Active & Intelligent Energy-Saving System Designed with WSN modules and Efficiency Analysis

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***Abstract*-This study mainly explored how to use WSN (Wireless Sensors Network) such as ZigBee wireless communication modules and Bluetooth modules to be implemented in the livelihood intelligent energy-saving system in which an active and intelligent energy-saving and its relative environmental detecting and sensor modules were validly constructed to accomplish proceeding to energy-saving mechanism. This research apply new technology to build up active & intelligent energy-saving system focus on system operation instead of materials or components, with those auto-detect mechanism and auto-judged back-end agent software, then deliver feedback control signals through bi-direction wireless communication interface, this system can effectively achieve the goal of energy-saving.**

Not only did this study construct hybrid WSN communication mechanism with 2.4GHz ZigBee and Bluetooth, in which BT was used to design the interface between end-device sensors such as temperature, luminance, CO2, number of persons, humidity etc. while ZigBee was designed as the communication mechanism between middle-way and server computer, to dynamically collect running parameters in power consumption space, but also some practical energy-saving methods were constructed in different environment to verify the efficiently of the system. Eventually, the experimental outcomes were proved to be entirely successful and some placements and suggestions were recommended to the future research as well as to the government departments.

Keywords*：*Wireless Sensor Network (WSN), Energy-saving, ZigBee, Bluetooth, Sensor

I. INTRODUCTION AND RELATED WORKS

Intelligent living space becomes part of advanced techniques in buildings. Literature [9] indicated the construction rules by Institute of Architecture of Taiwan Domestic Affairs Ministry with Living 3.0 that set up rules for green architecture materials, lighting techniques of LED, placement of WSN (Wireless Sensors Network), BACnet integrated monitoring and control system etc., in which all the energy-saving technologies are corresponding to teaching in school and practical application. Literature [10] was especially exploring indicators of energy-saving for regular green luminance techniques so as to improve the efficiency of lighting energy-saving, in addition, some older school buildings over than 50 years was proceeding to assess the benefits of energy-saving. Literature [3] proposed the study of luminance difference during the stage of decoration and established and revised the luminance energy-saving standard UPD with the statistics of luminance loading and electricity density /per area unit of office in Taipei city so as to improve the luminance energy-saving strategies.

ZigBee has become the best-option devices for practical placement of local wireless communication environment and in this paper ZigBee was used to be the information transmission interface of front-end environmental sensor data such as temperature, luminance, CO_2, number of persons, humidity etc which would be calculated by intelligent agent system built in server computer as the running parameters for feedback control of the active intelligent energy-saving system. Literature [7] proposed one capturing-system and estimating insect number in orchard with ZigBee; furthermore, with arranging pairs of GPS, a remote monitoring and control system was invented. Literature [6] proposed one health-check system for human bio-medical signals with sensors developed by ZigBee. Literature [8] proposed a solution for constructing local network with ZigBee techniques combined with UPnP techniques embedded into 3C products. In this paper we adopted Bluetooth as the communication mechanism between end-device (sensor modules) and middle-way or server computer. According to literature [2], a method with JAVA-WEB mode to connect server with remote control system with star topology BT network was proposed. Literature [1] explored the collision of BT network of facilities in living space during rush hours. Literature [4], [5] were used hybrid network combined with ZigBee and Bluetooth to construct intelligent living space and SCADA of small-scaled wind-power electricity generator. To sum up those related works mentioned above, applying ZigBee and BT in intelligent control system is feasible; hence, in this paper we used ZigBee and BT to construct the wireless sensor network for intelligent energy-saving system and to proceed to practically build up the prototype of the system is objective and integrated work.

II. SYSTEM FUNCTIONS

There are four parts in paper structure as shown in Figure1 and the system functions were planed as follow:

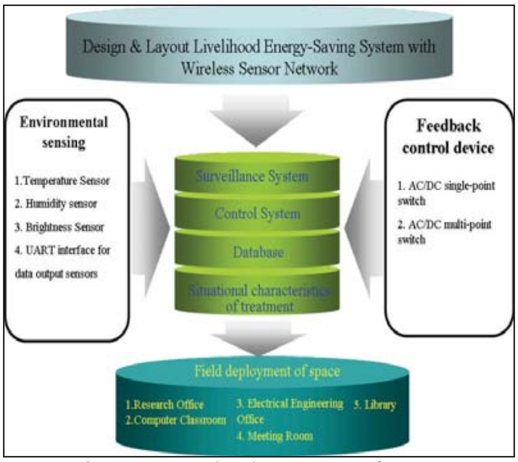


Figure 1. The plan structure of system

A. *Function 1: environmental factors (energy-saving running parameters) sensor and detecting*

The research design was to design sensors modules of temperature, humidity, luminance, CO_2, number of people (running parameters), and the data transmission interface with WSN. Those parameters would be detected and sent to the embedded middle-way or server computer as judged factors to be determined whether the system should proceed to feedback control by the intelligent agent according to the WSN modules placed in the proper location to match up the condition variety of environment.

B. *Function 2: practical placement of WSN in power consumption locations*

In this study, we implemented ZigBEE as the environmental sensors interface to collect the running parameters of energy-saving system, and the interface of controlled facilities was used BT. All sensors was designed with module-type so that those sensors could be reorganized by customers according to their environmental features. In addition to the sensors, the packet protocol of information could be established the communication-net mechanism by users. So far, the practical placement of sensor network was established in the local buildings which were mostly used rate in our campus such as experimental Lab., computer Lab., huge offices, big seminar room.

C. *Function 3: feedback control interface software for server computer*

The interface of feedback control of server was responsible for collect all running parameters from the sensors of energy-saving system established in certain power consumption space. All parameters would be set up a database for further judge indexes of operation situation of feedback control. In addition, there was designed ID for each node of end-device and those ID could be revised once the located position of the sensor nodes. That meant the parameters of system interface was visual-mode display and users could easily learn the condition of controlled facilities in the space.

D. *Function 4: feedback control for the controlled facilities in power consumption space*

The facilities in power consumption space ought to be monitored by server through all sensors, and once the condition of some abnormal facilities should be controlled with the BT wireless sensor network. The controlled node can be divided into single-switch and multi-switch that were controlled by the system control software of visualized interface on server computer.

III. ESTABLISHMENT OF ZIGBEE & BLUETOOTH WIRELESS SENSOR NETWORK

A. *Software Design of Coordinator*

In this intelligent energy-saving system, Coordinator was designed with structure of star top-logy and responsible to collect all running parameters of energy-saving system from end-devices (sensor nodes), finally, sent all parameters to server through internet and UART interface to receive all information. The basic facilities parameters of Coordinator was set as PAN ID = 0001, Coordinator = 0001, BAUD = 19200, Max End Device Node = 100 and its software design flow-chart was shown in Figure 2.

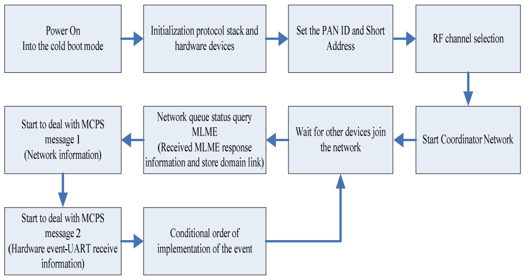


Figure 2. Software design chart of Coordinator

Jennic Corp. has proposed Application Queue API interface for chip JN5121, which could construct linkage among API, IEEE 802.15.4 stack, and hardware drivers. Application Queue API could be divided into 3 parts as follow:
(1) MLME (MAC Management Services)
(2) MCPS (MAC Data Services)
(3) HW (Hardware)

Figure 3 is part program of the basic starting procedure of Coordinator.

```
while(1)
    {
(a)      vProcessEventQueues();

         switch (sCoordData.sSystem.eState)
         {
(b)      case E_STATE_INIT:
             sCoordData.sSystem.u8Channel = CHANNEL_MIN;
             sCoordData.sSystem.eState = E_STATE_START_ENERGY_SCAN;
             break;

(c)      case E_STATE_START_ENERGY_SCAN:
             vStartEnergyScan();
             sCoordData.sSystem.eState = E_STATE_ENERGY_SCANNING;
             break;

(d)      case E_STATE_ENERGY_SCANNING:
             break;

(e)      case E_STATE_START_COORDINATOR:
             vStartCoordinator();
             sCoordData.sSystem.eState = E_STATE_RUNNING_UART_APP;
             break;

(f)      case E_STATE_RUNNING_UART_APP:
             vLoop();
             break;
```

Figure 3. The part program of basic starting procedure of Coordinator

B. *3.2. The software design of End Device*

Figure 4 showed the part program of starting basic procedure of End Device.

```
(a)     vWUART_Init();
(b)     vStartActiveScan();
     while(1)
     {
(c)         vProcessEventQueues();
(d)         vLoop();
        if((tLocal.bWSenserSend)   )
        {
(e)             if (sDeviceData.sSystem.eState == E_STATE_RUNNING)
            {
                /* Poll if there is data pending from the coordinator */
(f)                 vPollRequest();
(g)                 vWUART_TxData();
            }
            else
(h)             while (i16Serial_RxChar() != -1);
            tLocal.bWSenserSend = FALSE;
        }
     }
```

Figure 4. The part program of starting basic procedure of End Device

C. The basic connection design among Bluetooth modules

The software design flow-chart of basic connection of Bluetooth module was shown in Figure 5.

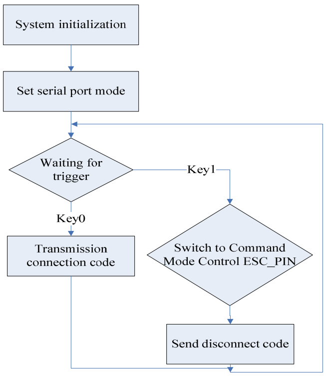


Figure 5. The software design flow-chart of basic connection of Bluetooth module

Figure 6 is part of the basic connection program of BT. (a) is the initialization of 89C51 and the setting of the baud rate of series transmission port with Timer 1. (b) is the function to judge its linkage between master and slave BT with manual connection and disconnection. If the linkage is triggered by connection button, and then (c) immediately fetch the data in Table 1from program memory and sequentially sent out through UART. Table 1 is the pair ID of linking BT, and if the disconnection button were triggered, (d) one pulse signal would be output from pin P1.3 (ESC), that means to notify the BT to change the "data mode" into "command mode". (e) the system program would fetch the data in Table 2 from program memory and sequentially sent out from UART, Table 2 means the command of disconnection of BT.

```
                ORG     00H
                JMP     START
(a)  START:
                MOV     TMOD,#00100000B
                ANL     PCON,#01111111B
                MOV     TH1,#0FDH
                MOV     TL1,#0FDH
                MOV     SCON,#01000000B
                SETB    TR1
                CLR     P1.3
(b)  LOOP:
                JNB     P1.1,CONNECT
                JNB     P1.0,DISCONNECT
                JMP     LOOP
(c)  CONNECT:
                MOV     DPTR,#TABLE1
                MOV     R1,#00H
                JMP     AGAIN
;**********************************************
(d)  DISCONNECT:
                SETB    P1.3
                CALL    DELAY1
                CLR     P1.3
                CALL    DELAY1
                JB      P1.3,DISCONNECT
                JB      P1.2,DISCONNECT
(e)             MOV     DPTR,#TABLE2
                MOV     R1,#00H
                JMP     AGAIN
;**********************************************
     TABLE1:
                DB      'c 00:07:80:83:83:0b 1101 rfc'
                DB      0DH,0AH,40H
;**********************************************
     TABLE2:
                DB      'CLOSE 0'
                DB      0DH,0AH,40H
;**********************************************
                END
```

Figure 6. Part program of basic connection of Bluetooth module

IV. Intelligent Information Processing and Decision Making

In this research, an ontological information agent with solution integration and proxy techniques for intelligent information processing was proposed, which not only helps the whole system find out proper and integrated processing results, but supports proxy access of information solutions through a three-tier solution finding process, as showed in Figure 7. The architecture involves two main modules, namely, CBR (Case-Based Reasoning) [11, 13] and predictor [12, 13], and shows how it interacts with the system interface. Solution Finder is designed to serve as the central control in finding solutions. To ensure that all the knowledge used in CBR and solution prediction can be automatically generated, we have introduced and a solution predictor into the system. They will be described in the following subsections.

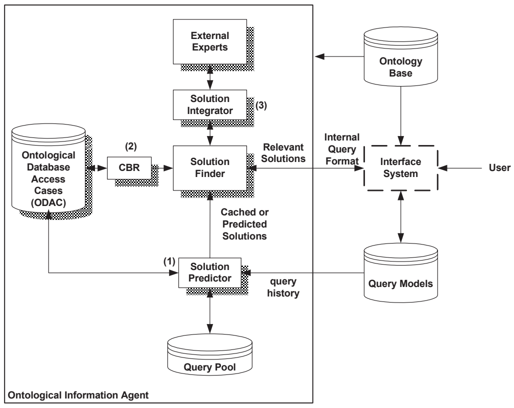


Figure 7. System architecture

As stated above, Solution Finder is a system control manager. After receiving a query from the interface system, it tries to produce an answer following a three-tier algorithm, which includes predicted solution retrieval, CBR, and solution integration. We briefly summarize this process here. They will be detailed later.

I. Predicted solution retrieval: Firstly, Solution Finder checks whether any predicted results exist in Query Model Base. If yes, it directly produces the answer retrieved from the question-answer pair. If none, Solution Finder starts CBR to find out query solution.

II. CBR: If the given query is already existent in ODAC (Ontological Database Access Cases), Solution Finder directly outputs its answer part. If none, Solution Finder performs case adaptation to solve the query.

III. Solution integration: The last mechanism of finding solutions is to trigger Solution Integrator to integrate solutions from external experts. If this integrated solution is credited with a high degree of satisfaction by the user, it will be stored in the ODAC serving as a new case.

A. Solution Predictor

Figure 8 shows the detailed architecture of Solution Predictor. First, Query Pattern Miner looks for frequent sequential query patterns inside each query group, using the Full-Scan-with-PHP algorithm [12,13], from the query histories of the same query group, as recorded in the Query Models Base. Query Miner then turns the frequent sequential query patterns to Case Retriever, which is responsible for retrieving corresponding solutions from ODAC and constructing "frequent queries" for storage in Cache Pool. Prediction Module finally bases on the frequent sequential query patterns to construct a prediction model for each query group. Pattern Matching Monitor is responsible for monitoring recent query records and using the prediction model to produce next possible queries for storage in Prediction Pool. With these two pools, combinedly called Query Pool, it provides query cache and query prediction as the proxy mechanism to reduce query response time. In summary, on the off-line operation, Solution Predictor is used to produce "frequent queries" for

Cache Pool and "predicted queries" for Prediction Pool. During on-line operation, given a new query, Solution Finder passes the query to Solution Predictor, which employs both query prediction and query cache mechanisms for producing possible solutions for the query. Details please refer to [13].

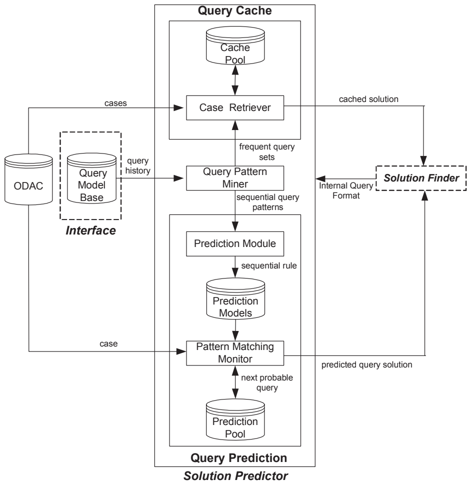


Figure 8. Detailed architecture of Solution Predictor

B. CBR

Figure 9 illustrates the detailed architecture of the ontology-supported CBR proxy mechanism. Again, ODAC is the case library, which contains query cases produced by the backend information preparation operation. Case Retriever is responsible for retrieving a case from ODAC, which is the same as or similar to the given query. Case Reuser then uses the case to check for any discrepancy against this query. If the case is completely the same as the query, it directly outputs it to the user. If the case is only similar to the query, it passes it to Case Reviser for case adaptation. Case Reviser employs the domain ontology along with Adaptation Rule Base to adapt the retrieved case for the user. Adaptation Rule Base contains adaptation rules, constructed by domain experts. Case Retainer is responsible for the maintenance of ODAC, dealing with case addition, deletion, and aging. Details please refer to [13].

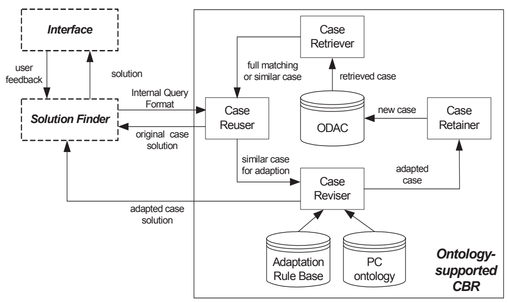


Figure 9. Detailed architecture of Ontology-supported CBR

V. THE FUNCTIONS OF HUMAN-MACHINE INTERFACE

A. Inquire of node information

By selecting the function on the touch-panel screen in the server computer, users could inquire all the information of the nodes, layout in the space, which would indicate the power consumption and all sensors information about the running parameters according to building name, floor, room, sensor ID (node) addressed in MAC Address. If user wants to add to new name of building, floor, room, or sensor, the user can select the function at right side function block as shown in Figure 10.

Figure 10. The screen of node information inquire

B. Inquire of historical information (data mode)

In this study the collected running parameters to sensor from power consumption environment would be save in one pre-constructed database which would be a feedback-control basis judged by the intelligent agent of the intelligent energy-saving system. If user selected the function of "historical data", then he could inquire the historical record of single node as shown in Figure 11. The inquire procedures are the same as the "node inquire", but the functions were increased "year", "month", "date", and "time".

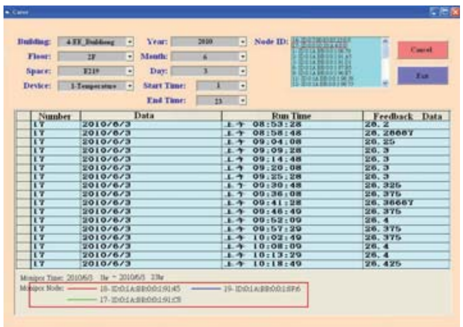


Figure 11. The screen of inquire historical data (data mode)

C. Inquire of historical information (curve mode)

The collected data through long period could be displayed in curve mode, and the designed screen could display 4 nodes simultaneously in different line-color as well as its MAC Address, and user could switch into the time period he wanted to inquire, the displayed screen was shown in Figure 12.

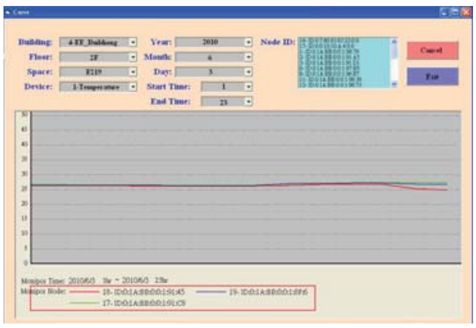


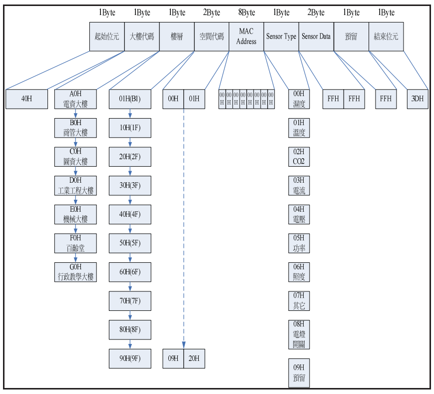
Figure 12. The displayed screen of historical information inquire (curve mode)

D. Communication protocol of data

In this paper we layout all kinds of nodes (sensors of collecting running parameters of intelligent energy-saving system) and set up the communication protocols in ZigBee wireless sensor network according to building name, floor number, node MAC Address, node Sensor Type, and node Data, the protocol format was shown in Figures 13 (a) and (b).

1Byte	1Byte	1Byte	2Byte	8Byte	1Byte	2Byte	1Byte	1Byte
Start bit	Building Code	Floor	Space code	MAC Address	Sensor Type	Sensor Data	Reserved	End bit

(a) The planned protocol format of communication data of ZigBee modules



(b) Originally planned communication protocol designed in Chinese of practical placement of energy-saving system

Figure 13. Communication protocol format

VI. 6. PRACTICAL ENERGY-SAVING SYSTEM ESTABLISHMENT AND VERIFICATION OF SYSTEM OPERATION

A. *WSN Sensors placement*

In this paper we selected the electrical & information technology building as the verification of intelligent energy-saving efficiency in our campus, and the sensors were layout in the Lab., classrooms, offices, computer Lab., huge conference room that were most power consumption spaces. Figure 14 was shown the bird's eye view of electrical & information technology building which was outlined with yellow line and the network of ZigBee was used scatted net domain structure as shown in Figure 15, in which each net domain has its own PAN ID, and there were totally three net domains. C1 was the coordinator node which was responsible for the information coming from all net domains, and then sent the information to server PC or embedded middle-way through Ethernet.

Figure 14. The bird's eye view of St. John's University—Electrical Engineering & Information Building (yellow- outlined)

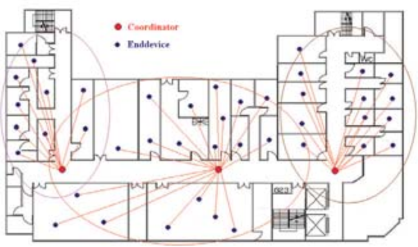


Figure 15. Practical placement of sensor nodes of 2nd floor in Electrical Engineering & Information Building

B. *6.2. Verification of system operation and efficiency analysis*

In this research, we have already practically layout the ZigBee wireless sensors into different teaching Lab. or room spaces as shown in Figures. 16 and 17, in which temperature and humidity sensors was mounted on the ZigBee modules. In order to avoid layout too close to the outlet of air conditioning and generated abnormal data. The layout location of nodes ought to be considered whether the space was high density of people or not because the more people is in the space, the higher is the temperature in the space. The number of the layout nodes (sensors) depended on the size of space area. In this study 40 sensor nodes including temperature and humidity detected function were distributed into 3 ZigBee net domains as shown in Figure 16. Since Coordinator needed to collect all sensor information any time, the power supply of coordinator used civilian electricity. As for End Device, the information collected by end device was sent to server every 80 seconds and once the information was sent out, the end devices would enter into sleep mode to save power consumption, so we used three #3 batteries. After long time experiment, all sensors could accurately accomplish the transmission task and the historical data was inquired and shown on the server screen with both data and curve mode as Figures 18. and 19.

Figure 16. Practical layout of sensor nodes of computer Lab

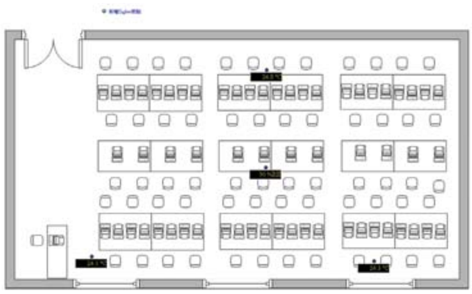


Figure 17. The displayed interface screen of sensors layout in computer Lab

Figure 18. The information inquire historical data screen of computer Lab.

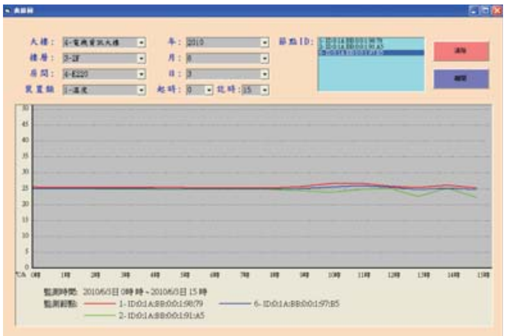


Figure 19. The information inquire curve screen of computer Lab.

VII. 7. CONCLUSION

TABLE I. THE EFFICIENCY ANALYSIS OF ENERGY-SAVING SYSTEM

Condition / Device	Before using energy-saving system	After using energy-saving system
Lighting	40w * 232Group= 9.280kw/hr	7.424kw/hr
Air conditioning	10kw * 19 Group=190kw/hr	142.5kw/hr
Computers	400w*153 Group=61.2kw/hr	52k w/hr
Service Machines	120w* 35 Group =4.2kw/hr	3.36 kw/hr
Toatl Energy-saving percentage	100%-(7.424+142.5+52+3.36)/(9.28+190+ 61.2+4.2)=22.44%	

The active intelligent energy-saving system was originally to design for preventing people from neglecting the rules and orders of energy-saving established by government, and the system was expected to actually save the energy especially in our daily living space through the mechanism and sensors we designed of course including the intelligent judged agent techniques in the server computers with its feedback control system. After practically layout the intelligent energy-saving system into the campus building mentioned above, we run the system for whole 4 months, the energy consumption data was shown in TABLE I. From the table, we could easily compare the electricity power consumption outcomes, in which one condition was running without the energy-saving system and the other was with the system. There was obviously different and with the help of intelligent energy-saving system, we could save 22.44% electricity power consumption. The experimental outcomes was now duplicating into all of the other buildings, and we hope we could offer the further data of total power consumption after we establish the wireless communication network and related sensors networks. At this moment, we at least could definitely be sure of the efficiency of the intelligent energy-saving system.

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