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# Supervisory and Energy Management System of Large Public Buildings

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*Abstract* – **Buildings are important contributors to energy consumption accounting for around one-third of energy consumed in cities, where large public buildings are the dominant energy consumers and energy consumption might be significantly decreased through Building Energy Management Systems (BEMS). A supervisory and management system for energy conservation in large public buildings is presented in this paper, with a PC or a embedded computer system running a BEMS software designed to connected to distributed energy metering system, wireless sensor networks, even conventional building automation (BA) systems. The supervisory and management software consists of information inquiry, energy consumption metering, energy efficiency analysis and decision support subsystems. The system framework is introduced with development and application of the software described in detail.**

*Index Terms – Building Energy Management System; Energy Conservation; Building Automation System; Wireless Sensor Network*

## I. INTRODUCTION

Energy conservation has always been a major theme of sustainable development for all worlds. It is a common object throughout the world to reduce energy consumption as more as possible. Buildings are important contributors to total energy consumption in China[1], accounting for around 30% of all energy consumed. Energy consumption in buildings, especially the large public ones, has aroused widespread concern for more energy conservation.

At present, China's large public construction area is about 500 million square meters, although 4% less than the total of urban ones, with almost 1000 billion kWh per year in electricity consumption accounted for 22% of total electricity consumption in cities. In order to build energy-efficient and environmental-friendly cities, energy conservation in large public buildings is a feasible solution in both technical and management background.

The building with a total floor area over 20000 $m^2$ occupied by public authorities or public service institutions is often considered as a large public building. Different type of buildings work with different energy consumption, especially the large public ones. A detailed investigation was conducted on large public buildings, revealing that large public buildings

unit energy consumption is as about 10 times as the ordinary living ones [2]. Therefore, the large public buildings have great potential for energy conservation.

There are many electric equipments in large public buildings, the energy consumption are different from each other too. The Hong Kong Polytechnic University had conducted a statistical report on the energy consumption of 16 hotels in 1998. According to the report, air-conditioning and lighting are important contributors to total energy consumption accounting for around two-third [3]. Beijing Tsinghua University and Shanghai Tongji University did a similar survey and proposed same conclusion with air-conditioning and lighting's energy consumption [4][5]. If comprehensive measures are taken to improve air-conditioning and lighting, the power consumption of existing building might be reduced by 30%~40%.

A building energy management system is developed for energy consumption monitoring and management, with main installation target of air-conditioning and lighting etc. Through the integrated monitoring of the environment variables and power consumption, the building energy-consuming characteristics and efficiency are analysed. The operation of energy system is expected to be optimized with energy consumption decrease and better efficiency.

This paper is organized as follows. Section II outlines the design and structure of proposed building energy management system. The methods of access to power and environment information are discussed in section III and IV. The development of desktop software is given in section V. Finally, brief conclusion is given in section VI.

## II. BUILDING ENERGY MANAGEMENT SYSTEM

Building energy management system (BEMS) is a system with combination of both intelligent and green building technology. In order to achieve being intelligent, energy-saving, green and other environmental objectives, the unified management of energy consumption is designed to improve the operation of the equipments and reduce the energy consumption. There are many energy modules in building, such as HVAC systems, lighting systems, elevators and office equipments, etc. In operation, these devices may be controlled or disturbed by people, environment and so on. Therefore, it is necessary to set up various measurement and control unit in the building, with the system temporarily deviating from the

optimal or normal operation status to be corrected back to the ideal status.

Building energy management is the process of monitoring and controlling the operating systems within a building. Though specific components may differ, these operating systems might be heating and air conditioning, ventilation, lighting, power, security, and alarm systems. Through the BEMS real-time monitoring, the following results can be achieved：

*1)* The level of building management is improved.
*2)* The inefficient equipment can be found.
*3)* Identify abnormal energy consumption.
*4)* Lower peak electrical demand.

The ultimate goal of BEMS is to make the building for near optimal consumption of energy, leading to energy conservation and high-quality indoor environment.

### A. System operational data

BEMS establishes an energy information database and processes the data to perform building energy saving by supervising, analyzing the amount and efficiency. Acquisition of energy data is the key to the energy conservation supervision system.

According to the Guideline of Energy Consumption Data Acquisition in National Office Buildings and Large Public Buildings[12], power should be divided into four parts: air-conditioning power, lighting and socket power, dynamical power, special power. Any of them can also be divided into multiple sub-items according to the actual conditions.

Environmental information is the direct performance of energy efficiency. The temperature and humidity reflect the energy utilization of air-conditioning system. Illumination intensity reflects the energy utilization of lighting system. While environment indoor is sensitive to the disturbance, such as environment outdoor and people indoor, it should be monitored in real time mode.
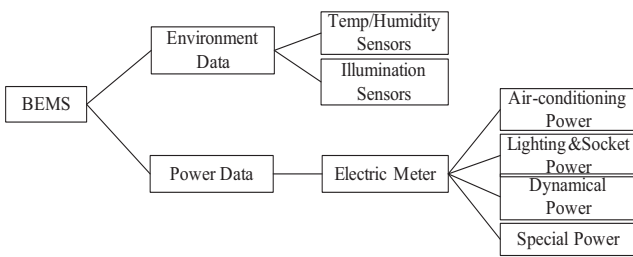
System data classification is shown in Fig.1.



Fig.1 Monitoring Data classification

### B. System Architecture

System adopts hierarchy design idea, is divided into data acquisition, data transmission, data interpretation, performance evaluation, energy optimization, as shown in Fig.2.
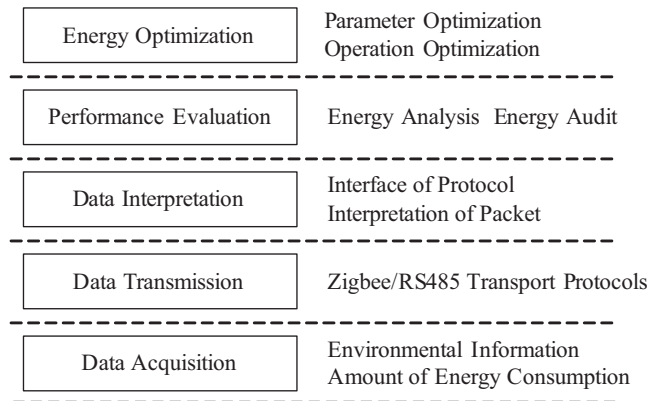


Fig.2 Framework of the system

The first is the data acquisition layer. The operation of equipment could be known by acquiring temperature, humidity, illumination intensity and the amount of energy consumption. Sensor and metering device are in this layer.

The second is the data transmission layer. There are usually two kinds of transmission media: cable and wireless. For a newly constructed building a cable network such as Ethernet, field bus or even a RS485 is preferred for easy pre-installation and more reliable communication. However, there are difficulties to install a new communication wires through various parts of a constructed building. wireless transmission is the first consideration for flexibility and connection. Wireless sensor network such as Zigbee systems are a new and practical option. The WSN system can even be used temporarily for regional monitoring.

The third is data interpretation layer. Data interpretation layer will be a preliminary process the field data, and save it to energy information database for the upper use.

The fourth is performance evaluation layer. According to the field data, it makes an assessment of the level of energy use and finds the defect of the energy consumption system.

The fifth is energy optimization layer. It improves the energy consumption system and optimizes the operation of the equipments that the consumption is reduced and the efficiency is raised. Optimization measures including optimal start/stop management, dynamic optimal settings of operation parameters, peak demand control, etc. A building environment and energy consumption model need to be built beforehand which is normally very important for system analysis and evaluation.

### C. Performance Units

The BEMS system including four units: monitoring system, metering system, control system and analysis system, as shown in Fig.3.

*1)* Monitoring System. Acquire temperature, humidity, illumination intensity etc; indicating the indoor quality of the air and the effect of energy utilization.

*2)* Metering System. Metering air-conditioning power, lighting and socket power, dynamical power, special power; reflect the amount of energy consumption.

*3)* Control System. Optimize the operation of equipments through the building automation system.

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*4)* Analysis System. Provide energy analysis or evaluation report; provide the advice for energy-saving approaches.
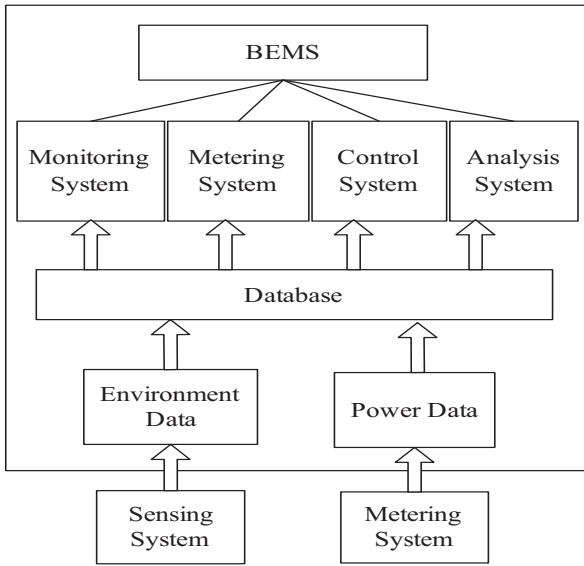


Fig.3 Performance units of the system

In real-time energy control, when BEMS detects abnormal energy utilization through on-line monitoring, it could adjust the running strategies of devices that ensure a comfortable indoor environment and eliminate energy loss. The control flowchart is shown in Fig.4.
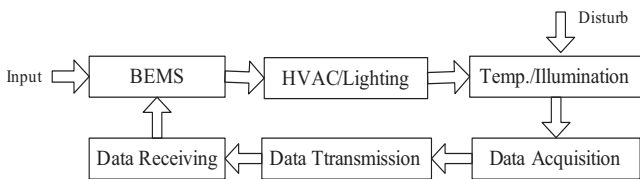


Fig.4 Control flowchart of the system

## III. ACQUIRING THE AMOUNT OF ENERGY

The amount of the energy consumption could be acquired by installing metering devices in the building, but through modern Building Automation (BA) system to gain the data is more convenient. The BAS from Honeywell, for example, provides the quantitative information of the energy consumed by the equipments in the building. Data could be exchanged between the BEMS and Honeywell EBI server through ODBC or NetAPI.

ODBC is Microsoft's strategic interface for accessing data in a heterogeneous environment of database management systems. Based on the Call Level Interface specification of the SQL Access Group, ODBC provides an open, vendor- neutral way of accessing data stored in a variety of proprietary personal computer, minicomputer, and mainframe databases.

The communication between BEMS and EBI server is shown in Fig.5.
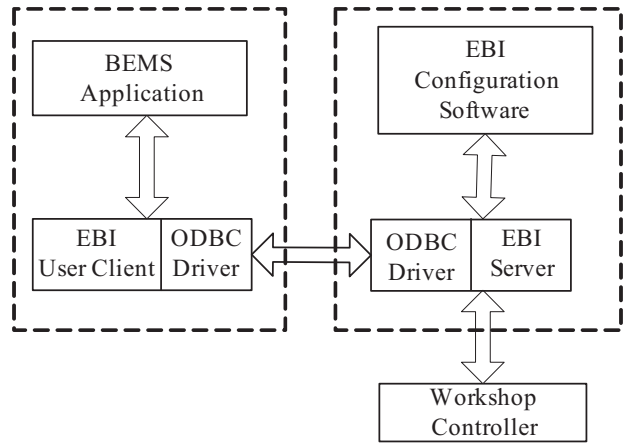


Fig.5 The communication between BEMS and EBI server

The realization of the interface module inside BA is aimed to Honeywell EBI, using EBI ODBC integration approach. BEMS read the electricity records in EBI database and store them in real-time database. The interface of the dynamic link library module is shown in Fig.6.
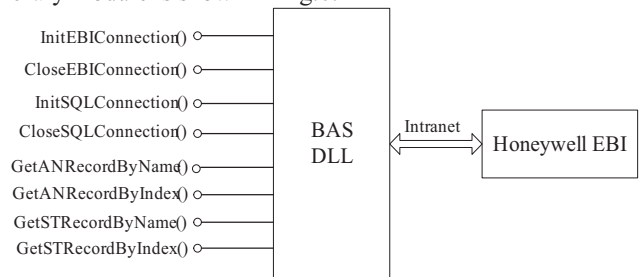


Fig.6 The interface of BAS

## IV. ACQUIRING ENVIROMENT INFORMATION

Emerging wireless sensor network technology promises to enable flexible and enhanced monitoring of conditions in and around buildings [6]. Wireless data communication between the sensor and a viewing or storage location opens up a range of possibilities because of the ease and the low-cost by which the sensors can be deployed. There is no need to get signal wires through various parts of a constructed building temporarily or permanently, and significant timesavings can be obtained for setting up the sensors [7].

The development of wireless sensor networks (WSN) was motivated by military applications such as battlefield surveillance. They are now used in many industrial and civilian applications, including industrial process monitoring and control, machine monitoring, environment monitoring, healthcare applications, home automation, and traffic control.

A wireless sensor network adopted in the BEMS consists of spatially distributed autonomous sensors to cooperatively monitor environmental conditions, and then transfers the information to the BEMS centre. The scenario is shown in Fig.7.
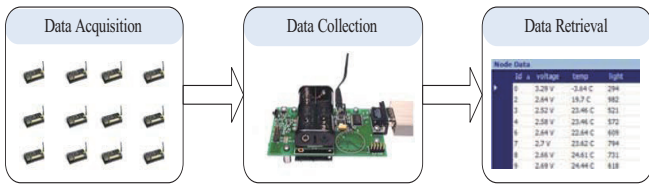
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Fig.7 The scenario of wireless environment monitoring

The wireless sensor node is composed by the MTS Series multifunction sensor board from Crossbow (Fig.8-a) and the Micaz transceiver based on TI CC2420 RF processor (Fig.8-b). Gateway to communicate with the central node is MIB520 (Fig.8-c), which is also from Crossbow.



Fig.8  (a) Sensor board   (b)RF processor   (c) Gateway

Mesh and star are most commonly used topology in WSN. Mesh networking describes a topology of a sensor network in which each sensor node communicates with its neighbours and can relay messages from that neighbour through the network. A contrasting topology would be a star network, in which each sensor node communicates directly to a base station that collects the data. The benefit of the mesh networking scheme lies in the fact that each sensor node need only communicate with a neighbouring node as opposed to directly to a base station. The most advanced mesh networking schemes allow the sensors to arrange themselves in an ad-hoc manner, so that the routing path of a message can change once the conventional route fails. This type of system adds robustness to the sensor network and permits it to be easily expanded. The topology of mesh network is shown in Fig.9.
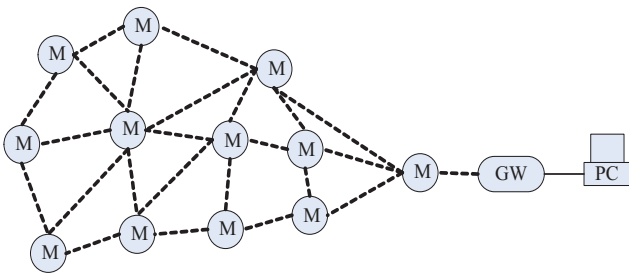


Fig.9 Mesh topology

To accomplish the mesh network, the software platform that is selected for programming the sensor nodes is the TinyOS operating system along with the nesC programming language. These platforms are developed at the University of California at Berkeley especially for sensor nodes, and an active user community has developed various software tools [8]. XMesh is an component library developed by Crossbow. The node is programmed with the components in XMesh, such as Main, XMTS300M, QueueSend, TimerC, XmeshBinaryRouter, NoLeds, HPLPowerManagementM, Voltage, PhotoTemp,

Sounder, GenericCommPromiscuous, etc. The wiring between these components is shown in Fig.10.
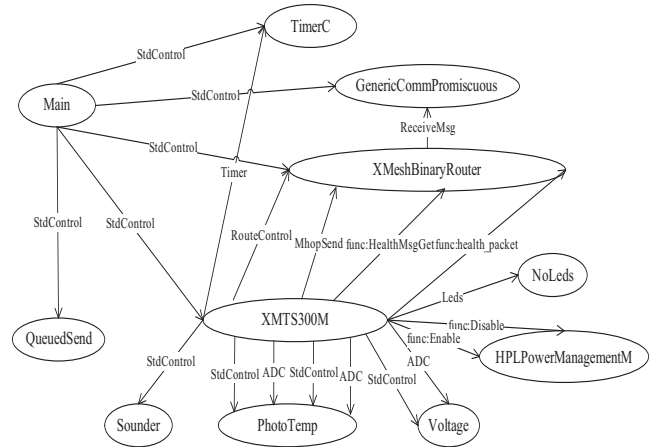


Fig.10 The relationship of the components in node

At the gateway, the acquiring data of all nodes eventually flood to the gateway node sink0, and then send to the host computer through the gateway. XServer have many components to accomplish it, such as Main, Xheartbeat, XmeshBaseM, XmeshBinaryRouter, NoLeds, XcommandC, etc. The wiring between these components is shown in Fig.11.
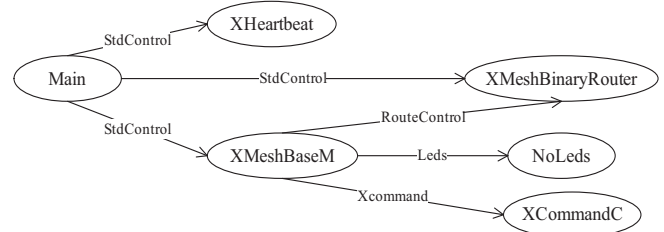


Fig.11 The relationship of the components in gateway

Data collection takes place at desktop computer. It receives raw data from UART. The raw data packet is described in the following table 1.

TABLE 1  RAW DATA PACKET

| SYNC_BYTE | Packet Type | Payload Data (TinyOS Message) | SYNC_BYTE |
|---|---|---|---|
| 0 | 1 | 2 ··· n-1 | n |

*1)* SYNC_BYTE: Packet frame synch byte, always 0x7E;
*2)* Packet Type: There are 5 packet type: user packet with no ACK required P_PACKET_NO_ACK(0x42)(,); user packet with no ACK required P_PACKET_ACK (0x41);  the ACK response to a P_PACKET_ACK packet P_ACK(0x40); an unknown packet type - P_UNKNOWN(0xFF).
*3)* Payload Data: TinyOS Message. Which is described bellow.
*4)* SYNC_BYTE: Always 0x7E.

The payload data will typically be a type of TinyOS message, as defined by the struct TOS_Msg in the file

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\tos\types\AM.h. The TOS_Msg data packet is described in the following table2.

TABLE 2  TINYOS MESSAGE

| Address | | Message Type | Group ID | Data Length | Payload Data | CRC | |
|---|---|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 | 5 ⋯ n-2 | n-1 | n |

*1)* Address: Broadcast Address (0xFFFF)-message to all nodes; UART Address (0x007E)-message from a node to the gateway serial port; Node Address-the unique ID of a node to receive message.

*2)* Message Type: Active Message unique identifier for the type of message it is. Typically each application will have its own message type. Such as AMTYPE_XSENSOR=0x32, AMTYPE_XMULTIHOP=0x33, etc.

*3)* Group ID: Unique identified for the group of motes participating in the network. The default value is 0x7D. Only motes with the same group id will talk to each other.

*4)* Data Length: The length in bytes of the data payload. It does not include the CRC or frame synch bytes.

*5)* Payload data: The actual message content. The data resides at byte 5 to byte 5 plus the length of the data( n-2). The data will be specific to the message type.

*6)* CRC: Two byte code that ensures the integrity of the message. The CRC includes the Packet Type plus the entire unescaped TinyOS message.

In the Mesh topology network, mesh message and senor message are added before the payload data. They are described in the table3.

TABLE 3 MESH MESSAGE AND SENSOR MESSAGE

| Source Address | | Origin Address | | Sequence Number | | Application ID | Sensor Board ID | Sensor Packet ID | Parent | | Data Payload |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | ⋯ |

We receive a raw data packet from UART as follow:

7E 00 33 7D 1B 00 00 01 00 00 00 00 83 81 7E 00

6D 01 1D 02 E2 01 C8 00 00 00 00 00 00 00 00 00

It can be known that:

*1)* Address=0x007E, the packet is from UART;

*2)* Message Type=0x33, it is a multi-hop message;

*3)* Group ID=0x7D, Data Length=0x1B, the payload data has 27 bytes;

*4)* Sensor Board ID=0x83, the data is sampled by MTS300 sensor board and the value of the variable defined by MTS300 is voltage=0x016D，thermistor=0x021D，light=0x01E2，microphone=0x00C8. According the formula (1) [9], it can be known that the current room temperature is 27.4℃.

$$Temperature = \frac{1}{a + b \times \ln\left(R_{thr}\right) + c \times [\ln(R_{thr})]^3} - 273.15 \quad (1)$$

$R_{thr} = R_1(ADC\_FS - ADC) / ADC$

$a = 0.00130705$

$b = 0.000214381$

$c = 0.000000093$

$R_1 = 10000$

$ADC\_FS = 1023$

$ADC = thermistor$

## V.  SUPERVISORY SOFTWARE

Energy management software needs to have a good collaborative multi-system capable of providing a variety of access patterns and supporting a variety of data objects to achieve system integration and expansion of buildings. The .NET Framework is adopted to develop the desktop software now while a C++ is chosen for embedded system in the future. The .NET Framework raises the abstraction level for applications that the software programmed in .NET has a good compatibility.

The supervisory software of BEMS should provide both C/S mode for local management and B/S mode for remote management. Traditionally, they should be de developed separately. But the WPF provides a ease approach to develop them together.

WPF is Microsoft's latest technology for creating graphical user interfaces, whether they consist of plain forms, document-centric windows, animated cartoons, videos, immersive 3D environments, or all of the above [10]. WPF technology provides a new development model, the interface display and functional logic codes are separated, that the desktop applications and browser applications are integrated. The WPF is selected to build the software system. Although WPF is a good choice for application, many standard controls do not exist at present. Window Forms has useful controls that WPF lacks. Window Forms is also chosen to compensate for missing features in WPF when developping the desktop software. A WPF application host Windows Forms controls inside. The subsystems, monitoring system, metering system, control system and analysis system are developed in Window Forms.

In the system, all functional modules require frequent data manipulation, the design of the data flow is very important. The real-time database receives the data from the interfaces of the subsystems and stores it in the SQL Server database. Users query the data via web server. When the real-time data is queried, the user communicates directly with the real-time database. When the historical data is queried, the user communicates with the historical database. The language to query the data is LINQ. LINQ is an elegant solution for accessing specific data using a query language that is independent of the data source [11]. With LINQ, we can access with the same unified query model a SQL database, an XML file, or even an array. The model of the data flow is shown in Fig.12.
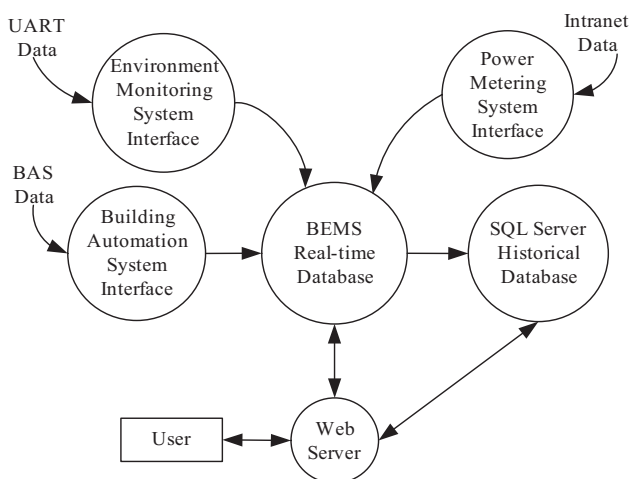
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Fig.12 The model of the data flow

## VI. CONCLUSIONS AND FUTURE WORK

In this paper, a new energy conservation supervision system and strategies for energy management in large public buildings are presented. An improving building energy management system is designed to maintain a comfortable environment and save the electrical energy. Wireless sensors are deployed to monitor the environment indoor temporarily and the BAS is integrated into the BEMS. The BEMS system developed to improve operation of the equipments, promote the energy efficiency and cut down energy consumption in the large public buildings. Future work will include optimal modeling, a complex algorithm to adjust the automation system, a uniform communication standard with different systems, and software for retrofit decision.

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