

G210

# A Building Audit Software to Support Energy Management and Conservation

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**Abstract** - Energy audit is one of the plausible efforts to do in energy conservation. This article describes the design and development of a tool being purposed to help in analyzing energy audit data of a building. Some requirements to provide for the success of the task include the knowledge of audit data parameters as well as their computation procedures, the mastering of the programming language to be used, and also logical analysis and criticism to the results of program codes execution. Visual C++ under Visual Studio Integrated Development Environment (IDE) of Microsoft is used as the programming language. Data of four categories of buildings, representing university-, religious-, junior high school-, and kindergarten-buildings are used. The obtained results show that using the chosen programming language and development environment, instruction codes should be grouped as declaration files containing the definition of variables and prototypes names to be used, and implementation files containing the detail instructions to execute. The resulted execution time of the program is relatively fast, with a reasonable tendency to become longer when the available data amount to be processed is larger. The resulted practical software will generally be useful to facilitate the analysis of a building energy audit data, because it covers most measures and analyses to be performed in an energy audit. Moreover, it can also be useful to give an understanding on how energy is used in buildings as well as how to identify opportunities to reduce energy consumption and furthermore to contribute to energy conservation efforts.

**Keywords**— *building energy audit; software; energy conservation*

## I. THE IMPORTANCE OF ENERGY AUDIT

Indonesia is a country with large potential of energy resources, but its people's access to energy is still limited. Therefore, the concern of sustainable development must always be borne in mind when taking decision and policy concerning national energy and natural resources management.

In 2011, the president of the Republic of Indonesia issued a legal instruction to save water and energy. In 2012, the Minister of Energy and Mineral Resources issued two

regulations, the one dealing with Electrical Energy Saving whereas the other with Management.

Ministry of Energy and Mineral Resources of the Republic of Indonesia enacted all users of energy and energy sources with consumption of energy in all forms greater than or equal to 6000 tonnes of oil equivalent (ToE), or equivalent to 69780 megawatt-hour (MWh) per year, to undertake energy conservation through energy management.

The energy conservation should be done by assigning an energy management, preparing energy conservation programs, carrying out regular energy audits, implementing recommendations resulted from energy audit, and reporting the implementation of energy conservation annually to the Minister, Governor, or Regent/Mayor in accordance with their respective authorities [1].

Energy audits become a very important activity in any energy management strategy. It is stated that energy management must be done by a competent and certified person, and that the audit on the main energy utilization must be conducted on a regular basis at least once every three years.

Meanwhile, the number of certified auditors is still limited compared to the number of buildings to be audited. Audits cost is also expensive, especially if it is desirable to obtain a certified audit results. For organizations/ institutions/large industry with consumption of energy/energy sources exceeding 6000 ToE, which are obliged to conduct energy management and conservation, the audit cost may not be a big problem compared to the possibility of savings that can be obtained, but for users of energy/energy sources less than 6000 ToE which are not required to perform the conservation measures, the audit cost could become a considerable amount being compared to the potential savings to get.

In this paper the design and development of energy audit software is described. The use of software is expected to ease the process of calculation and analysis of the possible energy waste, thus allows to obtain the information about the energy consumption in a building becoming the audit object, possible

waste of resources, and the selection of alternative recommendations to be implemented so that the waste can be reduced or even eliminated. Its use will also be able to reduce the required time and cost of the audit. Furthermore, the results can be used in the implementation of energy management, i.e. the planning of energy conservation program, as well as to increase awareness of users and operators of energy/energy source.

The specific objective of this paper is to describe the design of energy audit parameters algorithm, then its implementation using Visual Studio/Visual C++, to result in an energy audit tool in the form of practical software that is easy to use and interactive for users, so it does not require its use by someone who is already expert and experienced.

## II. ENERGY AUDIT DATA ANALYSIS TOOL

In an energy management, to reduce the negative impact of limited generation and transmission capacity, the efforts can be directed to the improvement of efficiency on the load side, known as Demand Side Management [2]. In practice, an in depth audit of all electrical equipments used is necessary.

Energy audits become a very important activity in any energy management strategy. As a consequence, the methodology associated with the improvement of efficiency also becomes very important. However, manual methodologies generally take a long time, more error-prone, and require highly skilled personnel actors [2]. Special technical expertise is needed to enable one to perform an audit on a building efficiently [3].

Accordingly, some researchers have proposed various methods and auditing tools [2-11]. Merwe, et al. (2011) proposed an energy audit tool development to improve the audit process using the methodology for calculating the energy usage profiles at various loads, as well as comparing it to theoretical result.

IEEE Standard 739-1995 can be used as a technical manual in the implementation of energy conservation [12]. This standard provides procedures and techniques that enable the optimization of efficiency in the design and use of any electrical system, taking into account all the aspects (safety, cost, environment, management needs, and so on).

A energy audits software tool was proposed by Prudenzi, et al. (2008). The software is designed and implemented in order to support every step in the implementation of a complete and thorough audit with a focus on energy use in buildings [3].

Maricar, et al. (2005) proposed the use of a web-based application for data mining models for the audit process in the industry [4].

Computational tools proved to be a valuable asset in the field of engineering. Melki, et al. (2009) proposed to design and build software which allows for the simulation and analysis of energy use in a building [5].

Based on the experience already gained by the authors as well as the results of researches previously described, it is

known that there are not many energy audit software tools which are specifically dedicated to the type of load as well as standards and regulations applicable in Indonesia [13-14]. Therefore it is purposed in this paper to describe such kind of audit tool. Started with the design of algorithms for an energy audit, followed with the development of the algorithms to results in a software tool, it is tested using the data obtained from the previous audit experience of the authors.

In the future, the software tool can be extended to consider much higher level of complexity of energy/energy sources as well as greater utilization capacity of energy/energy sources.

## III. DESIGN AND DEVELOPMENT METHODOLOGY

To design and develop an energy audit software, it is necessary to master the following aspects thoroughly, i.e. the audit data parameters of a building as well as their computational procedures, the logical analysis and criticism to the results of program running, and also the programming language to be used. It begins with the design of algorithms, being followed with its implementation, and then the testing.

The complete steps in designing energy audit software is described in Fig. 1, started with the requirements/specification determination, ended with the maintenance step to correct any error appearing during utilization.

The algorithms design is based on several alternative sequences of steps that could be undertaken in the implementation of a detailed energy audit, as well as tested using data from the audit as ever conducted by the authors at multiple institutions/government agencies [13-14]. So, it becomes imperative to understand and to know the audit process on each system in a building [15].

In general, the audit software includes some blocks that represent the user, output, and also database and data processing blocks. These blocks can be classified into three layers, i.e. presentation layers, business layer, and data layer.

Presentation layer becomes the interface between the business layer and the user. In this layer user can entry some input data, as well as retrieve some output data resulted from the business layer.

The business layer contains the engines used to process data located in the data layer. The engines constitute 'the brain' of the software. It is in these engines where all definitions of audit parameters and the procedures to compute them are intertwined to process the data located in the data layer.

In the research the results of which are presented in this article, Microsoft Visual Studio, an integrated development environment (IDE) from Microsoft, has been used to develop console and graphical user interface of this application. The programming language used is Visual C++ which is also supported by Visual Studio.

A set of code files and other resources which are used to build an application is called as solution in Visual Studio. The files in a solution are arranged hierarchically, which might or might not reflect the organization in the file system. The

Solution Explorer, as can be seen in Fig. 2, is used to manage and browse the files in a solution. It provides with an organized view of projects and their files as well as ready access to the commands that pertain to them.

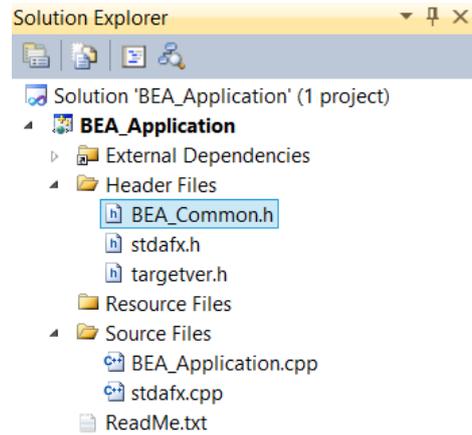


Fig. 2. Solution Explorer of Microsoft Visual Studio

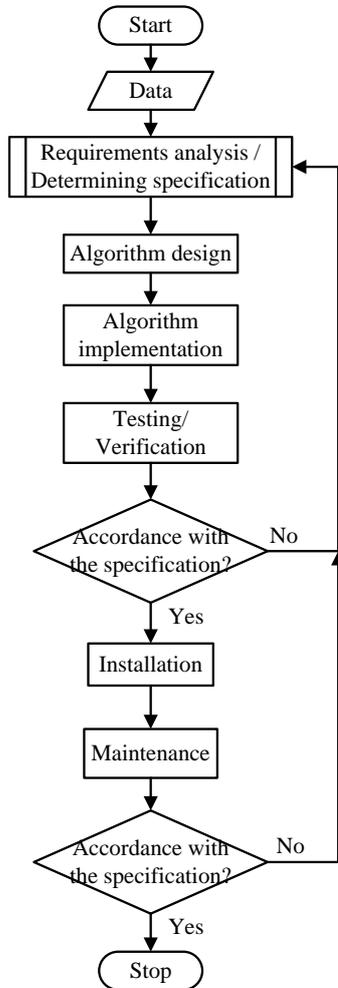


Fig. 1. Steps to follow in designing energy audit software

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Two folders mainly used to write the source codes of application are the Header Files and Source Files. All files in the Header Files folder have an .h suffix, identifying them as header files, whereas in the Source Files folder the files possess a .cpp suffix, even though both of those qualify as source code. A .cpp file is commonly called as an "implementation file", whereas a header file is called as a "declaration file". The main reason would be for separating the interface from the implementation. The header declares "what" a class (or whatever is being implemented) will do, while the cpp file defines "how" it will perform those features.

The separation reduces dependencies so that code that uses the header doesn't necessarily need to know all the details of the implementation and any other classes/headers needed only for that. This will reduce compilation times and also the amount of recompilation needed when something in the implementation changes.

A .cpp file includes the definitions from any header which it includes (because .cpp and header file together become a single 'translation unit'). A header file might be included by more than one .cpp file. The linker typically won't like anything defined in more than one .cpp file. Therefore any definitions in a header file should be inline or static. Header files also contain declarations which are used by more than one .cpp file.

Definitions that are neither static nor inline are placed in .cpp files. Also, any declarations that are only needed within one .cpp file are often placed within that .cpp file itself, instead of in any (shareable) header file.

#### IV. RESULTS AND DISCUSSION

Some declarations and definitions are put in the Header Files, an example of which is shown in Fig.2, BEA\_common.h. The source codes in this folder are aimed at defining global variables and the name of prototype functions. Header Files contain information that defines the fundamental Visual C++ codes the project relies on. The files in this folder along with the .dll files will be supplied to the executable files.

As can be seen from Fig. 3, there are no further detailed procedures describe in the source codes.

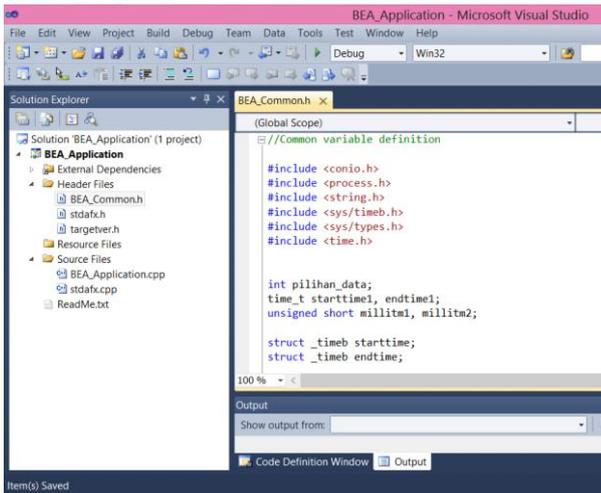


Fig. 3. Display of file source code in the Header Files folder

In Fig. 4, some function definitions are shown, the procedures of which are detailed in the source codes in the Source Files folder.

```
//Functions definition
void Input_Data(void); //inputting data
void Klasifikasi_Gedung(void); //determining classification of building
void Display_Data(void); //displaying data
void Hitung_Rekening(void); //calculating bill
void Display_Hitung_Rekening(void); //displaying results of bill calculation
void Hitung_Luas_Gedung(void); //calculating building area
void Display_Luas_Gedung(void); //displaying result of building area calculation
void Hitung_IKE(void); //calculating ECI of building
void Display_Hitung_IKE(void); //displaying result of building ECI calculation
```

Fig. 4. Example of global variable definitions and the name of prototypes in Header Files

In Fig. 5, the detailed procedure on how to calculate the building area is presented. It is more detailed than just the definition of function in Fig. 4.

```
void Hitung_Luas_Gedung(void)
{
    //Calculating the area and volume of the building
    tot_L_gedung = 0.0; //total building area
    tot_V_gedung = 0.0; //total building volume

    for(int i = 1; i<=tot_lantai; i++){
        L_gedung[i] = p_gedung[i]*l_gedung[i];
        V_gedung[i] = p_gedung[i]*l_gedung[i]*t_gedung[i];
        tot_L_gedung = tot_L_gedung + L_gedung[i];
        tot_V_gedung = tot_V_gedung + V_gedung[i];
    }
}
```

Fig. 5. Source code in the Source Files folder

The whole required functions are to be run in the main program, as can be seen in Fig. 6. Using four representative buildings, the data to be processed are classified into four choices of data that must be chosen by the user.

```
=====  
Choose the desired building data:  
1. Data of University Building (TEUB)  
2. Data of Mosque Building  
3. Data of Junior High School Building  
4. Data of Kindergarten Building  
=====
```

Fig. 6. Running the .cpp file, displaying Choice of building data to process

Using the data comparison shown in Table I, the utilization of the designed software has been shown. Fig. 7 and 8 show the example of results of program running.

TABLE I. DATA COMPARISON OF CASE 1 AND CASE 4

| Case   | Case 1   | Case 4             |
|--|--|--------------------|
| Amount of floors,<br>Amount of meters                            | 2 3  | 1 1                |
| Building<br>dimensions of each<br>floor, L, W, H                 | 15.00 10.00 4.00<br>12.00 10.00 4.50                                 | 16.00 10.00 6.00   |
| ID meters, Power<br>capacity (VA),<br>Amount of monthly<br>bills | 1469096157 105000 12<br>1469096337 105000 12<br>1469096346 105000 12 | 2039539034 1300 12 |

Fig. 7 is the result when the data are taken from the university building sample (Case 1), whereas in Fig. 8 the data are from the Case 4 (Kindergarten building). The calculation results of buildings area are presented. These results are obtained from the execution of the related procedures detailed in .cpp files, with definitions and functions which are declared in the header files.

A part of the results shown in Fig. 7 and 8 gives the calculation results of area and volume of the buildings, the total energy used, its related bill already paid, the index of energy consumption, and also the potential saving being compared to standard.

```
Calculation of Building Area and Uolume
-----
| Floor # | L (m) | W (m) | H (m) | A (m2) | Uo1 (m3) |
-----
| 1 | 15.00 | 10.00 | 10.00 | 150.00 | 600.00 |
| 2 | 12.00 | 10.00 | 10.00 | 120.00 | 540.00 |
-----
| Total | 270.00 m2 | 1140.00 m3 |

ECI and IRPE of Building
-----
Total kWh of Building : 393555.00 (kwh)
Total Rp of bill of Building : 528150784.00 (Rp)
Total Building Area : 270.00 (m2)
ECI of building : 1457.61 (kWh/m2)
IRPE of building : 1956114.00 (Rp/m2)
Standard of Minimum ECI : 210.00 (kWh/m2/th)
Standard of Maximum ECI : 285.00 (kWh/m2/th)
Saving ECI Minimum : 1247.61 (kWh/m2/th)
Saving ECI Maximum : 1172.61 (kWh/m2/th)
-----
Start Milliseconds: 233
End Milliseconds: 631
Milliseconds Execution Time: 398
```

Fig. 7. Results of program running for Case 1

```

Calculation of Building Area and Volume
-----
| Floor # | L (m) | W (m) | H (m) | A (m2) | Uo1 (m3) |
-----
| 1 | 16.00 | 10.00 | 10.00 | 160.00 | 960.00 |
-----
| Total | 160.00 m2 | 960.00 m3 |
-----

ECI and IRPE of Building
-----
Total kWh of Building : 143300.00 (kWh)
Total Rp of bill of Building : 1317739.00 (Rp)
Total Building Area : 160.00 (m2)
ECI of building : 895.63 (kWh/m2)
IRPE of building : 8235.87 (Rp/m2)
Standard of Minimum ECI : 165.00 (kWh/m2/th)
Standard of Maximum ECI : 295.00 (kWh/m2/th)
Saving ECI Minimum : 730.63 (kWh/m2/th)
Saving ECI Maximum : 600.63 (kWh/m2/th)
-----
Start Milliseconds: 789
End Milliseconds: 964
Milliseconds Execution Time: 175
    
```

Fig. 8. Results of program running for Case 4

The execution times of both Case 1 and Case 4 are very different, as the amount of data to be processed in Case 1 is higher than that in Case 4, as can be seen from Table II. There are three kWh-meters at the building 1, but only one kWh-meter at the building 4.

The audit software helps in simplifying and reducing the time and cost of energy audit. The results of the study will generally useful to facilitate the analysis of the energy audit, because the resulting practical software covers most measures and analyzes to be performed in an energy audit. Moreover, it gives also an understanding on how energy is used in buildings as well as on how to identify opportunities to reduce energy consumption.

TABLE II. RESULTS OF EXECUTION TIME TESTING

| Running no. | Case 1 | Case 2 | Case 3 | Case 4 |
|-------------|--------|--------|--------|--------|
| 1           | 210    | 120    | 150    | 140    |
| 2           | 250    | 140    | 110    | 150    |
| 3           | 270    | 180    | 140    | 130    |
| 4           | 220    | 160    | 110    | 130    |
| 5           | 230    | 150    | 150    | 140    |
| 6           | 280    | 150    | 150    | 120    |
| 7           | 290    | 140    | 160    | 150    |
| 8           | 300    | 140    | 140    | 150    |
| 9           | 240    | 90     | 120    | 110    |
| 10          | 280    | 90     | 140    | 110    |
| Average     | 257    | 136    | 137    | 133    |

The audit software helps in simplifying and reducing the time and cost of energy audit. The results of the study will generally useful to facilitate the analysis of the energy audit,

because the resulting practical software covers most measures and analyzes to be performed in an energy audit. Moreover, it gives also an understanding on how energy is used in buildings as well as on how to identify opportunities to reduce energy consumption.

## V. CONCLUSIONS AND PERSPECTIVES

From the design and development of building energy audit software described in this article, some conclusions can be drawn as follows:

- Processing energy audit data is far easier and faster with the help of a computing tool.
- A computing tool in a form of energy audit software can be designed and built based on the parameters to determine and the corresponding required audit data.
- Recommendations to improve the energy efficiency can be proposed to the energy manager/decision maker based on the implementation results of the software on the available energy audit data.

The design and development of the audit software can also be used to identify potential priorities of measures for energy conservation and savings opportunities, either from the maintenance and operation at a low cost or even no cost at all.

Especially for the industrial/business and trade sectors, in addition to comply with government regulations related to the obligation to conduct an energy audit, it would also be beneficial to reduce the energy cost, which will furthermore reduce the operation and production cost, which can result in an increased profit margins to be gained or product competitiveness in the market.

## ACKNOWLEDGMENT

The authors would like to thank the Directorate General of Higher Education of the Ministry of Education and Culture of the Republic of Indonesia through the Brawijaya University for having financed the research, the results of which are presented in this article.

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