Building environment assessment and energy consumption estimation using smart phones

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ABSTRACT

In this paper, an APP for building indoor environment evaluation and energy consumption estimation based on Android platform is proposed and established. While using the APP, the smart phone built-in sensors are called for real-time monitoring of the building environmental information such as temperature, humidity and noise, etc. the built-in algorithm is developed to calculate the heat and power consumption, and questionnaires, grading and other methods are used to feed back to the space heating system. In addition, with the application of the technology of big data and cloud technology, the data collected by users will be uploaded to the cloud. After the statistics of the uploaded data, regional difference can be obtained, thus providing a more accurate basis for macro-control and research of energy, thermal comfort, greenhouse effect.

Keywords: Building environment assessment, Energy consumption estimation, Smart phone, APP, Big data

1. INTRODUCTION

Begin the Introduction two lines below the Keywords. The manuscript should not have headers, footers, or page numbers. It should be in a one-column format. References are often noted in the text[1] and cited at the end of the paper.

In recent years, building environment, energy conservation and emission reduction has become an important area concerning to the national economy and the people's livelihood. However, most of the known energy consumption monitoring technologies are designed, integrated and installed to the large infrastructure by professional and technical personnel, and equipped with relatively expensive sensors, data acquisition device as well as data transmission system, which have a high cost of equipment, inconvenient mobile, less data acquisition and other shortcomings. Therefore, the traditional energy consumption monitoring technology cannot be applied to every civil buildings. It will have a very important significance if some convenient monitoring technologies can be equipped and operated by general public [1]-[3].

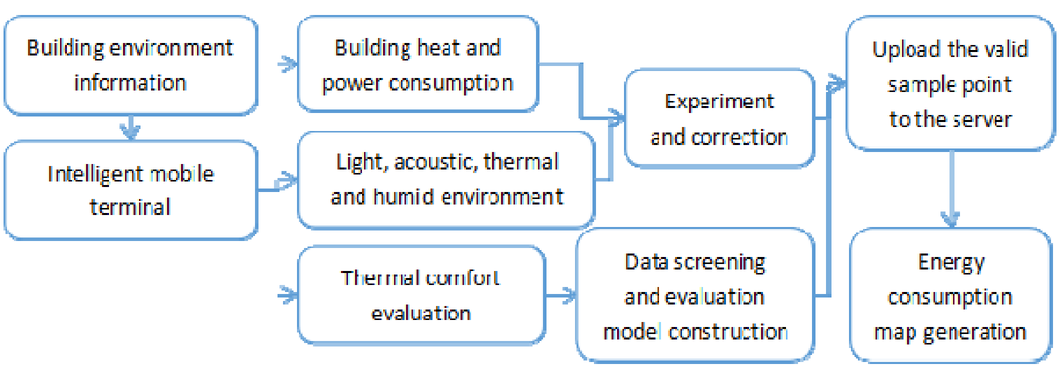

Figure 1. Flow chart of building environment evaluation and energy consumption estimation system

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At present, with the use of smart phone's APP, people have been able to carry out human health monitoring, car collision detection, motivation recognition and earthquake remote sensing. There is no energy monitoring system that takes the intelligent mobile phone as the carrier and has the public participation in China and abroad. We hope to develop a mobile phone application to collect and process the environmental information such as temperature, humidity and illumination, and achieve the monitoring of energy consumption. This technology makes full use of the advantages of the mobility of smart mobile clients, to establish a network of energy monitoring system [5]-[7]. With the advantages of large sample size and low cost, it is expected to make important contribution in the future environmental management, energy conservation and emission reduction, and also will be a huge challenge and a strong complement to the traditional energy monitoring technology.

2. THEORETICAL DESIGN

2.1 The Calculation Method of Heating Energy Consumption

Heating consumption consist is made up of basic heat consumption of building envelope $Q_{1,}$ additional heat consumption of building envelope Q2 and heat consumption by cold air infiltration Q3[3][4].

2.1.1 The Basic Heat Consumption of Building Envelope Q_1

For non top building envelope：

$$Q_1 = \alpha F_{wall} K_{wall}(t_R - t_{O.W}) + \alpha F_{window} K_{window}(t_R - t_{O.W})$$

For the top building envelope：

$$Q_1 = \alpha F_{wall} K_{wall}(t_R - t_{O.W}) + \alpha F_{window} K_{window}(t_R - t_{O.W}) + \alpha F_{roof} K_{roof}(t_R - t_{O.W})$$

where Q_1 = basic heat consumption of building envelope ; α = temperature difference correction factor , which is elected by room type menu; F_{wall}, F_{window} and F_{roof} = the area of outer wall, outer window and roof; K_{wall}, K_{window} and K_{roof} = heat transfer coefficient of outer wall, outer window and roof; t_R = calculating temperature of indoor air ; $t_{O.W}$ = outdoor temperature.

2.1.2 Additional Heat Consumption of Building Envelope Q_2

For non top building envelope：

$$Q_2 = Q_1 \times (\varepsilon_1 + \varepsilon_2) \times (1 + \varepsilon_3)$$

For the top building envelope：

$$Q_2 = [\alpha F_{wall} K_{wall}(t_R - t_{O.W}) + \alpha F_{window} K_{window}(t_R - t_{O.W})] \times (\varepsilon_1 + \varepsilon_2) \times (1 + \varepsilon_3) + Q_1 \times \varepsilon_3$$

Where ε_1 (Orientation additional factor) = 5% when north, northeast and northwest direction, 5% when east and west direction, 12.5% when southeast and southwest direction and 25% when south direction; ε_2 = wind additional factor, for buildings that are not sheltered from the high ground, the river, the coastal, the wilderness and the cities and towns are significantly higher than the other buildings around the building, its vertical enclosure structure = 7.5%; ε_3 = story height additional factor，for heating room，ε_3=（h-4）×2% and $\varepsilon_3 \leq 15\%$, and for radiant heating room，ε_3=（h-4）×1% and $\varepsilon_3 \leq 8\%$.

2.1.3 Heat Consumption by Cold Air Infiltration Q_3

$$Q_3 = 0.278 L \rho_{ao} c_p (t_R - t_{O.W})$$

where L = volume flow of cold air infiltration (m^3/h), and L = Ventilation frequency × S × H when the number of ventilation is selected by the user; S = the area of room (m^2); H = the height of room (m) ; $\rho_{ao} = 1.342$（kg/m^3）; $c_p = 1.0056 kJ/(kg \cdot ℃)$.

2.2 The Calculation Method of Daily Average Power Consumption

The electricity project is elected by user as：

$$P_d = \frac{P_m}{30}$$

where P_d = daily average power consumption; P_m = the monthly electricity consumption which the user fill in.

The valuation cycle electricity project is elected by user as：

$$P_d = \frac{P_Z}{d_2 - d_1}$$

where P_z = the electricity consumption of the valuation cycle；d_1 and d_2 = The begin and end date of the billing cycle.

2.3 Thermal Comfort Evaluation Method

According to the user's selection, thermal sensation vote, thermal comfort vote and heat can accept the vote distribution and the average results, specific problem setting and tested corresponding parameters as shown in Table1 [9], roughly reflect the user's thermal comfort, and the feedback to related departments to make proper adjustments, such as winter users vote bias uncomfortable partial heat, existing heating overheat waste.

Table 1. Problem setting and the corresponding table to be measured [9]

Your thermal sensation stat	**Thermal sensation vote (TSV)**
Hot	3
Warm	2
A little warm	1
Normal	0
Cool	-1
A little cool	-2
cold	-3
Your thermal comfort	**Thermal comfort vote (TCV)**
Can't stand	4
Extremely uncomfortable	3
Not comfortable	2
Slightly uncomfortable	1
Comfortable	0
Satisfaction with the current thermal environment	**Acceptable level vote**
Extremely dissatisfied	1
Not satisfied	2
A little not satisfied	3
A little satisfied	4

Satisfied	5
Extremely satisfied	6

3. FUNCTION DESIGN

3.1 Weather Module

Figure 2. Weather module

The data of GPS sensor and import the data of the meteorological station automatically will be called to get the weather information including humidness, wind direction, wind force and so forth every two hours, thus realizing the weather forecasting function.

3.2 Energy Consumption Module

Figure 3. Heat and power consumption estimation module

After putting parameters of the front and height of room and so forth, the application will compute four indicators of the basic heat consumption of building envelope, the additional heat consumption of building envelope, the heat consumption by cold air infiltration and the total consumption of heating respectively. Similarly, the result will be computed such as monthly electricity consumption according to the corresponding data.

3.3 Building Environment Module

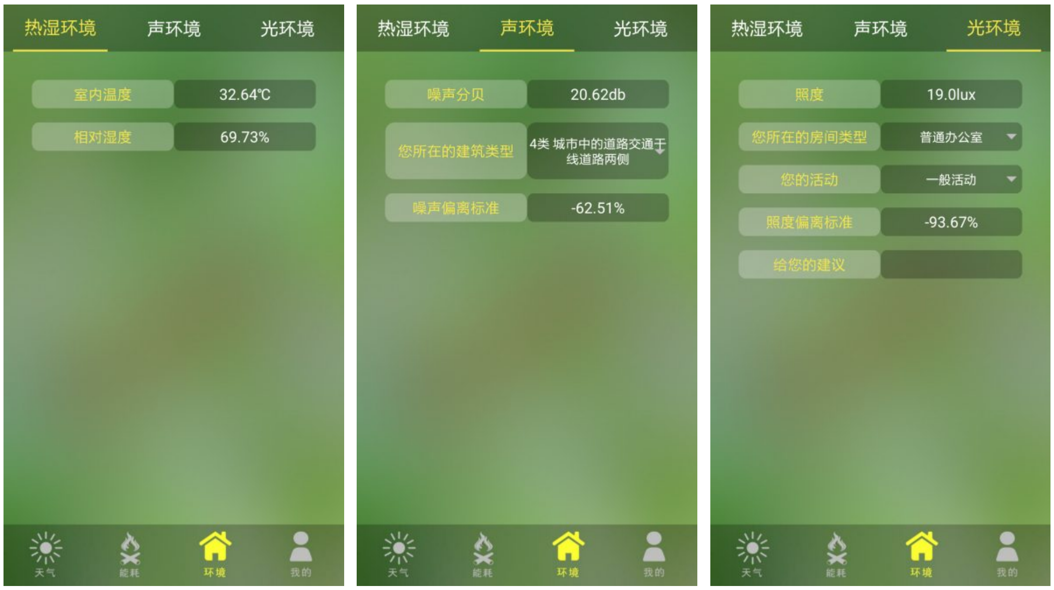

Figure 4. Building environment module

By invoking the built-in sensors of modern smart phones, the application can measure the internal thermal and humid environment, luminous environment, acoustic environment of the building directly.

In the aspect of thermal and humid environment, the environment temperature and relative humidity will be measured. And in the aspect of luminous environment, the illumination of the working plan of the phone will be measured, so the percentage that deviate from standard will be obtained. Similarly, in the aspect of acoustic environment, the environmental noise level will be measured and the percentage that deviate from standard will be obtained as well. However, temperature and humidity measurement temporarily supports the smart phones with the environmental temperature and humidity sensors only, such as Samsung S4, Note3 and MI 2/2s/3.

3.4 Thermal Comfort Evaluation Module

Figure 5. Thermal comfort evaluation module

The thermal comfort evaluation function of the application, which requires to collect the data of two aspects mainly: one is the personal information that related to thermal comfort, such as gender and age, and the other is thermal sensation vote, thermal comfort vote and thermal acceptability vote, which all completed by users. According to collection and transmission, a thermal comfort fundamental database of an actual structural internal environment has been built up.

4. SERVER CONSTRUCTION AND DATA PROCESSING

4.1 Server Construction

Figure 6. Data processing

Due to the traditional energy consumption estimation method often has high equipment cost, inconvenient movement and less data collection, it is difficult for people to evaluate the building environment and energy consumption in a large scale. Android smart phone's built-in sensors are called to directly measure various environmental data, and the acquired data is transferred to the premade built server. After screening, operation, data analysis and results statistics, the regional differences in building energy consumption will be obtained.

4.2 Data Processing

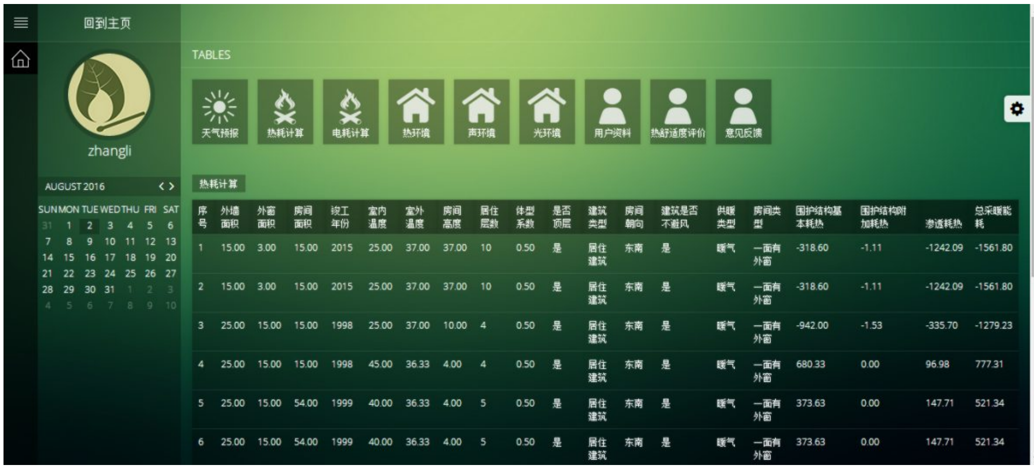

Figure 7. Data processing

Each time users access to a data, whether it is a sensor acquisition or operation, the information including Android ID, monitoring time, GPS, building information, input and output data and so forth will be automatically uploaded to the corresponding categories of the database. The database has a variety of retrieval functions to facilitate data collation and the data export function to export according to categories or all export. At the same time, the data can be filtered, merged, and so on. The information such as the result of thermal comfort evaluation, power consumption and heat consumption is also intuitively presented at the corresponding position on the map of website home page.

5. EXPERIMENTAL TEST

In order to investigate the sensitivity of the temperature, humidity, illumination and noise sensor in the software, a number of measuring points were selected to compare the data measured by software with the data measured by professional instrument.

5.1 Temperature Test

In the temperature test, 12 measuring points are selected, and the temperature is measured by the software and the professional instrument. The measured data are shown in the following table.

Table 2. Temperature values measured by software and instrument (Unit: ℃)

Times	1	2	3	4	5	6	7	8	9	10	11	12
Software	31.1	22.0	23.4	24.0	24.3	21.8	22.9	18.8	24.1	18.3	18.3	17.4
Instrument	33.2	23.7	22.6	24.6	23.1	22.7	22.2	17.4	22.0	18.9	18.9	17.6

The regression analysis shows that the temperature value of the instrument is 1.0027 times of the software, and the *Goodness of Fit* is 0.9088.

5.2 Humidity Test

In the humidity test, 12 measuring points are selected, and the humidity is measured by the software and the professional instrument. The measured data are shown in the following table.

Table 3. Humidity values measured by software and instrument (Unit: %)

Times	1	2	3	4	5	6	7	8	9	10	11	12
Software	31.6	34.4	37.9	39.3	45.2	42.9	37.1	36.6	33.4	44.7	41.5	35.0
Instrument	15.5	28.7	29.2	27.3	30.0	30.4	23.5	26.7	13.6	34.8	30.7	31.1

The regression analysis shows that the humidity value of the instrument is 0.7029 times that of the software, and the *Goodness of Fit* is 0.4648.

5.3 Illumination Test

In the illumination test, 12 measuring points are selected, and the illumination is measured by the software and the professional instrument. The measured data are shown in the following table.

Table 4. Illumination values measured by software and instrument (Unit: lux)

Times	1	2	3	4
Software	12.0	11.0	20.0	17.0
Instrument	3357.1	3120.4	4981.9	4788.2

The regression analysis shows that the illumination value of the instrument is 267.97 times of the software, and the *Goodness of Fit* is 0.9106.

5.4 Noise Test

In the noise test, 12 measuring points are selected, and the noise is measured by the software and the professional instrument. The measured data are shown in the following table.

Table 5. Noise values measured by software and instrument (Unit: dB)

Times	1	2	3	4	5	6	7	8	9	10	11	12
Software	12.2	25.8	26.6	46.8	49.0	49.1	66.3	79.5	80.6	78.7	80.4	82.3
Instrument	32.0	32.3	37.4	45.6	46.4	52.1	63.5	78.1	79.5	84.9	85.7	91.7

The regression analysis shows that the noise value of the instrument is 1.0434 times of the software, and the *Goodness of Fit* is 0.8821.

According to the results of the data analysis, the temperature sensor and the noise sensor have a high sensitivity. There is a big difference between the measurement results of the illumination sensor and the professional instrument, but there is a good linear response between the two sensors. Nowadays, the mobile phone humidity sensor technology needs to be improved, so the temperature sensor error. In the future, we should develop the technology of mobile phone humidity sensor.

Above all, the temperature, illumination and sensor of the software have high sensitivity, which can be used in practice.

6. CONCLUSION

According to statistics in February 2012, the number of Chinese mobile phone users exceeded 1 billion, and most of the mobile phone with the sensor network for network communications can be a smart phone. By using smart phones, the real-time collection and transmission from sensor data (sound, image, GPS, speed, gyroscope, brightness, geomagnetism, direction, pressure, short range, temperature sensor data, etc.), and by manual input to real-time transmission environment of various descriptive data. With the idea of big data and cloud technology, a mobile phone application based on Android system is developed. By collecting and calculating the environmental variables such as temperature and humidity, the construction environment evaluation and energy consumption estimation are completed. From the user environment and energy consumption information is uploaded to the cloud, after mathematical statistics can be regional differences in building energy consumption, government departments and research institutions and the macro control and Research on energy, haze, the greenhouse effect to provide a more accurate basis for.

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