Energy Saving Solution for Air Conditioning Systems

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Abstract. With the looming threats of environmental changes due to global warming, independence from fossil fuels together with energy saving are being prioritized. Among the electrical equipment in buildings, air conditioning has the potential to provide a lot of savings. Despite efforts in energy saving technology, the waste in air-conditioning is primarily due to the users' inattentiveness, e.g. forgetting to turn off the air-conditioning, turning it on even in cool weather, setting the temperatures too low, etc. This paper proposes a simple but effective solution to minimize this waste. A system that allows managers to remotely monitor status of devices, temperature controllers, set operating schedules or temperature thresholds, enable manual or automatic modes is developed. It also allows the export of statistical reports to improve operations.

Keywords: Energy saving · Air conditioner · Sensor networks · Information system

1 Introduction

Energy is a fundamental ingredient for all life on Earth. There is no industrial, agricultural, healthcare, domestic, or any other sort of process that doesn't require a degree of external energy. And the needs for electricity in all areas, be it office, school, home or public place is growing exponentially [1]. It is easy to recognize a refrigerator in every home, air conditioning in every office, high-voltage light bulbs in almost every street. These devices make our life better, but there are always some trade-offs. One of them is that they are consuming too much of energy. For example, a 2-way air-conditioner draws approximately 1500 W, a high-voltage lighting bulb about 1000 W to 3000 W, a television 40 W to 80 W on average. From there, it is easy to see that the cost for air-conditioning is substantial.

Energy saving has been concerned for a long time and people have many solutions. These include the search for renewable energy sources and new energy sources such as: biomass, hydropower, geothermal, wind, solar [2].

For electrical devices, many energy saving technologies have been introduced. For example, energy-efficient lightbulbs such as halogen incandescent lamps, compact

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fluorescent lamps (CFLs), and light emitting diodes (LEDs) typically use about 25%–80% less energy than traditional incandescent bulbs but can last 3–25 times longer [1, 3]. The new Smart Inverter system using microcomputer control can adjust air conditioners to lower the operating costs – up to 40%, when in its high efficiency mode [4, 5].

On a larger scale, Smart Grids, electrical systems that use information and communication technologies to optimize the transmission and distribution of electricity between manufacturers and consumers, are built [6, 7]. Smart Grids are developed in all 4 stages: Smart Generation, Smart Transmission, Smart Distribution, Smart Power Consumers. Smart Grids allow the operation of the entire electrical system to be automatically optimized at all times. Also, and importantly, they will not stop at the customer's electrical meter. They can provide customers with new prices, payment options and up-to-date information. The customers can actively control their energy use, by always knowing their electricity consumption. This can also lead to significant power savings.

Another research and application segment is smart building as an energy efficiency application. The concept of Smart Building could be defined as a set of communication technologies enabling different objects, sensors and functions within a building to communicate and interact with each other, which can also be managed, controlled and automated remotely. The scope of Smart Building is very wide covering various objects within the household from windows, elevators to vehicle charging points. But energy efficiency is expected to mainly come from the two following categories: Smart lighting and Smart HVAC (Heating, Ventilation, Air Conditioning) [8–12].

The above solutions and studies have shown that there are interesting problems to study in energy saving. We conducted interviews with 10 managers, 30 staffs and 25 students of 10 buildings and 5 schools in Hanoi about using electrical equipment and obtained the following opinions:

- Managers claim that monthly electricity bills are substantial. In particular, the electricity for air conditioning accounts for about 50–70% of the total bill.
- Most managers are willing to spare a budget for power-saving solutions. However, the investment cost must be consistent with the depreciation of electrical equipment and the need to bring about significant efficiency.
- Many employees and especially students acknowledge wasteful use of air conditioners. For example, they do not turn them off even if they are the last to leave the room, they turn on the air conditioners to low temperatures even when the weather is cool, etc.

It can be seen that smart building systems, smart schools, smart offices [13, 14] are very good, but the price is too high because the system consists of many functions. In addition, they are not open or can be difficult to customize for some small and medium-sized practical needs.

This paper presents an energy saving system for buildings. The system focuses on:

- Saving power consumption from air conditioning equipment.
- The system is cheap, easy to install and expand.

- Remote monitoring and control.
- Collection of data and extraction of statistical reports.

The remainder of the paper is organized as follows. Section 2 describes the system design and implementation. Then, conclusions and perspectives are made in Sect. 3.

2 System Requirements

2.1 Architecture Overview

The system consists of three main parts: the hardware, the server and the management website (Fig. 1).

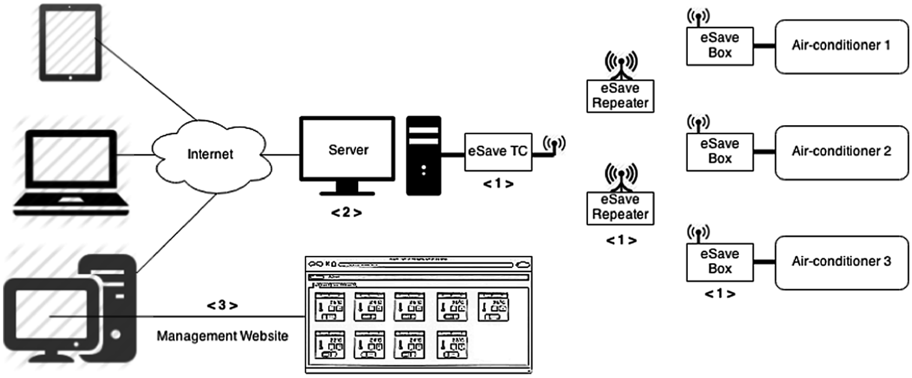

Fig. 1. Architecture overview of eSave system.

The Hardware Consists of 3 Modules

eSave Box. The first module, called the eSave Box, is attached to all air conditioners. The eSave Box receives incoming commands via radio waves and emits infrared signals that control the air conditioner as a remote control. It also measures the status of the air conditioner and responds to the system.

The eSave TC (Transceiver). This module is attached to the server computer. It communicates with the computer via a USB port and communicates with eSave Boxes via radio interface.

The eSave Repeater (optional). In case the distance between the eSave Box module and eSave TC is too large, affecting signal quality, an eSave Repeater is used to relay signals between these two modules.

The Server

The server is a computer that contains a database of the system containing information such as users, air conditioners, control modules, etc. and the operating logic of the entire system. MongoDB is used as the database for the eSave system. MongoDB is a crossplatform document-oriented database system. It has many advantages, with a dynamic schema and object-oriented structure, making it a great fit for real-time analytics and dash boarding along with ecommerce, mobile, archiving and more.

The Management Website
The website provides interfaces for the remote monitoring of the status of all air conditioners, for management, scheduling, and report extraction by managers. The system allows the control of air conditioners according to a schedule, but it also permits manual operation, which means the user can still use the remote control, but it will be subjected to the temperature limit set according to the location or weather. The status of air conditioners, the turn-off time, user, room location will be collected and put into reports. From there, the administrator can make adjustments to operating modes and recommend users appropriately.

2.2 System Requirements

The system has two main types of user that are system users and administrators. The functional requirements of each user are described in Table 1.

Table 1. Functional requirements.

Type	Content
Administrator	Create/Manage schedule
	Manage location: Add new, Edit, Delete
	Manage device: Add new, Edit, Delete
	Manage Users: Create, Edit, Remove
	Manage Account: Login, Change password, Update information
	Control Device: Turn on/off, Adjust temperature, Set Thresholds
	Monitor Device: Search device, View device status, Scan active device
	View reports: View, Export
System User	Personal account management
	Control Device: Turn on/off, Adjust temperature
	Monitor Device: Search device, View device status

3 System Design and Implementation

3.1 Network and Transmission

The system operates according to Master-Slaves architecture and transmits and receives information via radio signals. The SIM20A radio frequency communication module is used for communication between eSave Box and eSave TC with maximum distance about 1.5 km without repeaters, and more repeaters are used. The number of devices according to the datasheet can be up to more than 1000 devices, ensuring realworld usage [15].

3.2 Hardware Design

The designs of the eSave Box, eSave TC, eSave Repeater modules are described in Figs. 2, 3 and 4. The eSave Box device runs on the same 220 V AC source of the air conditioner, through an adapter that provides 3.3 V DC power supply to the control circuit. The STM32F100C8T6B microcontroller is selected [16]. This microcontroller is cheap, small in size and supports 2 UART ports: 1 port for communication with the SIM Module, the other port for communication with the PC (required for the eSave TC module).

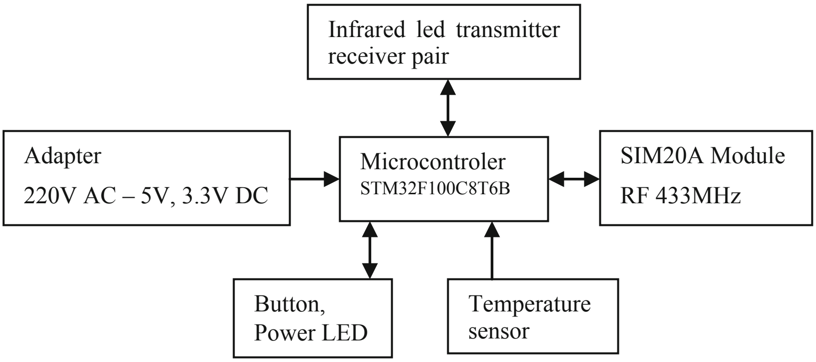

Fig. 2. Design of eSave Box.

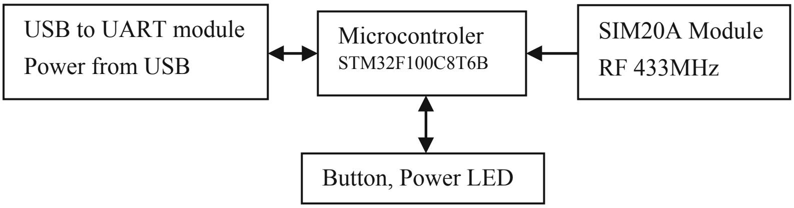

Fig. 3. Design of eSave TC.

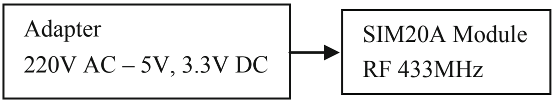

Fig. 4. Design of eSave Repeater.

On the module there is an infrared receiver LED to learn the basic commands of air conditioners: turn on, turn off, increase temperature, reduce temperature, etc. It also has an infrared transmitter LED to be used in control mode. A red LED indicates the system's power status and microcontroller status. An LM35 temperature sensor placed directly at the air outlet of the air conditioner can determine whether the air conditioner is on or off and the current temperature [17]. For communication, a SIM20A module is used. This module operates in the 433 MHz frequency band, multi-channel with low power. It include a high speed MCU and high performance RF chip for the ideal receiving sensitivity, programmable transmitting power and data rate.

The eSave TC design is similar to the eSave Box, but it does not require the two infrared LEDs or temperature sensors. This module takes power from the computer's USB port and uses an additional conversion cable from USB to UART and vice versa.

The eSave Repeater has the simplest design. It does not use any infrared or sensor LED. The purpose of this module is only to repeat the signals to ensure the quality and to extend the distance between the eSave Box and Server.

All three modules share the same PCB, while different modules can omit some unnecessary components.

When installing the eSave Box into an air conditioner, the user can press the Button to switch it to Learning mode. Project the air conditioner's original remote controller into infrared receiver to let it learn the basic commands. The commands are obtained as a sequence of bits and will be stored in a fixed position in the EEPROM memory. After completing the commands, press the button again to go to Control mode. From then on, the eSave Box and the PC will operate under Master - Slave model, the eSave Boxes are the Slaves and the PC is the Master of the system.

3.3 Command Format

In the Master/Slave model, the data format for transmission and reception between Master and Slave is designed as follows:

The Data Transfer from Master to Slave

The data transfer from Master (eSave TC) to Slave (eSave Box) has 4 fields:

[Type] [Method] [ID] [CMD]

[Type]: 1 byte, indicates type of device such as air conditioner, light
- d air conditioner
- c light (for future development)

[Method]: 1 byte, indicates the kind of transmission
- D not through transmitter
- R through transmitter

[ID]: logical ID, between 000 - 999

[CMD]: 1 byte, a character that indicates the action
- 'A' turn on
- 'C' turn fan on
- 'E' fan mode: High, Low, and Medium
- 'F' increases 1oC
- 'G' decrease 1oC
- 'H' air-conditioner mode: Heat, Cool, Cold
- 'I' read air-conditioner state: On/Off
- 'K' read fan state: On/ Off
- 'L' current location temperature

The Data Transfer from Slave to Master

The data transfer from Slave to Master has 2 fields:

[Method][Result]
[Method]: 1 byte, indicates the kind of transmission
'D' not through transmitter
'R' through transmitter
[Result]: result of command

All commands are summarized in Table 2.

Table 2. List of commands.

Command	Meaning	Result
A	Turning on	[OK]/[NOT OK]
B	Turning off	[OK]/[NOT OK]
C	Turning fan on	[OK]/[NOT OK]
D	Turning fan off	[OK]/[NOT OK]
E	Choosing fan mode	[OK]/[NOT OK]
F	Increasing 1 Celsius	[OK]/[NOT OK]
G	Decreasing 1 Celsius	[OK]/[NOT OK]
H	Choosing air-conditioner mode	[OK]/[NOT OK]
I	Reading air-conditioner state	[ON]/[OFF]
K	Reading fan state	[ON]/[OFF]
L	Getting temperature	T: [temperature]

3.4 Database Design

The system uses MongoDB for the database [18]. MongoDB eschews the traditional table-based relational database structure in favor of JSON-like documents with dynamic schemas (MongoDB calls the format BSON), making the integration of data in certain types of applications easier and faster. A data model for the eSave system is shown in Fig. 5.

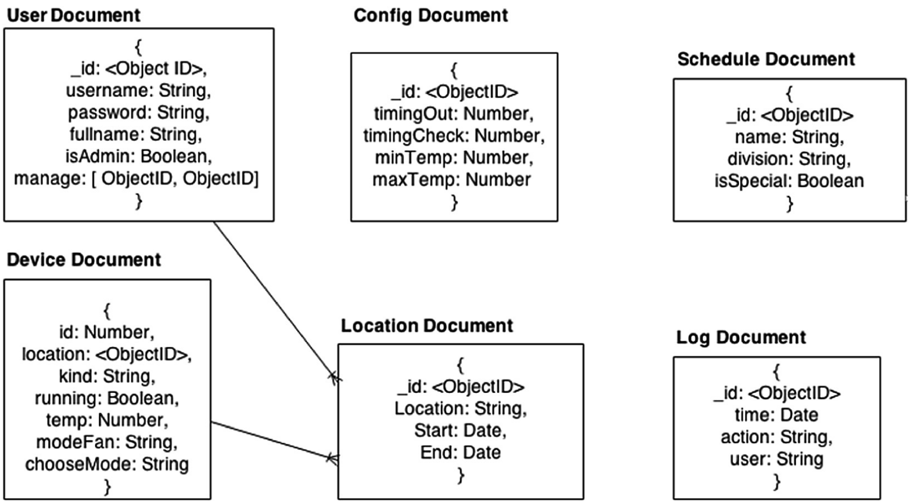

Fig. 5. Data model for eSave database.

3.5 Website Design

Some of the main screens of Web applications are listed below. Figure 6 shows a monitoring screen that monitors the status of all air conditioners. On each detailed window, the system users can turn on, turn off, increase or decrease the temperature. Statistics of usage time and wasted time when the user did not turn off the air conditioner according to the working schedule (when the system does not run in automatic mode) is shown in Fig. 7. The administrator's device management screen is shown in Fig. 8.

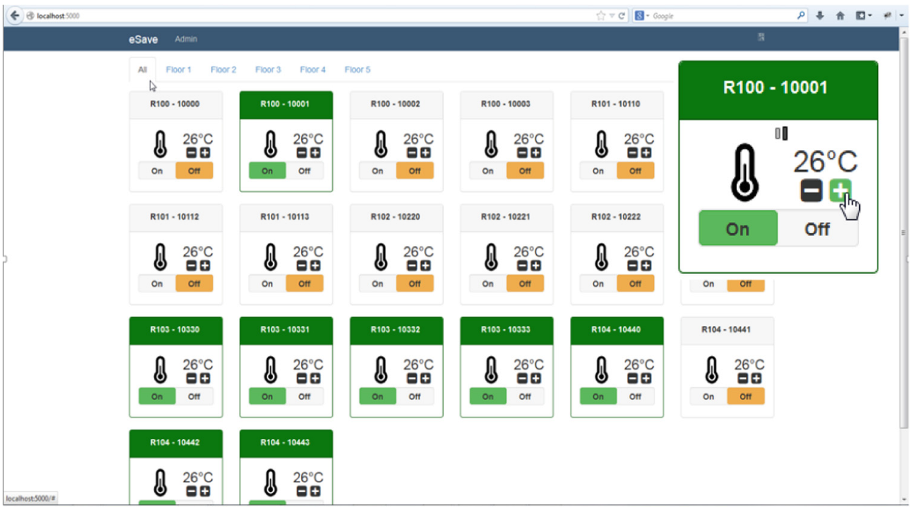

Fig. 6. Monitoring screen.

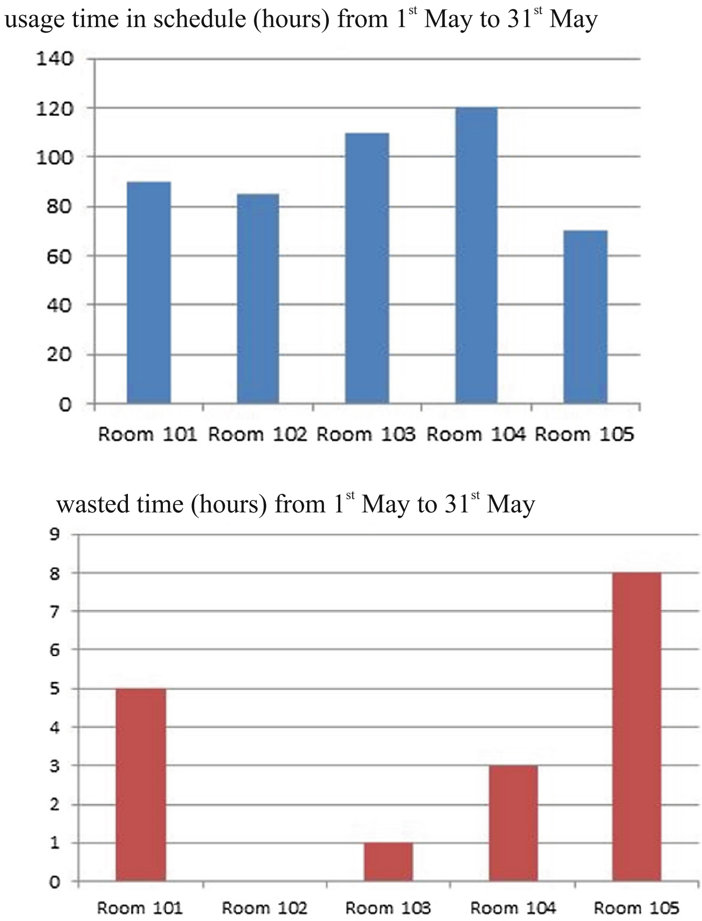

Fig. 7. Statistics of usage time and wasted time.

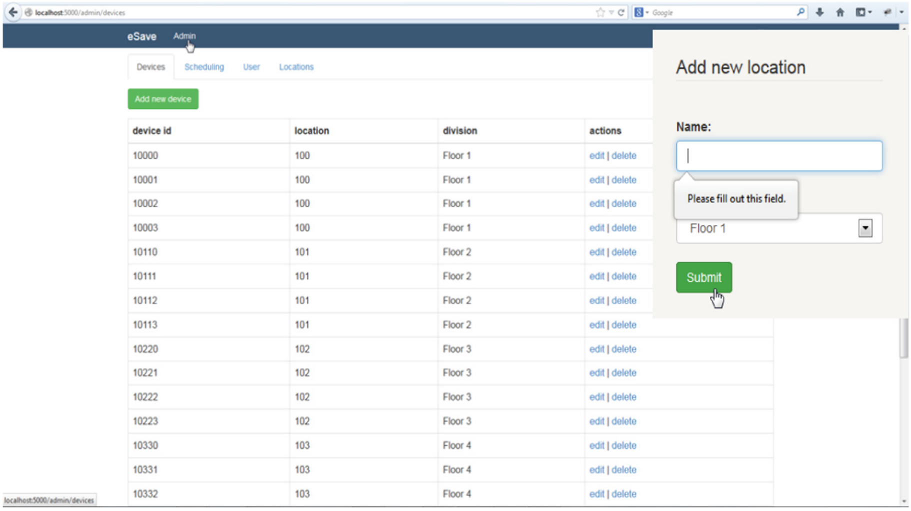

Fig. 8. Device management screen.

4 Conclusion and Perspectives

Energy saving for electrical equipment, especially for air conditioning is a practical and urgent issue. This paper has provided a centralized management, monitoring and control system for air-conditioning equipment at a low cost while still being extendable and easy to deploy. The system can be used for buildings, schools for high efficiency electrical monitor and control with low investment costs compared to integrated solutions of large technology firms, where many functions will be irrelevant where the demand for electricity savings only focuses on a few components. The system hardware can be expanded up to 1000 nodes and a distance of up to several kilometers.

This solution is also fully applicable for similar models, such as high-voltage lighting on roads or in stadiums, swimming pools, etc.

This paper is also a good reference for research directions of IoT [19, 20], Embedded Systems [21, 22], etc.

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