database collected in the initial stages discussed in the previous section includes reviewing energy conditions in Indonesia to find out issues regarding energy management in Indonesia and current energy conditions in Indonesia by conducting a review of a report from the National Energy Council published in 2019. Based on these data, it is known that the projected energy demand and energy supply, especially electricity. Furthermore, conducting an overview of Energy Management, Energy Management Systems, and Energy Management Standards as a solution to deal with energy management problems. Define the objectives of energy management based on the SDGs category. Reviewing current technological developments to support energy management systems through IoT technology.

The next step is to conduct a literature review of articles/ papers relating to the implementation of IoT in Energy Management. The database of related research collected will be mapped, processed, and analyzed. Mapping is meant by grouping based on certain criteria based on the contents of the database. After that, it is processed with qualitative and quantitative techniques to be compared, and processed into statistical data. Data that has been processed are analyzed to get insights that can be used for further research.

IV. Results and Discussion

The development of IoT is a major revolution in the field of Technology. IoT will distort daily activities and lifestyle. IoT has been researched and implemented in various fields. One use of IoT technology is for automatic energy management systems. IoT works with sensors attached to electrical devices. Prasetyo et al (2019) researched Smart Home for monitoring and control of electrical energy in Indonesia [41]. The research aims to conduct the effectiveness of electricity usage by monitoring and controlling power using cloud-based IoT. The Smart Home design was built using several devices such as an Arduino microcontroller, Internet module, AC Voltmeter, Relay, LDR Sensor, and PIR Motion Sensor. The output of the research is still in the form of design, not yet at the stage of developing and implementing the tool.

Hiremath et al (2017) researched IoT-based energy control and monitoring devices [42]. The research presents the design and implementation of energy meters using an Arduino microcontroller which can be used to measure the power consumed by each electrical device. The main objective of the research is to monitor the power consumption of the device, send measurement data to the server using the Wi-Fi module and the measurement results can be monitored from anywhere via a web-based application so that users can control energy use. The microcontrollers and sensors used are Arduino Uno, ESP8266, ACS712 Current Sensor, LCD, RTC, and Relay Driver. The measurement results are not explained in the paper, because the focus of the study is more on the application of the tool.

Kurde and Kukarni (2016) researched IoT-based Smart Power Metering [43]. This research focuses on designing devices that can measure and report energy usage or receive control inputs through the network. IoT devices used to take measurements are the ACS712 Current Sensor, Relay, Transistor, Arduino Uno, and Raspberry pi. Protocol for data communication using MQTT, the data is stored and processed using ThingSpeak. The way this system works is the current sensor measures the current flowing through the device, then the controller performs the required calculations on the data and places the data on the internet. Current data and voltage data obtained are processed to obtain the amount of energy consumption.

Medina et al (2018) conducted a study of monitoring and control of IoT-based electrical energy consumption using Raspberry Pi, where measurement data is displayed on an Android application [44]. The devices used to build the IoT are Arduino Uno, ACS DC8A AC/DC 50A Current Sensor, Raspberry Pi, and Relay Module. The workings of this system are Relay and Current Sensor connected to Arduino Uno. The analog input from the sensor is accepted by Arduino Uno and controlled by Raspberry Pi. The collected data is processed and sent to the database via Raspberry Pi. Data visualization is displayed in the Android Application. Based on the results of testing, the system has a high accuracy that is equal to 99.5% in certain devices but there are some devices with low accuracy.

Marinakis and Doukas (2018) conducted a study to present an IoT for intelligent energy management in buildings [45]. The Internet of Things based system is implemented to increase the interactivity of building energy management systems, and support changes in the behavior of occupants who are active in buildings. The system built gives the end-user to find out how much energy is consumed in total and information on the estimated impact on energy use. This system uses sensors that are installed in buildings and get real-time electricity consumption data. A web-based system is implemented in this study, its function is as a virtual distribution of energy consumption in buildings that can be accessed via the Internet. Through the web application, users can continue to monitor energy consumption data and other indicators.

Electricity consumption in India is very high, recorded in 2015 to 2016 electricity consumption in India reached 6.76 GW while the following year rose to 12.28 GW so David et al (2019) researched the decrease of Power Consumption Utilizing IoT [46]. This research was conducted to overcome the problems faced by the existing system and help reduce electricity consumption in an inexpensive and environmentally friendly way with the help of IoT. The devices used to build the IoT are Arduino, CT Sensor YHDC SCT-013-000, Burden Resistor, and Capacitor. This system provides a vitality screen directly on the breadboard that can be used to measure how much electrical vitality is used at home, based on the measurement of the current with a voltage received fixed 220V.

Santos and Ferreira (2019) conducted a study with the title "IoT Power Monitoring System for Smart Environments" which is about the development and validation of the EnerMon System which is an IoT-based system using LoRa for monitoring electrical energy consumption [47]. This system provides real-time information and a descriptive analysis process/big picture of electricity consumption over time and identifies energy wastage. The technology used is Arduino, transformer sensors, RaspberryPi as an application server, LoRa for communication with an edge-computing approach so that it can carry out real-time monitoring. This solution enables easy installation without communication coverage and barriers so that it can be used in different situations from large complex buildings to smaller consumers. The disadvantage of this research is that the analysis has a limitation that is only for the consumption of electrical energy, not yet entering the management level such as an analysis of expenses/costs.

Chooruang and Meekul (2019) from Nakhon Phanom University in Thailand conducted a study entitled "Design of an IoT Energy Monitoring System" where they designed and implemented a low-cost IoT-based energy monitoring system that could be applied in various applications, such as billing systems electricity, energy management in smart grids and home automation [48]. This design uses low-cost sensor nodes PZEM-004T, such as CT sensors, electrical energy measurement chip SD3004, and mini microcontroller ESP8266 Wemos D1. Raspberry pi 3 model B is used as a local server and to store data in InfluxDB. The results of the research carried out show that the energy monitoring system developed can successfully measure voltage, current, active power, and accumulative power consumption. Weaknesses in the developed system are the absence of analysis or further reports of the results of measurements that have been made.

Nasar et al (2019) researched a simple realtime energy analysis model for intelligent buildings using the Open IoT platform [49]. The research presents how simple real-time analytics and energy are built with low cost and high accuracy to check for significant energy fluctuations, anomalies, and patterns. The PZEM004T-100A module is used to measure voltage, current, and other electrical parameters. The microcontroller used is ESP8266. Actual and historical electrical data visualized in high-resolution graphics. The experimental results show that data on electricity usage can be captured in realtime and energy fluctuations can be known.

Shamshiri et al (2019) conducted a study of an IoT-based electrical energy monitoring system at the Malaysian Technical University of Melaka [50]. The research presents the development of an IoT-capable device that can communicate with digital energy meters via the Modbus protocol. The prototype system has been successfully installed in three places on the Main Campus of the Technical University Malaysia Malacca. The paper does not explain the components that make up the IoT hardware because it is only a prototype design.

Pinheiro et al (2018) researched a software model for an IoT-oriented and low-cost energy monitoring platform with the MQTT messaging protocol [51]. Great emphasis is given to this research for future integration on a decentralized IoT network. Hardware devices are built using current sensors, Arduino, and Raspberry Pi. Current-voltage and current sensors communicate with Arduino via I2C bus. The collected data is then processed and sent over a wireless LAN to Raspberry Pi, which operates as a network center point and is the only interface point. The use of the MQTT protocol provides device-to-device communication without changes to existing infrastructure. This research focuses on the Raspberry Pi service layer that can better support REST services while reducing the burden on sensor nodes by using MQTT.

Firmansyah et al (2019) researched an IoT-based digital kWh meter monitoring system using a Light Dependent Resistor (LDR) sensor and CodeIgniter API Service [52]. In this study, a prototype of a digital household kWh monitoring tool was designed using an LDR sensor to detect the blinking of an LED light on a digital kWh meter controlled by a microcontroller and can be connected to the server via an API service with the CodeIgniter framework. The microcontroller used is Arduino ESP8266 which already has a wifi module in it. The calculation is done by comparing the results of digital kWh meter readings with the prototype reading results. This comparison will produce an error value. The test results show that the prototype that has been made gives an error value of 0% for the difference in reading. While sending data from the prototype to the server on average takes 36.23 s with a wi-fi connection.

Jayanthi and Rama (2017) researched an IoT-based Intelligent Energy Tracking System [53]. The research proposes an IoT-based energy monitoring and control system that can monitor energy usage by measuring the voltage and current of various equipment regularly. The system built consists of several devices including Raspberry Pi 3, GSM Module, Analog to Digital Unit (MCP3008), Current Transformer (CT) sensor, and Potential Transformer (PT) sensor. Users have control over devices that are connected to IoT when the consumption of energy usage exceeds a predetermined usage threshold. Energy consumption is displayed via the GSM module and web interface.

Joshi et al (2016) researched IoT-based Smart Energy Meters [54]. Smart meters are the next generation meter which is very efficient and user friendly, which provides a great way to save and control energy usage. Smart meters are connected wirelessly to users via IoT. This means users can easily have control over the meter according to their needs. The advantage of smart meters is that they can be used by utilities to communicate information to customer bills and operate their electrical systems. The technology used is Arduino and Light Dependent Resistor (LDR). This system is divided into three elements, namely smart meters, android applications, and interconnected servers. The use of energy meters will reduce power consumption.

Lorenzo Bottaccioli et al (2017) researched the development of energy modeling and monitoring by integrating IoT devices and Building Information Models (BIM) [55]. The research presents software architecture for management and simulation of energy behavior in buildings that integrate heterogeneous data such as BIM, IoT, Geographic Information System (GIS), and meteorological services. The purpose of this integration is to enable real-time visualization of energy consumption information in building contexts, build performance evaluations through energy modeling and simulations using data from the field. Various hardware technologies are integrated through the IoT gateway which is a middleware-based software component to abstract device features into web services. Special gateways have been developed for various standards and protocols, such as ZigBee and Spirit. Simulation results show that the system has good accuracy.

Okafor et al (2017) conducted a study on the development of an Arduino-based IoT measurement system for residential energy monitoring on-demand using the multidisciplinary concept in Mechatronics [56]. This system displays demand-side management in real-time using Composite Design Methodology (CDM) which consists of cluster metering units and cloud servers. The device used is the ACS712 Hall Effect current sensor, Arduino Uno, and GSM SIM800L module. This approach is evaluated through selected case studies and usability trials. The system provides an efficient means of monitoring energy consumption with minimal errors. Utilities can intelligently provide value-added services using the system.

Utami et al (2018) conducted a study of a System Monitoring System for buildings in Indonesia [57]. In this study, the energy monitoring system was designed and installed in the Building of the Department of Nuclear Engineering and Physics, Gadjah Mada University. This study aims to design and install a cost-effective Building Energy Management System (BEMS) based on satisfying residents' ratings of lighting quality, acoustics, and air conditioning. The sensor system is designed to measure electrical loads using the SCT 013-000 electric current sensor and the ZMPT101B voltage sensor. The sensor is tested using input and output correlation which is used as a calibration factor. The correlation value depends on the condition of the building's utility power cable. The calibration factor will be used by the microcontroller to process data and produce measurable, accurate, and precise values. Data will be used as a decision support system (DSS) by building management through the use of a GUI. The interface design is based on survey results from prospective users. Survey results show that the GUI is categorized as fair in design without significant differences between user perceptions with and without survey supervision.

Apsitis et al (2018) conducted a study on the monitoring of electrical power at Industrial Greenhouse using the Secure IoT platform [58]. The study presents a report of the power monitoring system used at the Industrial Greenhouse. The device used for measuring and processing is the imp003 development board, but the scoreboard is LBWA1ZV1CD-716 Multi-Chip-Module (MCM). MCM means that on one chip several separate components are placed. In this case a 32-bit microcontroller and a Wi-Fi chip. The way the system works is that data is monitored and processed on a device, then transferred to a secure cloud service, where data can be further processed, formatted, and sent to the server that is used for data storage. The power monitoring system is part of the project where various parameters are measured and as a result, can offer guidelines for more efficient use of electric power.

Gunturi and Reddy (2018) researched IoT-based domestic energy monitoring devices [59]. The research presents an economically, technically, and compact tool for measuring the kWh reading of a particular device. The device used to build the IoT is MSP430F6736 Mixed Signal Microcontroller, Wi-Fi Module, and Lithium-ion battery. The way the system works is that the device sends data to the cloud that is assigned when the device is connected to a Wi-Fi router. Users can only access services by scanning unique QR codes on the device. Users can easily operate the device that has been built and also monitor the kWh reading.

Sahani et al (2017) researched IoT Based Smart Energy Meters [60]. The research presents a smart energy measurement system using IoT and Arduino. Arduino is used because it saves energy, consumes less power, is faster, and has him UART. The use of the GSM module is used to provide notification features via SMS. In detail, the devices used are Arduino ATMEGA Uno 328, Max 232, GSM SIM900, Relay, Wi-Fi Module ESP8266, Driver Circuit (MOC3011), and Signal Condition (P817). Data on electricity consumption and costs are displayed on a web page. This system is also equipped with a threshold value for energy use, when consumption exceeds the threshold value the user will get a notification.

Talwar and Kulkarni (2016) researched an IoT-based energy meter reading system [61]. The research presents a system to measure energy consumption at home and generate bills automatically using telemetry communication by checking the consumption of electricity units at home. The calculation is done automatically and the bill is updated through the database. The amount of the bill can be checked by the owner anywhere and anytime. Project design and implementation are mainly based on ARM controllers using the IoT concept. The project block diagram consists of a controller section, a theft detection section, and a Wi-fi unit. The controller part consists of the ARM 7 controller and Arduino Uno. WIFI ESP8266 is used for IoT operations. LCD, Relay, Buzzer, 555 monostable multivibrators are other components in the system. A microcontroller is a core component of the project that connects input and output devices. Microcontrollers used were ARM 7 LPC2148 and Arduino Uno.

Abhiraj et al (2018) researched IoT-based Smart Energy Monitoring [62]. This research presents digitizing the use of energy through the internet. The design of the system built eliminates human involvement in electricity maintenance. Users can monitor electrical energy consumption through web pages by entering the power line ID. Web pages use a third-party service, ThingSpeak, to analyze and visualize energy usage statistics in more detail. Through this system, consumers can do power management by knowing energy usage from time to time. The resulting unit can be displayed on a web page via the Wi-Fi module. The hardware used in building IoT includes the Allegro ACS712 Current Sensor, Arduino Nano, ESP8266 Wi-Fi Module (Node MCU), LCD Display, buzzer, and power supply.

Jagtap et al (2019) researched real-time data collection to improve energy efficiency with a case study of food producers [63]. This research presents a case study from a beverage factory where the application of IoT technology is based on an embodied product energy (EPE) model to help reduce energy consumption. This arrangement makes provisions for the collection of energy data in real-time in food production systems to support energy-conscious operational decisions and lead to optimal and efficient energy consumption. The result allows the company to use energy more efficiently to have an edge over its competitors and a better market position. More data can be entered into the energy management system using IoT. The availability and accuracy of such valuable data will help managers make better energy-efficient decisions.

Karthikeyan and Bhuvaneswari (2017) researched the IoT-based Real-Time Housing Energy Monitoring System [64]. The system presented provides consumers with ubiquitous and continuous access to energy consumption by utilizing advances in IoT technology. The devices used to build IoT are energy meters, optical sensors, and NodeMCU (ESP8266). The optical sensor used to detect blinking LEDs mounted on the energy meter. The wireless router that is on the customer side is configured with internet connectivity. After the authentication process is complete, consumption data is transferred to the ubidots cloud. Through experimental analysis, it was found that from the data collected, it is possible to obtain consumption patterns and errors that exist in the existing system. The research presented can also be extended to a large scale from where the burden distributed in the area can be estimated so that the system can be strengthened to improve performance.

Pereira et al (2018) conducted a study of IoT embedded Linux based systems on Raspberry Pi applied to real-time cloud monitoring of a decentralized photovoltaic plant [65]. The research presents the implementation and testing of the Renewable Energy Monitoring System (REMS), a new concept of data acquisition and transmission systems (DATS) that is applied to real-time cloud monitoring of a decentralized photovoltaic (PV) plant. REMS can sense and modify the monitoring process management through remote firmware updates via the Analog/Digital Converter Embedded System (ADCES) that was developed and communicate with cloud server profiles that were developed personally through the RPi Embedded Linux System (ELS), so it does not require a special PC. The measured variables are PV voltage and current, ambient and PV module temperature, solar radiation, and relative humidity.

Komal and Prachi (2017) researched monitoring industrial processes using IoT [66]. The research presents a system that can be used to monitor industrial applications by implementing industry-standard protocols using IoT. In this system it is equipped with several features such as fluid level control, energy monitoring, etc. that can be monitored via mobile android, laptops, and other devices connected to the internet. The main objective of this research is to summarize the importance of IoT which will monitor small-scale industrial applications. This system uses existing PLCs, industrial equipment, and the IoT Wi-fi module ESP8266. For energy monitoring using ESP8266 and MAX485 IC.

Jasmeet and Punit (2016) researched IoT-based Smart Home designs using Power and Security Management [67]. The research presents the design and implementation of an intelligent Smart Home System based on Ethernet to monitor electrical energy consumption based on real-time tracking of devices at home. The microcontroller used is Intel Galileo 2nd Generation. This system works on real-time monitoring and voice control so that devices and electrical switches can be controlled and monitored remotely with or without an Android-based application. The purpose of this study is to save on electricity bills for the home and maintain the security of the user's home with the option to control the switching of devices using voice or an android application.

Al-Kuwari et al (2018) researched Smart-Home Automation using IoT-based Sensing and Monitoring Platforms [68]. This research presents a complete design of IoT-based sensing and monitoring systems for smart home automation. The system design uses the EmonCMS platform to collect and visualize monitored data and remote control. Sensors used in this system are an LM35 temperature sensor, HIH40000 humidity sensor, Light Dependent Resistor (LDR), and Air Quality Sensor. Microcontrollers used are NodeMCU and ESP8266. The smart home design that has been built is very flexible and can be easily extended/applied to larger buildings by increasing the number of sensors, measured parameters, and control devices.

Pandit et al (2017) researched Smart Energy Meters using IoT [69]. This study aims to project ways to monitor energy consumption at the domestic level so that it can help in reducing energy consumption and monitoring the units consumed. The design and implementation of this system are based on IoT technology using the Arduino UNO microcontroller. If interference occurs, the microcontroller will send data to the server and also reduce the energy supply automatically. Ethernet performs IoT operations where data is sent to web pages. Besides, there are other components such as Buzzer, Relay, Energy Meter, and UART Communication.

Despa et al (2018) conducted a study on the implementation of IoT technology in real-time monitoring of electricity quantities [70]. This research presents monitoring of changes in the state of electricity online based on IoT implemented in the Department of Mechanical Engineering, University of Lampung. The aim is to be able to make more effective decisions when there is a change in the state of electricity. The measurement system involves several sensors such as current sensors and voltage sensors, while data processing is carried out by Arduino, the measurement data is stored to a database server and displayed in real-time via a web-based application. The results of this study indicate that the condition of the electric power system in the campus building has an unbalanced load, which often causes a drop-voltage condition.

Based on the analysis of all of the papers discussed in this sub-section the scope of works reported can be divided into three categories. The research on energy management using IoT more leads to simulations or device trials, which is 73%, the rest leads to prototype (17%) and implementation (10%).

The microcontroller that is widely used in the research reported above is Arduino. Arduino is a microcontroller that is cost-effective, easy to obtain, and easy to configure with various programming languages. Besides Arduino there is ESP8266 (NodeMCU), this microcontroller is one that is also often used because it is directly equipped with Wi-Fi Module. Arduino and NodeMCU are highly recommended for conducting research related to energy management. There are several other microcontrollers such as Raspberry Pi, MSP-430F6736, ARM, and Intel Galileo, but the costs may be incurred. Fig 5 shows a statistical comparison of the use of a microcontroller based on the papers above.

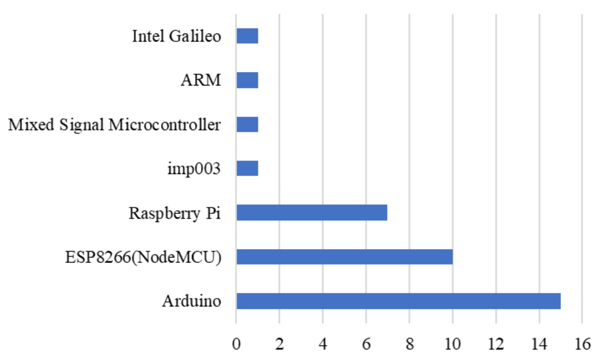

Fig 5. Statistics Comparison Microcontroller based on Review

The research object on IoT for energy management can be divided into Smart Home, Smart Building, Smart Metering, Smart Environment, and Other/Commercial. The analysis shows that 47% of IoT users in energy management are for Smart Metering. The Commercial Sector by 20%, Smart Home by 17%, Smart Building by 13%, and Smart Environment by 3% as shown in Fig 6.

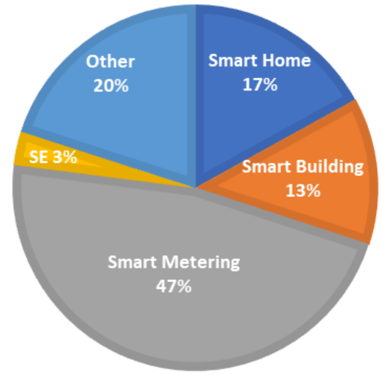

Fig 6. Statistics Comparison Objectives of IoT based on Review

Sensors used in electrical energy monitoring systems using IoT technology are also very diverse, depending on measurement parameters and needs such as voltage using voltage sensors, current using CT sensors, active power, accumulative power consumption, and so on. The sensor used to measure energy also requires the help of several electronic modules installed on the microcontroller such as Relay, LDR, PIR Motion, LCD, RTC, Transistor, Resistor, Capacitor, Buzzer, Power Supply, and others.

IoT network protocols are used to connect devices over a network and are a set of communication protocols that are usually used over the Internet. IoT network protocols allow end-to-end data communication to be used within the network. Communication and data transmission from IoT devices to the cloud can use several communication infrastructures such as WiFi, LoRa, ZigBee, Spirit, UART, and others. Each communication tool has a different function, depending on conditions in the field where the IoT system is implemented Table 1 below shows the sensors and communication tools used based on the analysis of related research.

TABLE I
SENSOR & MODULE TYPE FOR ENERGY MONITORING BASED ON THE REVIEW

No	System/Application	Sensor & Module
1	Smart Home for monitoring and control of electrical energy using cloud-based IoT [41]	Wi-fi module, AC Voltmeter, Relay, LDR Sensor, PIR Motion Sensor
2	IoT-based energy control and monitoring devices [42]	Wi-fi module, ACS712, Current Sensor, LCD, RTC, Relay
3	IoT-based Smart Power Metering [43]	Wi-fi module, ACS712, Current Sensor, Relay, Transistor
4	Monitoring and control of IoT-based electrical energy consumption using Raspberry Pi [44]	Wi-fi module, ACS DC8A, AC/DC 50A, Current Sensor, Relay Module
5	IoT for intelligent energy management in buildings [45]	Not defined The focus of the paper is an implementation

6	Decrease of Power Consumption Utilizing IoT [46]	CT Sensor, YHDC SCT-013-000, Burden Resistor, Capacitor
7	IoT Power Monitoring System for Smart Environments [47]	LoRa, Transformer Sensor
8	Low-cost IoT-based energy monitoring system [48]	PZEM-004T, CT sensors, Electrical energy measurement chip SD3004
9	Realtime energy analysis model for intelligent buildings using the Open IoT platform [49]	PZEM004T-100A module
10	IoT-based electrical energy monitoring system at the Malaysian Technical University of Melaka [50]	Not defined The focus of the paper is the communication protocol
11	Software model for an IoT-oriented and low-cost energy monitoring platform with the MQTT messaging protocol [51]	Current sensors The focus of the paper is the communication protocol
12	IoT-based digital kWh meter monitoring system [52]	Wi-fi module, LDR Sensor
13	IoT-based Intelligent Energy Tracking System [53]	GSM Module, Analog to Digital (MCP3008), Current Transformer (CT) sensor, Potential Transformer (PT) sensor
14	IoT-based Smart Energy Meters [54]	Light Dependent Resistor (LDR)
15	Energy modeling and monitoring by integrating IoT devices and Building Information Models (BIM) [55]	ZigBee & Spirit The focus of the paper is the communication protocol
16	Arduino-based IoT measurement system for residential energy monitoring on-demand using the multidisciplinary concept in Mechatronics [56]	ACS712 Hall Effect current sensor, GSM SIM800L module
17	System Monitoring System for buildings in Indonesia [57]	SCT 013-000 electric current, Sensor ZMPT101B voltage sensor
18	Monitoring of electrical power at Industrial Greenhouse using the Secure IoT platform [58]	Not defined The focus of the paper is the implementation
19	IoT-based domestic energy monitoring devices [59]	MSP430F6736 Mixed Signal Microcontroller, Wi-Fi Module, Lithium-ion battery
20	IoT Based Smart Energy Meters [60]	Max 232, GSM SIM900, Relay, Wi-Fi Module ESP8266, Driver Circuit (MOC3011), Signal Condition (P817)
21	IoT-based energy meter reading system [61]	WIFI ESP8266, LCD, Relay, Buzzer, 555 monostable multivibrator
22	IoT-based Smart Energy Monitoring [62]	Allegro ACS712 Current Sensor, ESP8266 Wi-Fi Module (Node MCU), LCD Display, Buzzer, Power supply
23	Real-time data collection to improve energy efficiency with a case study of food producers [63]	Not defined The focus of the paper is the implementation
24	IoT-based Real-Time Housing Energy Monitoring System [64]	NodeMCU (ESP8266), Optical sensor
25	IoT embedded Linux based systems on Raspberry Pi applied to real-time cloud monitoring of a decentralized photovoltaic plant [65]	PV voltage and current, Ambient and PV module temperature, Solar radiation, Relative humidity
26	Monitoring industrial processes using IoT [66]	Wi-fi module ESP8266 & MAX485 IC
27	IoT-based Smart Home designs using Power and Security Management [67]	Not defined The focus of the paper is the implementation
28	Smart-Home Automation using IoT-based Sensing and Monitoring Platforms [68]	LM35 temperature sensor, HIH40000 humidity sensor, Light Dependent Resistor (LDR), Air Quality Sensor
29	Smart Energy Meters using IoT [69]	Buzzer, Relay, Energy Meter, UART Communication
30	Implementation of IoT technology in real-time monitoring of electricity quantities [70]	Current sensors & Voltage sensors

An overview of the IoT-based energy monitoring system architecture can be analyzed based on the microcontroller, sensor, module, and data transmission communication protocol used in several related studies. Fig 7 shows the IoT system architecture for energy monitoring which is divided into several parts consisting of a microcontroller, sensors, modules, communication protocols, and applications.

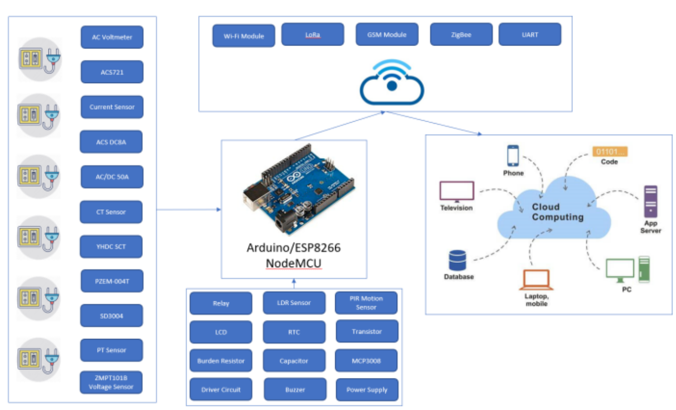

Fig 7. IoT Architecture for Energy Monitoring

The architecture shows that all sensors and modules are connected to a microcontroller. Microcontrollers send data to the cloud via communication protocols that are connected to the internet network. Data sent to the cloud is stored on the storage media/server and processed according to needs, where the data that has been processed will be displayed on the side of the client such as websites, mobile applications, APIs, etc.

V. Conclusion

In this research, a literature review has been conducted on several studies related to the application of IoT technology in energy management systems. IoT technology has been applied in various fields such as Smart Home, Smart Building, Smart Metering, Smart Environment, Commercial, and others. Microcontrollers available to build IoT devices also vary from the cheapest to the most expensive. Arduino and NodeMCU are microcontrollers most often used in building IoT-based systems because they are cost-effective and modules that are provided compact with microcontrollers such as Wi-Fi modules that are directly installed on NodeMCU. In its application in the research environment, there are still many in the simulation/testing phase because to implement IoT it requires the readiness of each element in it, such as the availability of devices and also the environment/activities of each person must also adapt to these developments.

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