Energy-Saving and Management of Telecom Operators’ Remote Computer Rooms Using IoT Technology

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ABSTRACT In order to achieve the energy saving and management, this article proposes an IoT-based energy-saving and management system for Telecom operators’ remote computer rooms (RCRs). Firstly, a management system based on IoT technology for RCRs is designed. By using technologies such as embedded systems, sensor technology and Java Web, this system realizes equipment management and real-time data visualization of RCRs. Then, a simple but effective air conditioner energy-saving algorithm, called ET algorithm, is developed. Without causing high investment cost, ET algorithm minimizes the energy consumption of air conditioners which accounts for nearly 40% of total consumption, and thus improves the overall energy efficiency of RCRs. Moreover, the proposed system has been implemented at many Telecom operators’ RCRs distributed at different regions in Guangdong Province of China, and stably operating for more than two years. Experimental results show that the proposed system not only effectively manages and monitors RCRs, but also achieves 16.64% energy-saving effect.

INDEX TERMS Internet of Things (IoT), energy saving, management system, operators, remote computer rooms.

I. INTRODUCTION

With the advent of 5G era, energy consumption in operator field has been growing rapidly, due to an explosion in network flow of base station. It is reported that the recognized energy-saving potential for Chinese three major operators in 2014 was approximately 6.71 million tons of standard coal, equivalent to 2% of the total electricity consumption in China [1]. Researchers predict that the annual growth rate of energy consumption in operators’ remote computer rooms (RCRs) will reach 7.5%-20% [2]. However, since electricity production mainly relies on burning fossil fuel, increasing energy consumption aggravates CO₂ and pollutant emissions, which bring great threat to nature [3]. Therefore, the energy saving and carbon emissions reduction of operators’ RCRs is a very meaningful issue.

Generally speaking, a computer room (CR) mainly consists of information technology (IT) equipment (including servers and storages) and other service facilities such as air conditioners (ACs), ongoing power supply, and lighting system [4]. In order to ensure the high-efficient operation of IT equipment, ACs usually work 24/7 to maintain the required indoor temperature [5]. Recent studies indicate that the energy consumed by ACs accounts for nearly 40% of the total energy consumption of a CR [6], [7]. Hence, reducing the energy consumption of ACs is very significant for the energy saving of operators’ RCRs.

Except for energy-saving issue, the management and maintenance of RCRs, especially for that in suburbs, is another challenging problem for operators. Without remote management system, engineers usually spend tremendous time and effort on the fault diagnosis of equipment in RCRs distributed across different regions, resulting in huge operation and maintenance cost.
TABLE 1. Comparison of some representative literatures.

|                     | Energy-saving | Management |
|---------------------|---------------|------------|
|                     | Practicability| Contains algorithms? | Energy-saving rate | Investment cost | Stability | Convenicne | Remote control | Alarm function |
| Delfani et al. [8]  | Yes           | No          | 55%         | High            | NA        | NA         | No            | No            |
| Chen et al. [9]     | Yes           | No          | 7.3%        | Low             | NA        | NA         | No            | No            |
| Ma et al. [10]      | Yes           | No          | 56.9%       | High            | NA        | NA         | No            | No            |
| Chio et al. [12]    | Maybe         | Yes         | 8.92%       | NA              | NA        | Maybe      | No            | No            |
| Lee and Tsai [13]   | Yes           | Yes         | 9.12%       | Low             | Maybe     | Maybe      | Maybe         | No            |
| Yang et al. [16]    | Yes           | No          | No          | NA              | Yes       | Yes        | Yes           | Yes           |
| Nakamura et al. [17]| Maybe         | Yes         | 6.6%        | NA              | Yes       | Maybe      | No            | No            |
| Shoukourian et al. [19]| Yes     | No          | No          | NA              | Yes       | Yes        | No            | Maybe         |
| **The proposed system** | **Yes**      | **Yes**     | **16.64%**  | **Low**         | **Yes**   | **Yes**    | **Yes**       | **Yes**       |

Existing researches either focus on reducing the energy consumption of ACs, or on developing management system for RCRs. However, few literatures achieve both energy-saving and management purpose of RCRs. Table 1 summarizes some representative works from two aspects: 1) energy-saving and 2) management.

For energy savings in ACs, researchers have proposed various schemes such as designing novel energy-conserving equipment, utilizing renewable energy, and adopting intelligent control algorithms, etc. Delfani et al. [8] decreased the energy consumption of a packaged unit AC by using an indirect evaporative cooler to pre-cool air. Chen et al. [9] improved the energy efficiency of a split-type AC by adding an energy-saving device. Ma et al. [10] investigated the feasibility of solar-assisted air conditioning systems for energy savings in office buildings. Shahnawazahmed et al. [11] proposed a fuzzy logic based thermostat setting strategy to preserve the indoor temperature and humidity and to lower the energy consumption of a central AC compressor. Chio et al. [12] proposed a fuzzy temperature control scheme for multi-unit ACs. By controlling the operational number of compressors and fans, the energy efficiency of the ACs can be increased. Lee and Tsai [13] developed a cloud-based AI platform that can run different control algorithms and remotely control ACs. Experimental results show that Fuzzy-PID control and model predictive control (MPC) are the two most energy-efficient control methods. However, the investment cost and implementation difficulty of above methods are much higher than that of controlling ACs’ working time. Hence, adjusting the working time of ACs without sacrificing the required temperature is a simple and cost efficient way to lower the energy consumption of ACs.

For the management of remote CRs or data centers (DCs), existing references have developed some remote management systems for CRs or DCs, which have good management performance but low or even no energy-saving ability. Zhang et al. [14] presented a CNN-based automatic collection and management system for CRs, which only realized the image acquisition and classification of devices. Xiang et al. [15] designed an intelligent environment monitoring system to manage and maintain power equipment in DCs. However, this system cannot collect and display energy consumption data of DCs. A cloud green energy management system, proposed by Yang et al. [16], is a good example for displaying and analyzing electricity consumption behaviors of various equipment. However, they need to improve these behaviors by developing energy-saving strategies. Nakamura et al. [17] presented a data center infrastructure management system to minimize energy consumption by the coordinated control of equipment. Unfortunately, the reduction rate of total power consumption is relatively low. Marcos-Jorquera et al. [18] proposed a smart monitoring model for DCs based on embedded technology, which realized the management of equipment. Nevertheless, this model does not involve any energy-saving algorithms. Shoukourian et al. [19] presented a toolset, named Power-DAM, able to collect and analyze all kinds of energy-related data from HPC data centers, but incapable of boosting energy efficiency.

To the best of our knowledge, this study provides the following two contributions: (1) we propose an IoT-based management system for Telecom operators’ RCRs. By using technologies such as embedded systems, sensor technology and Java Web, this system enables convenient equipment management and real-time data visualization of RCRs. (2) we design a simple but effective air conditioner energy-saving algorithm, called ET algorithm. Without causing high investment cost, ET algorithm minimizes the energy consumption of ACs by controlling their working time, and thus improves the overall energy efficiency of RCRs.

The rest of the paper is arranged as follows. Section II gives the architecture of the proposed system. Section III and IV describe the hardware and software design of the proposed system, respectively. Section V introduces a simple ET energy-saving algorithm. Section VI evaluates the experimental results. Finally, Section VII concludes the paper and provides directions for future research.
II. ARCHITECTURE OF THE PROPOSED SYSTEM

A. OVERALL FRAMEWORK

Based on the understand of primitives and elements of IoT in [20], we design the architecture of an IoT-based energy-saving and management system, as shown in Figure 1. The proposed system can be divided into three layers [21], [22]:

1) Perception layer: this layer has sensors and actuators to interact with the physical environment of RCRs. Specifically, sensors collect environmental information and actuators effect a change in the environment. Consider the stability and reliability of the proposed system, Modbus protocol, a standard industrial communication protocol, is adopted to connect sensors and actuators with an ARM9 embedded system via RS485 bus.

2) Network layer: this layer mainly consists of an ARM9 embedded system, a router, a Web server and a database. ARM9 is a bridge that connects underlying sensors and actuators with the Internet. A router is used to construct CR LAN (local area network) and transmit the collected data to Web application server through TCP/IP protocol. Besides, various operation data of RCRs are stored in a database, which contributes to analyzing energy efficiency, diagnosing equipment fault, and mining big data of RCRs;

3) Application layer: This layer includes an energy management and service platform (EMSP) which can execute on all kinds of communication devices (such as PC, tablet and cellphone). Based on this platform, authorized users can conveniently monitor and manage the real-time running condition of various equipment in each RCR, saving manpower and material resources.

Next, we further introduce the main components of the proposed system, including sensors, actuators, ARM9 embedded control system, and EMSP.

B. SENSORS AND ACTUATORS

In the proposed IoT system, sensors are smart meters and temperature modules. And they are used to collect electricity usage and temperature of RCRs, respectively. While an infrared module, as the actuator, is adopted to learn infrared instructions of different air conditioners and to control them, so as to adjust the indoor temperature of RCRs. The prototype and design of each sensor and actuator will be described in detail in the next section.

C. ARM9 EMBEDDED CONTROL SYSTEM

The main controller unit (MCU) of the proposed system is an industrial-grade ARM embedded development board, which is produced by HTNICE Co., Ltd [23]. Due to its flexible daughter-mother-board design, it is easy and convenient for engineers to maintain and upgrade. The daughterboard features an ARM9-series Samsung’s S3C2416 processor with a 128MBytes DDR2 SDRAM and a 256MBytes NAND Flash. And the motherboard offers 8 serial ports, 2 USB interfaces, 1 Ethernet port, and many other peripherals.

Furthermore, this ARM board is also the decision trigger that implements control strategy to satisfy the energy-saving purpose of RCRs.

D. ENERGY MANAGEMENT AND SERVICE PLATFORM

Based on Web and database technology, EMSP is developed, which mainly includes four modules: a) system management module, b) intelligent information module, c) remote control module, and d) alarm module, as shown in Figure 2.

System management module includes the management of department, user, role authority and log. Super administrator can add, delete, modify and search any information of any department, user, role or log in the whole platform, and it also empowers local administrators with the authority to administrate the RCRs of their own region. However, ordinary users can only look over the information of some specific RCRs.

Intelligent information module mainly offers map display, real-time and historical data, and device information. The geographical distribution of all RCRs using the proposed system will display in Baidu Map. By selecting a specific RCR, users can examine device information to ensure each device operates normally. Moreover, real-time and historical data such as power, voltage, current, electricity consumption and indoor temperature are available for analyzing energy efficiency.

Remote control module consists of remote-controlling air conditioners and setting up energy-saving strategies. According to the real-time operation situation of a RCR, administrators can remotely and manually turn on/off ACs and adjust temperature set point of ACs. Besides, engineers can also analyze historical electricity usage and predict future energy consumption according to the change of climatic conditions and indoor temperature, so as to design an automatic energy-saving control strategy to reduce energy consumption and liberate manpower.
Alarm module is responsible for publishing real-time alarm information and checking historical alarm records such as temperature abnormality, PUE overload, and ARM embedded system disconnected, etc.

III. HARDWARE DESIGN OF THE PROPOSED SYSTEM

Figure 3 shows the connection diagram between each hardware module. It can be seen that smart meter 1, 2 and 3 are responsible for collecting the electricity data of AC1, AC2 and rectifier, respectively. Note that a separate smart meter is needed for each AC, because ET algorithm needs to know its individual energy consumption to determine how to control ACs. Each smart meter is connected with city grid by three-phase alternating current (zero line is ignored) and transmits the collected data to ARM embedded system through RS485 bus. An infrared module, as an actuator, wirelessly controls two ACs to realize the adjustment of indoor temperature of RCRs. While temperature modules measure the temperature of equipment and indoor air. Table 2 summarizes the main hardware components of the proposed system.

| Category     | Hardware components | Description |
|--------------|---------------------|-------------|
| Sensors      | Smart meter         | Collect electricity data by using an electrical energy measurement chip ADE7758 |
| Temperature  | Temperature module  | Acquire temperature data by using DS18B20 |
| Actuators    | Infrared module     | Control ACs by infrared receive-transmit circuits |
| Aggregators  | ARM board           | A bridge that connects sensors and actuators to the Internet |

A. SMART METER

The prototype of smart meter is shown in Figure 4. By using a transformer to seize up the power line, a smart meter can sense the current, voltage, power and power factor of an air conditioner, and calculate its energy consumption. Then, the smart meter will transmit all electricity data to ARM board via RS485 bus. Note that this smart meter is designed by our research team, which has been applied to our previous work [24] and shows excellent performance.

FIGURE 2. Overall framework of EMSP.

FIGURE 3. Hardware connection diagram of the proposed system.

TABLE 2. Main Hardware Components of the proposed system.

FIGURE 4. Prototype of smart meter.
B. TEMPERATURE MODULE
The prototype of temperature module is shown in Figure 5. It can be found that the temperature module first measures indoor temperature by DS18B20 sensor (connected to J2 in Figure 6) and then transmits the measured temperature data to ARM board via RS485 bus.

![Figure 5. Prototype of temperature module.](image1)

![Figure 6. Temperature acquisition circuit.](image2)

Figure 6 shows the temperature acquisition circuit of temperature module. By inserting the DQ pin (Data in/out) of DS18B20 into port 2 of J2, we connect DS18B20’s data line with PA0 port of STM32F030, realizing the communication between them. All sensors and actuators in the perception layer communicate with ARM embedded system based on Modbus protocol [25], which mainly relies on RS485 cable. Unfortunately, STM32F030 does not offer RS485 interface. As a result, we use SP3485, a RS485 transceiver, to design an UART to RS485 interface conversion circuit, as shown in Figure 7. We can see from Figure 7 that the pin 1 and 4 of SP3485 are connected to the RXD and TXD of STM32F030, respectively. Note that the data transmission direction of SP3485 depends on the electrical level of TX/RX (pin 14 of STM32F030). For instance, if TX/RX inputs a low-level signal “0”, then RE port will be enabled but DE port will be disabled, resulting in SP3485 receives data from RS485 bus.

C. INFRARED MODULE
Figure 8 shows the prototype of infrared module. It can be seen that the infrared module is mainly composed of infrared ray receive-transmit circuits (as shown in Figure 9) and a STM32F103 microcontroller (as shown in Figure 10).

![Figure 7. UART to RS485 interface conversion circuit.](image3)

![Figure 8. Prototype of infrared module.](image4)

![Figure 9. Infrared ray receive-transmit circuits.](image5)

![Figure 10. A STM32F103 microcontroller.](image6)

Currently, most of operators’ RCRs use ordinary household ACs as their cooling equipment, and the control command of these ACs is actually a string of instruction code. By using a receiving circuit (see top of Figure 9) to learn infrared control command, STM32F103 encodes the learned
commands and uploads them to database. When the indoor temperature of a RCR needs to be modified, corresponding instruction code will be downloaded to the infrared module from database. Then, STM32F103 decodes this instruction and uses a transmitting circuit (see bottom of Figure 9) to send out a 2KB infrared control signal. We can see from Figure 10 that STM32 minimum system communicates with infrared ray receive-transmit circuits via pin 10-12 (please see red box on the left side).

IV. SOFTWARE DESIGN OF THE PROPOSED SYSTEM

A. COMMUNICATION PROGRAMS

As shown in Figure 11, the overall communication flowchart of the software structure of the proposed system mainly includes three parts: 1) communication between EMSP and application server, 2) communication between application server and ARM embedded system, and 3) communication between ARM embedded system and sensors and actuators.

Consider the length of this study, we only introduce the communication programs between application server and ARM embedded system. Based on the three-times handshake of TCP/IP protocol, the network connection between ARM embedded system and server can be successfully established, then the sensor data and infrared control command can be transmitted between them, as shown in Figure 12.

B. DATA FORMAT

In the whole software system, there are many kinds of communication data such as heartbeat data (used for confirming the network connection is normal), sensor data, instruction data and so on. Although they are all aggregated to AMR embedded system using Modbus protocol, the format of different data types varies. In order to clarify this, we give the general format of sensor data and instruction data along with two examples. One is receiving electricity data and the other is transmitting the “turn on/off” command.

Table 3 and 4 indicate the general format of receiving sensor data and transmitting instruction data, respectively. It can be seen that the basic structure of these two kinds of packets is similar but the data in their “ALL_Data” area is different. Figure 13 gives a real example of receiving electricity data from smart meters. According to the data format in Table 3, the valuable data of the received electricity data packet is “12 06 07...00 00” (the data with red underline in Figure 13). They can be understood as follows:

Table: 12 06 07 0E 35 09——2018.12.07 14:53:09
Voltage of A-phase: 00 09 67——240.7V.

......
TABLE 3. General format of receiving sensor data.

| Frame header | Data length | ALL_Data | CRC |
|--------------|-------------|----------|-----|
| 0x0B         | 0x4F        | 0x0B     |     |
| 3 Bytes      | 2 Bytes     | 11 Bytes |     |
|              |             | 1 Byte   |     |
|              |             | 1 Byte   |     |

TABLE 4. General format of transmitting instruction data.

| Frame header | Data length | ALL_Data | CRC |
|--------------|-------------|----------|-----|
| 0x0B         | 0x4F        | 0x0B     |     |
| 3 Bytes      | 2 Bytes     | 5 Bytes  |     |
|              |             | 1 Byte   |     |
|              |             | 2 Bytes  |     |

Energy consumption of A-phase: 00 00 18 6A—62.5kwh.
Energy consumption of B-phase: 00 00 88 9A—349.7kwh.
Energy consumption of C-phase: 00 02 D5 0A—1856.1kwh.
Total energy consumption of three-phase: 00 03 78 AC—2275kwh.

Similarly, Figure 14 gives another instance of transmitting “turn off” command to an air conditioner. According to Table 4, the data underlined in red in Figure 14 can be analyzed as follows:

0B 4F 0B——The frame header of this packet.
08 00——The amount of “ALL_Data” is 8 Bytes.
FF 00 02 D5 0A——Client ID.
01——Command flag (This command is a “turn on/off” command).
02——Data flag (The following are real data).
00——Turn off air conditioners (“01” indicates “turn on”).
F6 6A——CRC code.

C. DESIGN OF DATABASE

The design of database is the core of EMSP, which directly affects the development, operation and management of the whole software system. Due to advantages like small size, fast speed, low cost and open-source, MySQL database is adopted. The main data entities in our database can be divided into three categories: 1) user rights management data, 2) device information data, and 3) fundamental data.

User rights management data consist of four entities, i.e., department table, user table, role table, and menu permission table, as shown in Figure 15. We can see from Figure 15 that the relationship between departments and users is 1-to-N, because a department has N users but a user only belongs to
one department. And the relationship between users and roles is M-to-N, because a user can possess N different roles while a role can also belong to M different users.

As shown in Figure 16, device information data are mainly made up of computer room table, embedded system table, electrical equipment table, and sensors and actuators table. The relationship between computer rooms and embedded systems is 1-to-1, because a computer room only needs one embedded system. However, the relationship between computer rooms and electrical equipment is 1-to-N, which means a computer room may have N different electrical equipment. In this way, all relationships between various entities can be clearly understood.

D. DESIGN OF WEB-BASED EMSP

Based on Java Web technology, database technology and B/S framework, we design the basic structure of EMSP, as shown in Figure 17. In Figure 17, this structure mainly includes presentation layer (Web client), business logic layer (Web application server), and data layer (SQL server). The programs of data layer are automatically generated by code generator. Logical business such as data exchange and data display are processed on the business logic layer. Presentation layer uses JSP to produce dynamic HTML interface, and responds to the request from Web client.

After publishing projects on the Web application server, users can use any networked electronic devices to login in the proposed system by typing a specific website in any browser, as shown in Figure 18. Since no software needs to be installed, it is very convenient and fast for users to manage and monitor numerous RCRs.

V. A SIMPLE AIR CONDITIONERS ENERGY-SAVING ALGORITHM

In this section, we propose a simple air conditioners energy-saving algorithm, called ET (Energy-Temperature) algorithm, which maximizes the energy efficiency of air conditioners without carrying out large-scale transformation on RCRs. Note that this algorithm is currently only applicable to the RCR with two ACs. For RCRs with more than two ACs, the algorithm needs to be further modified.

As shown in Figure 19, the basic principle of ET algorithm is to control the running time of ACs according to their respective energy consumption of reducing 1 °C indoor temperature. Specifically, under the same outdoor temperature,
the air conditioner’s energy-saving controller (ARM9 embedded control system) will collect the energy consumption of each air conditioner when indoor temperature drops from \( T_0 \) to \( T_f \) within a certain time interval \( T \), and calculate the value of \( ET_1 \) and \( ET_2 \) by

\[
\Delta T = T_0 - T_f, \quad ET_1 = \frac{E_1}{\Delta T}, \quad ET_2 = \frac{E_2}{\Delta T},
\]

where \( T_0 \) is initial indoor temperature, \( T_f \) is final indoor temperature, \( E_1 \) and \( E_2 \) are the energy consumed by AC1 and AC2, respectively.

Assume that \( ET_1 / ET_2 = m : n \), the exact working time of AC1 and AC2 can be determined by the following seven rules:

Rule 1: If \( T_{sys} \in [00 : 00, 09 : 00) \) and \( m \leq n \), then \( T_{w1} = T \) and \( T_{w2} = 0 \);

Rule 2: If \( T_{sys} \in [00 : 00, 09 : 00) \) and \( m > n \), then \( T_{w1} = T \) and \( T_{w2} = 0 \);

Rule 3: If \( T_{sys} \in (18 : 30, 24 : 00] \) and \( n - m \leq 1 \), then \( T_{w1} = T \) and \( T_{w2} = 0 \);

Rule 4: If \( T_{sys} \in (18 : 30, 24 : 00] \) and \( n - m > 1 \), then \( T_{w1} = T \) and \( T_{w2} = 0 \);

Rule 5: If \( T_{sys} \in [09 : 00, 18 : 30] \) and \( m < n \), then \( T_{w1} = T \) and \( T_{w2} = T \times \frac{m}{m+n} \);

Rule 6: If \( T_{sys} \in [09 : 00, 18 : 30) \) and \( m > n \), then \( T_{w1} = T \) and \( T_{w2} = T \times \frac{n}{m+n} \);

Rule 7: If \( T_{sys} \in [09 : 00, 18 : 30) \) and \( m = n \), then \( T_{w1} = T \) and \( T_{w2} = \frac{1}{2} T \),

where \( T_{sys} \) is system time, \( T_{w1} \) and \( T_{w2} \) are the working time of AC1 and AC2, respectively.

It is not hard to understand the above rules. In order to minimize the total energy consumption of two ACs, energy-saving controller tends to control the air conditioner with smaller \( ET \) to work longer time. Because, the smaller \( ET \) of an air conditioner is, the less energy for reducing 1 °C indoor temperature it consumes, and the higher energy efficiency of that air conditioner is. Note that when \( T_{sys} \) beyond \([09 : 00, 18 : 30) \), the outdoor temperature is not very high, thus one AC is enough to maintain the desired indoor temperature. While in order to balance the work load of two ACs during \([00 : 00, 09 : 00) \cup (18 : 30, 24 : 00] \), when they have similar \( ET \), the controller prefers to motivate AC1 but demotivate AC2 during \([00 : 00, 09 : 00) \), and to motivate AC2 but demotivate AC1 during \((18 : 30, 24 : 00] \).

One example is given to clearly illustrate how to figure out \( T_{w1} \) and \( T_{w2} \) during \([09 : 00, 18 : 30] \), as follows:

If \( T = 60 \) min, \( T_0 = 30 \) °C, \( T_f = 28 \) °C, \( E_1 = 0.5 \) kwh and \( E_2 = 1 \) kwh, then \( \Delta T = 2 \) °C, \( ET_1 = 0.25 \) kwh/°C and \( ET_2 = 0.5 \) kwh/°C. Due to \( ET_1 / ET_2 = 0.25 / 0.5 = 1 / 2 \), which satisfies Rule 5. Hence, we can get \( T_{w1} = 60 \) min and \( T_{w2} = 20 \) min.

Figure 20 shows the flowchart of ET algorithm. At the beginning, the energy-saving controller pre-runs two ACs for 10 min to get their initial ET (\( ET_{init}^1 \) and \( ET_{init}^2 \)). Subsequently, if the real indoor temperature \( T_r \) exceeds the desired indoor temperature \( T_d \), the controller will calculate \( T_{w1}^1 \) and \( T_{w2}^1 \) according to the seven rules mentioned above and turn on/off two ACs. Once \( T_r \leq T_d \) and the smaller \( T_w \) arrives, the AC with smaller \( T_w \) will be immediately turned off. At the end of every \( T \) min, \( ET_1 \) and \( ET_2 \) during temperature dropping stage of this period will be recalculated to determine the setting of \( T_{w1}^2 \) and \( T_{w2}^2 \) in the next period.

**FIGURE 19.** The basic principle of ET algorithm.

**FIGURE 20.** The flowchart of ET algorithm.

The pseudo code of ET algorithm is shown as follows.

**VI. EXPERIMENTAL RESULTS AND DISCUSSION**

Since March 2018, the proposed system has been implemented at and serving for many Telecom operators’ RCRs distributed at different regions in Guangdong Province of China. In order to assess the effectiveness and practicality of the proposed system, a Telecom operators’ remote computer room, located at suburbs of Zhongshan City of Guangdong Province in China, is considered as the study object.
Algorithm 1 ET Algorithm

1: Set $t$, $T_d$
2: $ET_{init}^1$, $ET_{init}^2$ ← Pre-run two ACs for 10min
3: while (1) do
4:   if ($T_r > T_d$)
5:      Calculate $T_{w}^1$, $T_{w}^2$ to turn on/off two ACs
6:      for ($t \leftarrow 1$ to $T$) do
7:         if ($T_r \leq T_d$)
8:            if ($t = min(T_{w}^1$, $T_{w}^2$))
9:               Turn off the AC whose $T_{w}$ is $min(T_{w}^1$, $T_{w}^2$)
10:            else
11:               Keep the working status of ACs unchanged
12:         else
13:            Keep the working status of ACs unchanged
14:      end for
15:      Update $ET_1$, $ET_2$
16:   else
17:   end while

Figure 21 and 22 show the physical map and plane graph of the study object, respectively. As we can see from Figure 22, there are a server rack and several service facilities such as two vertical air conditioners, a rectifier and two batteries. And No.1—4 temperature module are deployed at air conditioner1, air conditioner 2, the rectifier and smart meters, respectively. While No.5 temperature module is placed against the wall opposite the door, responsible for acquiring indoor air temperature.

Figure 23 and 24 show the implementation of the proposed system. As shown in Figure 23(a), there are three smart meters (see white box), one power supply module (see red box) and one IoT gateway (actually, it is the embedded system mentioned above, see sky-blue box). These devices

![Figure 21. A remote computer room located at suburbs of Zhongshan City of Guangdong Province in China.](image1)

![Figure 22. The plane graph of experimental object.](image2)

![Figure 23. Implementation of smart meters and IoT gateway.](image3)

![Figure 24. Implementation of infrared module and air conditioners.](image4)
are installed in an iron box, while this iron box is placed near an electricity cabinet, as shown in Figure 23(b).

It can be seen from Figure 24(a) that infrared module is hanged on the cables, directly facing two air conditioners to control them. In Figure 24(b), we can find that the infrared module is installed at the place marked with blue box, and that the server rack is deployed near air conditioner 2.

A. GUI OF EMSP

Figure 25 shows the distribution of all computer rooms managed by the proposed system in Zhongshan City. It can be seen from Figure 25 that the computer rooms operating normally are marked as green bubbles, while a computer room with alarm report appears as a red bubble.

By double-clicking a specific bubble in Baidu Map displayed in Figure 25, we can enter the main management interface of the RCR corresponding to this bubble, as shown in Figure 26. We can see from Figure 26 that there are three menu items: 1) real-time monitoring, 2) overview of computer rooms, and 3) analysis of energy consumption. In the real-time monitoring menu, we can manage four kinds of devices (rectifier, AC1, AC2 and Bus) by monitoring their current, voltage, power, energy consumption and temperature. And the detailed monitoring interface of these devices is shown in Figure 27, 28, 29 and 30, respectively.
we can examine the operation status of IT equipment and various service devices such as batteries, rectifier and smart meters. Under the “Analysis of energy consumption” menu, we can view and analyze daily, monthly and annual energy consumption as well as the power usage effectiveness (PUE) [26] of RCRs. Figure 32 and 33 depict the GUI used to analyze daily energy consumption and PUE, respectively.

B. IMPACT OF ET ALGORITHM

In the early stage of this project, the initial version of the proposed system can only manage RCRs but fail to save energy. In order to realize the energy saving and carbon emissions reduction of RCRs, we develop an ET algorithm and implement it on the updated version of the proposed system. Before 10 January 2019, the proposed system operated without any energy-saving algorithms. But since 10 January 2019, ET algorithm has been implemented. Note that according to the climate conditions in South China, $T_d$ (desired indoor temperature of RCRs) is set to 28 °C.

Figure 34 shows the impact of ET algorithm on indoor temperature. We can see from Figure 34 that before using ET algorithm, the indoor temperature dramatically fluctuates between 26.5∼30 °C during [00:00-09:00) and (18:30-24:00]. Although the temperature becomes stable during [09:00-18:30], the price is to keep two ACs working continuously, which leads to high energy consumption. Interestingly, after using ET algorithm, the temperature during [00:00-09:00] and (18:30-24:00) is humbly fluctuates around 28 °C. During [09:00-18:30], the indoor temperature periodically climbs to 28.5 °C and then drops to 27 °C. This is because ET algorithm turns off the AC with lower energy efficiency when its working time is over and the required temperature is reached, which avoids the long-term “ON” status of two ACs during [09:00-18:30] but results in a $-1\sim0.5$ °C error range between $T_r$ and $T_d$. However, reducing the energy consumption of ACs at the price of allowing indoor temperature to fluctuate around a small error range is acceptable.
Figure 35 shows the impact of ET algorithm on ACs’ operation status. It can be found from Figure 35 that before using ET algorithm, AC1 and AC2 have highly similar operation status, that is, they almost turn on/off synchronously. However, frequent startup and shutdown of ACs not only shorten their life span but also waste a lot of electrical energy. Fortunately, after using ET algorithm, their switching frequency is greatly reduced and working hours are also reasonably balanced.

C. ANALYSIS OF ENERGY-SAVING EFFECT

In this subsection, we analyze the energy-saving effect of ET algorithm as well as that of the proposed system. Figure 36 compares the energy consumption of AC1, AC2 and the total energy consumption of the objective RCR before and after using ET algorithm. Obviously, before using ET algorithm, the daily energy consumption of AC1, AC2 and the total is around 30kwh, 37kwh and 140kwh, respectively. After adopting ET algorithm on 10 January 2019, the daily energy consumption of them decreased to about 25kwh, 16kwh and 114kwh, respectively. That is to say, the proposed ET algorithm can save approximately 18.57% daily total energy consumption of the objective RCR.

Owing to climatic conditions of different months vary, monthly energy consumption is also affected by the weather to a large extent [27]. In order to eliminate the influence of climatic changes, we analyze the overall energy-saving effectiveness of the RCR based on “year-on-year” rather than “month-on-month”. Figure 37 shows the comparison of total energy consumption of the proposed system before and after using ET algorithm. It can be clearly seen from Figure 37 that after using ET strategy, monthly energy consumption in 2019 declines significantly, compared with that in 2018. Moreover, monthly energy-saving rate ranges from 10% to 25%, with average value reaching 16.64%.

Similarly, Figure 38 compares the PUE of the proposed system before and after using ET algorithm. Compared with PUE in 2018, that in 2019 decreases a lot due to using
ET method. In addition, the average PUE of the objective RCR in 2019 is lowered to 1.56, which means that the proposed system has achieved notable improvement of energy efficiency of RCRs.

VII. CONCLUSION
This article presents an IoT system to manage Telecom operators’ remote computer rooms and to save their energy. Smart meter, temperature module, infrared module and ARM9 embedded control system are applied as the hardware platform, while EMSP is regard as the software platform. Furthermore, a simple but effective ET energy-saving algorithm is proposed to control the switching frequency and working time of air conditioners, which maximizes their energy efficiency. A Telecom operators’ remote computer room, located at suburbs of Zhongshan City of Guangdong Province in China, is adopted as the study case. Numerous operation results during 2018-2019 demonstrate that the proposed system not only successfully manages the remote computer room but also effectively reduces its total energy consumption, and has promising engineering application value.

In the future, we will develop fuzzy control algorithm to further enhance energy-saving rate and apply the proposed system to large data centers or buildings. And wireless technology such as NB-IoT and ZigBee will be employed to replace TCP/IP and RS485 communication, thus avoiding wiring inconveniency and providing better remote computer rooms management.

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