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Design and Implementation of IoT-based HVAC and Lighting System for Energy Saving

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Abstract. Building Energy Management System(BEMS) technology is under study as one of the various solutions to environmental problems such as depletion of energy resources, global warming, and climate change. Solving the energy problems of the future BEMS is not the only goal. Occupants must be guaranteed a comfortable environment. HVAC systems and lighting systems are a large part of building energy consumption, which also means that it is an important part of energy conservation. In this paper, we propose IoT-based HVAC and Lighting(I-HVAC&L) system for HVAC system and lighting system management. With I-HVAC&L System, you can save energy efficiency without compromising the convenience of residents'.

1 Introduction

Since the Industrial Revolution, industrial development, technology development, and population growth have increased energy consumption around the world. This causes environmental problems such as depletion of energy resources, global warming, and climate change. Global energy consumption is increasing day by day, and due to the limited energy resources, the energy problem has become a hot topic all over the world with efforts being made to develop new alternative energy. Recently, buildings are becoming larger, and heating and cooling, lighting, and ventilation systems are increasingly used. This is expected to increase the amount of energy used in buildings. According to the International Energy Agency (IEA), the energy consumption of buildings is the most energy consuming in the world and predicts that by 2050, it will increase by 50%. Considering that energy used in buildings and energy used in lighting systems and HVAC systems make up a large part of building energy consumption, the economic impact that can be gained by reducing the energy used is large.

HVAC systems (Heating, Ventilation and Air Conditioning) means for heating, ventilation, and air conditioning. The main purpose of the HVAC system is to create a pleasant environment by adjusting the four elements of air conditioning (temperature, humidity, air flow, cleanliness) to the person or goods to suit the purpose. Dezfouli et al. [1] proposed applying a high-efficiency motor to an HVAC system using a large number of motors. They found that by using high-efficiency motors, energy savings could be achieved. Long Chang et al. [2] proposed a cloud-based intelligent classification algorithm for efficient fault detection and diagnosis of HVAC systems. Preglej et al. [3] proposed a method to control the HVAC system through a fuzzy model based on the multivariate prediction. The proposed method was implemented in the actual test site, resulting in a 44% reduction in energy consumption. Alessandro Beghi et al. [4] proposed a system to predict the cooling load of an HVAC system using an artificial neural network (ANN) to minimize energy consumption. Currently, a lot of research is being done to save the energy consumed by HVAC systems in various aspects.

Lighting systems not only provide a basic visual environment for occupants, but also have a significant impact on human health, work efficiency, and building energy consumption. Today, many people spend most of their day indoors. Therefore, it is important to create a comfortable visual environment to improve the living environment of the occupants and improve the efficiency of work. In addition, unnecessary lighting energy needs to be reduced. Siriporn Bannamas et al. [5] proposed an intelligent lighting energy management system. The system manages the lighting energy through six control functions such as occupancy control, time planning, daylight control, job control, personal control and variable power cut-off. Ivan Chew et al. [6] designed an energy-saving controller that processes the data received from the sensor and controls the brightness of the light. It is noteworthy that the brightness of the light is controlled via feedback. Chun Yin et al. [7] proposed a method of minimizing energy consumption by individually manipulating the brightness of various lighting devices. Furkan Hasan Sakaci et al. [8] proposed a method of reducing energy consumption by applying fuzzy logic control to the lighting system with the number of people in the space and intensity of sunlight reaching the space as parameters. Wan Norsyafizan W. Muhamad et al. [9] proposed a system that improves energy efficiency by determining the minimum number of lights required at a specific location without compromising the quality of the lighting. Increasing energy efficiency without compromising user convenience is a must for lighting systems. In order to save energy, the lighting system is undergoing much research on the brightness and scheduling of the lighting.

The main goal of the building is to provide shelter to residents and create a comfortable environment. This means that you need to provide a pleasant environment for your residents while reducing building energy. If the residents are not provided with a comfortable environment, they can take the traditional approach rather than the energy saving method. In this paper, we propose an I-HVAC&L System that manages and controls the HVAC and lighting system, which occupies a large part of the building energy consumption, by combining IoT technology. The I-HVAC&L System based on the IoT network environment manages the HVAC system and the lighting system according to the environmental information acquired by the space.

The remainder of this paper is organized as follows. Section 2 introduces the architecture for the proposed system in paper and also introduces sequence diagrams for setting up, operating, and creating energy management policies for the system. Section 3 discusses the implementation of the proposed system hardware and software and experimental results. Finally, conclusions and future studies are presented in Section 4.

2 System architecture

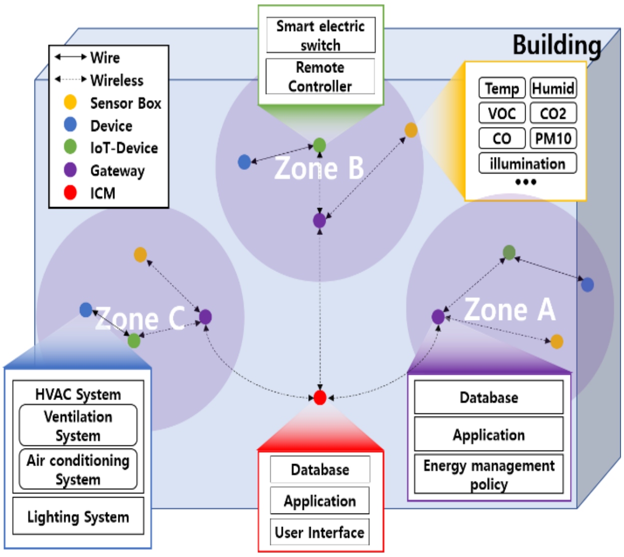


Figure 1. Overview of System Architecture.

Figure 1 shows an overview of the proposed system. The proposed system consists of the device, sensor box, IoT-Device, gateway and intelligent central manager (ICM). The device consists of an HVAC system consisting of a ventilation and air conditioning system and a lighting system and device is connected to an IoT-based device for control. An IoT-based device consists of a smart electronic switch and a remote controller and collects data such as control and energy usage and current operating status of the devices. The IoT-based device is connected to the gateway and sends and receives control signals and data. The sensor box collects temperature, humidity, illumination and air quality data (CO2, CO, PM10, VOC, etc.) inside and outside of the building to be used to control the HVAC system and lighting system. The gateway connects to the sensor box and IoT-based device through Zigbee communication and stores the device information and the data collected from the sensor box in the database. The ICM connects to all gateways in the building through the network and stores and manages the data stored in the gateways in the database. The ICM can also provide customized services based on sensor data per gateway installed. Administrators can analyze the operation of the system through the monitoring function of the interface and establish an energy management policy. The central management unit also has the capability to detect abnormalities of the devices and notify the manager in the event of an error. This feature allows administrators to quickly recognize and respond to device anomalies.

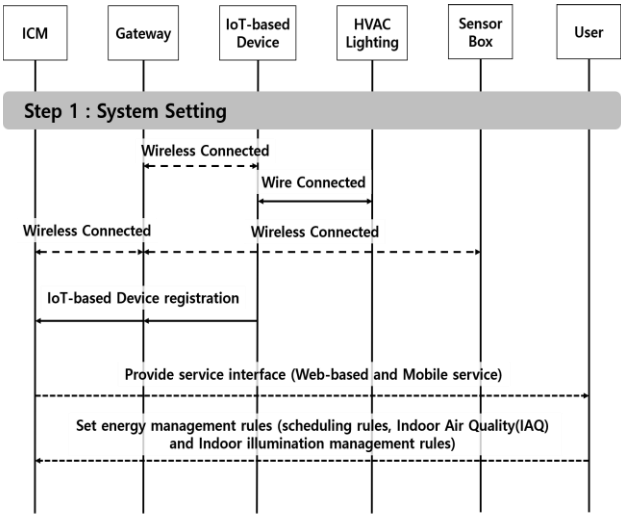


Figure 2. Sequence of system setting.

Figure 2 shows the system setup sequence. As shown in the figure, the connection between each device is performed first. Then the IoT-based device in the gateway and ICM are registered. The ICM provides web-based and mobile interfaces to administrators. Administrators can set up an energy management policy in accordance with the indoor air quality (IAQ) and finish through it.

Figure 3 shows the system operating sequence. The system automates the operation of the system by comparing the indoor and outdoor air and illuminance information collected in real time with the administrator setting energy management policy set up previously. The automated operation can improve user convenience and energy efficiency. To automate the lighting system, make sure that the amount of light currently in the room meets the level set by the administrator. Compare the indoor and outdoor illumination data and reduce the brightness of the lighting if the outside is brighter than the inside. Also, if there are no people in the area, reduce the brightness. This follows the policies set by the administrator so that you can conserve Lighting energy consumption without compromising user comfort. Compare temperature and humidity data collected in real time for automation of HVAC systems with policies set by the administrator. After that, the air conditioning system is activated based on the comparison to maintain the desired temperature and humidity conditions. In addition, if the room air is contaminated, the system automatically activates the ventilation system to purify the air. At the same time, it reports the air pollution information and the ventilation system operation information to the manager in real time. This allows the administrator to know why the ventilation system started to operate at that specific time. It is also designed to report to the administrator in real time when a device failure is detected. This allows the administrator to know what is wrong with the device and to check the device to take appropriate action.

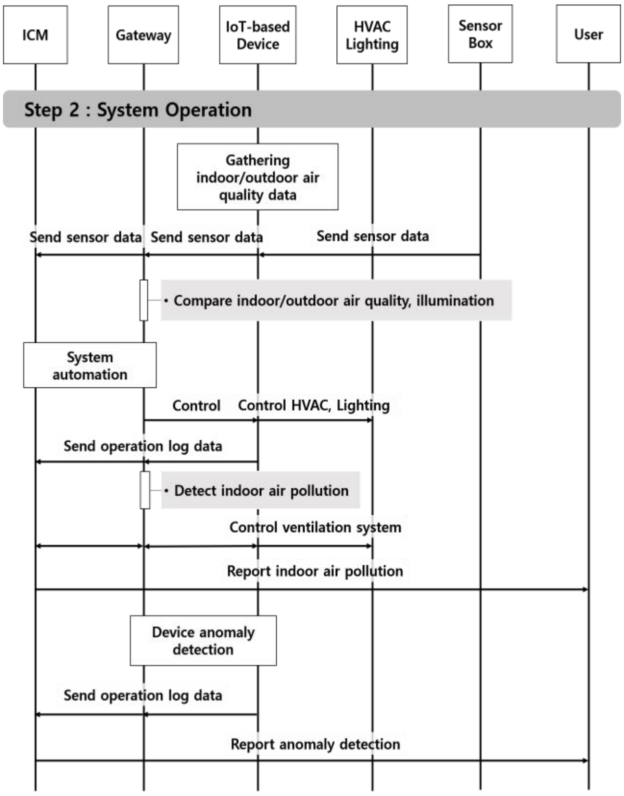


Figure 3. The sequence of system operation.

Figure 4 shows the energy management policy creation sequence. As shown in the figure, the ICM analyses energy consumption. Administrators monitor IAQ information, system operation information, and energy consumption analysis information through the service interface. Based on this information, you set up scheduling rules, IAQ management rules, user-optimized temperature, humidity and roughness management rules. This allows users to flexibly provide feedback regarding energy management policies.

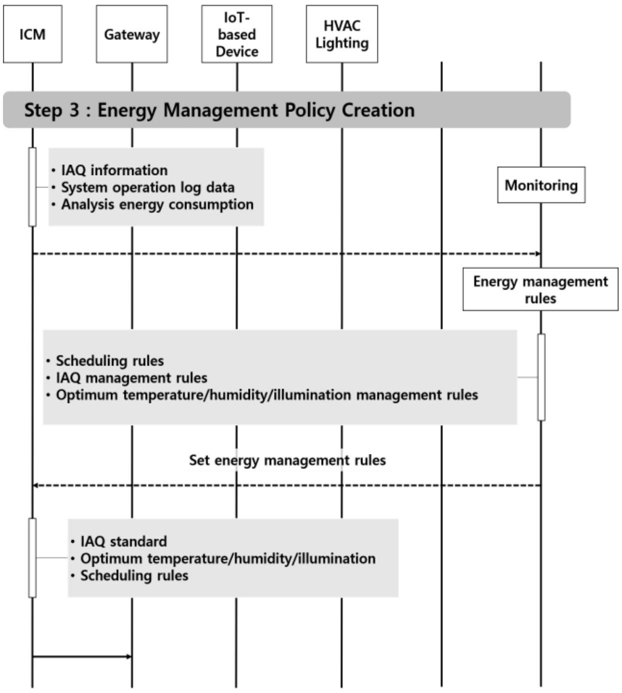


Figure 4. Sequence of energy management policy creation.

3 Implementation

We have verified the energy-saving efficiency of the I-HVAC&L system by building a pilot testbed environment in the actual building. The testbed building is three rooms in Chun-Ang University. Each room is equipped with a single gateway to control the HVAC system and lighting system in the room. An IoT-based device consists of a smart electronic switch and a remote controller and performs the functions mentioned in the system architecture. The sensor box is also installed on each room and roof to measure room temperature, humidity, illumination and air quality.

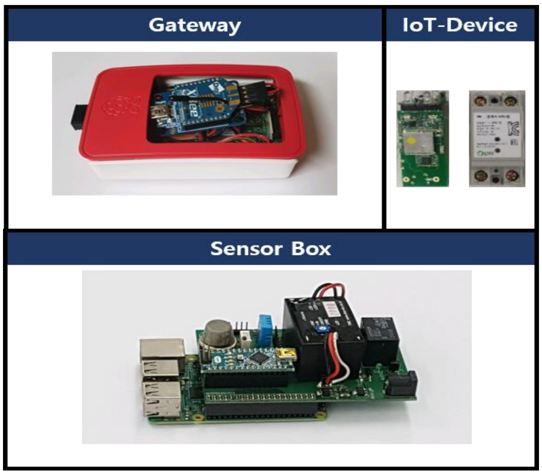
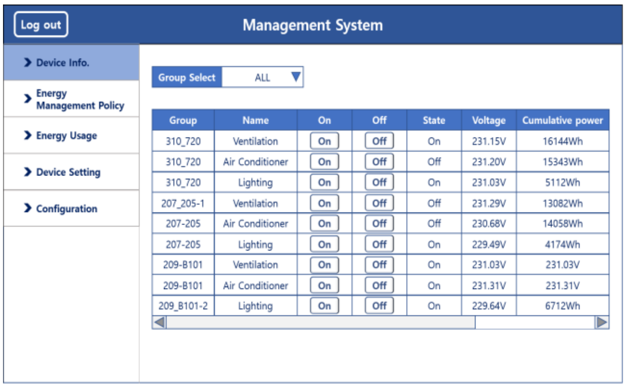


Figure 5. Hardware of the proposed system.

Figure 5 shows the prototype of the proposed I-HVAC&L system. The gateway consists of Raspberry Pi3 and Zigbee based on the open source IoT platform. The sensor box consists of an 8-bit microcontroller unit

(MCU), various sensors, and a Zigbee module. The MCU collects the aforementioned data through various sensors. And it communicates with the Gateway using Zigbee. The gateway sends and receives data to and from the ICM over the Internet. We have also developed user applications for the management and control of I-HVAC&L systems. Figure 6 is the user application.



Group	Name	On	Off	State	Voltage	Cumulative power
310_720	Ventilation	On	Off	On	231.15V	16144Wh
310_720	Air Conditioner	On	Off	Off	231.20V	15343Wh
310_720	Lighting	On	Off	On	231.03V	5112Wh
207_205-1	Ventilation	On	Off	Off	231.29V	13082Wh
207-205	Air Conditioner	On	Off	Off	230.68V	14058Wh
207-205	Lighting	On	Off	On	229.49V	4174Wh
209-B101	Ventilation	On	Off	On	231.03V	231.03V
209-B101	Air Conditioner	On	Off	On	231.31V	231.31V
209_B101-2	Lighting	On	Off	On	229.64V	6712Wh

Figure 6. User application.

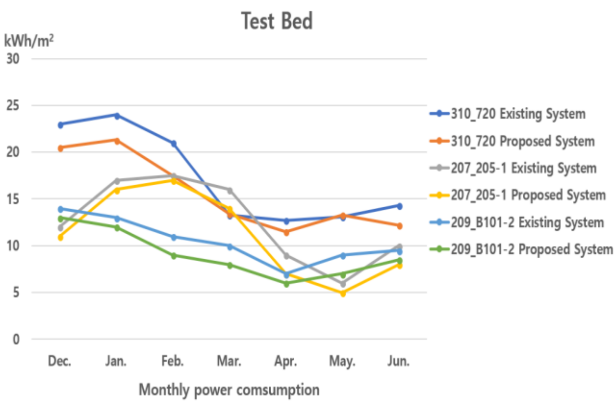


Figure 7. Result of energy efficiency of the proposed system.

Figure 7 shows the results of a test bed with an I-HVAC&L system installed. The result is calculated as electricity per unit area for lighting, air conditioning, heating and ventilation. The results show and compare the electricity used from December 2016 to June 2017 and the amount of electricity used from December 2017 to June 2018 using the I-HVAC&L system. The proposed system reduced energy consumption by 9.3%, 10.6%, and 13.7% for each room.

4 Conclusion

In this paper, we proposed IoT-based HVAC and Lighting (I-HVAC&L) system to reduce building energy consumption. I-HVAC&L collects indoor and outdoor environmental data to enable independent operation of HVAC and Lighting systems by space. The proposed system operating conditions are designed to allow the administrator to set up the system flexibly. This allows the administrator to set an energy management policy that considers the user's convenience. The hardware and software of the proposed system are also implemented and demonstrated on a test bed. The power consumption of the test bed was reduced by about 11.2% compared to the existing installed system. Applying the proposed system to various buildings is expected to contribute to reducing energy consumption. Future research will be carried out on how to elaborate user-customized services by analysing Bigdata based on collected environmental data.

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