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SUPPORT SYSTEM FOR IMPROVEMENT AND PREDICTION OF THE ENERGY PERFORMANCE OF AN APARTMENT ENVELOPE IN SCHEMATIC DESIGN

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ABSTRACT

Establishing the appropriate measure for estimating and improving the energy performance of a new building is very important at Schematic Design. As an initial attempt toward this end, this research sought to determine at Schematic Design if the designed apartment envelop structure ensured proper energy conservation performance and to develop a support system that could suggest for the envelop structure an improvement measure meeting the targeted energy conservation performance depending on whether or not the calculated value was satisfactory. Specifically, the calculation method for the building energy efficiency rating system based on which the amount of apartment energy conservation could be calculated was applied to determining the performance of the apartment envelop structure. EnergyPlus, a program for interpreting energy, was used for building energy interpretation to suggest an appropriate envelop structure. In addition, the process of setting a specific part suggesting the appropriate envelop structure for the improvement of performance of envelop structure energy was developed by introducing AHP and Fuzzy Logic technique.

INTRODUCTION

In Korea, the import dependency of energy stands at approximately 97%; building energy consumption accounts for more than 25% of the nation's total energy consumption, with 18% estimated to come from a residential building. Constituting a large part of energy consumption, the construction industry provides buildings with long durable life expectancy compared to other industries. Furthermore, buildings cannot be replaced or changed once they are constructed. Energy conservation measures for completed buildings are limited to efficient use and management. Therefore, designing energy-efficient buildings at Schematic Design is critical in the construction industry. Accordingly, this research aimed at developing a support system wherein energy performance can be easily estimated for a new building at Schematic Design and improvement measure for the energy performance of the building can be suggested based on such estimation.

As an initial attempt toward this end, a support system was developed in this research for the envelop structure sensitive to outside climate change and with direct influence on energy consumption in an apartment whose energy conservation design is becoming more and more important due to the increasing size and number of stories. As the two important features of the support system to be developed, the estimation of performance of the apartment envelop structure and suggestion of performance improvement measure should be practical and realistic. For this purpose, the estimation method for the performance of newly built apartment envelop structures was developed based on the law of the Republic of Korea concerning building energy conservation. In addition, to secure the reliability of energy consumption as required in the course of setting the appropriate envelop structure for energy performance improvement, the most suitable programs for this research purpose were selected from several accepted building energy interpretation programs and used.

DESIGN STANDARD FOR BUILDING ENERGY CONSERVATION AND ANALYSIS TOOL

In this chapter, the estimation standard and interpretation program as the basis of the major features of the support system were selected by analyzing the design standards for building energy conservation as applied in Korea and the accepted building energy interpretation programs.

Schematic Design and analysis of the design standard for building energy conservation

Schematic Design for establishing the comprehensive design framework based on the direction of and guideline for architectural design is the most critical architectural design process that greatly affects the quality and result of the design. As in other areas, the direction of design factors and design values affecting building energy performance are determined during the process. Even though there are many different factors affecting the process, the regulation based on the law to ensure building energy conservation design is the most fundamental one.

The analysis of building energy conservation design in Korea from this viewpoint shows that the standard is shifting from the specification of each part of the building to the comprehensive performance-oriented standard of the entire building. More specifically, government standards such as the "Environment-friendly Building Certification Standard (Ministry of Construction and Transportation, Ministry of Environment)," "Housing Performance Rating (Ministry of Construction and Transportation)," and "Building Energy Efficiency Rating Certification System (Ministry of Industry and Resource)" -- which are substantially applied to field construction works -- are examples of such direction change. The Building Energy Efficiency Rating Certification System in particular reported is a system that rates the degree of energy conservation for the apartment from the planning stage and enables checking -- even before the construction work starts -- how much energy can be saved from the entire apartment complex. Taking a look at the process of rating energy efficiency, efficiency rating was found to depend on the composition of the apartment envelop structure. From this viewpoint, the Building Energy Efficiency Rating Certification System can be said to be usable as a practical standard for estimating the performance of the apartment envelop structure.

Analysis of the building energy program

To estimate the degree of energy conservation on the appropriate part of the envelop structure that has been changed to improve energy performance, a measure should be established during the process of developing the support system. There are two different methods for the estimation: experiment-based method and simulation-based method. Note, however, that the simulation-based method using the building energy interpretation program is generally preferred because it is more reliable and convenient. There are also several building energy interpretation programs, although EnergyPlus – which has been developed on the basis of BLAST and DOE-2 -- not only matches the researcher's purpose and intention but also offers a structure that can be interfaced with other programs. Due to these characteristics, EnergyPlus is the most suitable program for the energy consumption estimation of the support system as the purpose of this research.

Support system and estimation of building energy performance

Used as one of the methods of solving a specific problem in a given field, the expert system is a system wherein experts' way of thinking and expertise are reorganized through a computer and the necessary information is obtained by inferring based on such reorganization. Since such characteristics can be said to coincide with the purpose and contents of the support system to be developed, system development techniques for developing the support system were used on the basis of the concepts and development process of the abovementioned expert system.

The development process of the expert system generally consists of problem setting and requirement analysis stage, target setting stage, problem-solving structure setting stage, development planning stage, knowledge collection stage, knowledge analysis and systemization stage, system design stage, coding and assessment, reassessment and maintenance, etc. In developing the support system based on the abovementioned general development process, the following should be considered:

First, the fact that the analysis, calculation, and basis of judgment in the process of estimating building energy performance require logical and accurate calculation method and judgment criteria other than the experts' empirical knowledge should be considered. Second, knowledge of the order of the priority decision algorithm, which serves as a critical judgment criterion in deciding the areas of performance improvement during the process of suggesting the measures for improving building energy performance -- should be secured on the basis of the expert's empirical knowledge and should be built continuously. Finally, convenience and simplicity in usage aside from the educational functions for users should be secured first in the development process.

DEVELOPMENT OF THE SUPPORT SYSTEM

In this chapter, the support system for estimating the energy performance of the apartment envelop structure and deciding the improvement measure is developed based on the development process of Building Energy Efficiency Rating Certification System, EnergyPlus and expert system mentioned in the previous chapter.

Investigation and analysis of the apartment envelop

To investigate and reflect the present condition of the apartment envelop structure as the subject of this research, an apartment considered to reflect the latest trend was chosen as shown in Table 1. The envelop structure was investigated and analyzed in terms of 5 parts including the outer wall, intermediate floor, roof, windows and doors, and base floor.

Table 1
Apartment subject to the investigation

PROJECT	FLOOR AREA	NUMBER OF HOUSEHOLDS
A-Project	184,319 m^2	1,226
B-Project	489,823 m^2	2,752
C-Project	99,904 m^2	332
D-Project	295,748 m^2	1,792
E-Project	205,993 m^2	848
F-Project	532,428 m^2	2,614
G-Project	197,287 m^2	1,122

For the residential and commercial complex building and residential apartment, the outer wall structure of each was investigated and analyzed separately. The outer wall structure of the residential apartment consists of "outer finish-concrete-insulation material-cement brick-cement mortar-tile finish" as shown in Figure 1 in case the interior space is utility space such as bathroom and "outer finish-concrete-insulation material-gypsum board-wall paper" in case the interior space is a bedroom or the living room. In the case of residential and commercial complex buildings, the outer wall has a variety of structures.

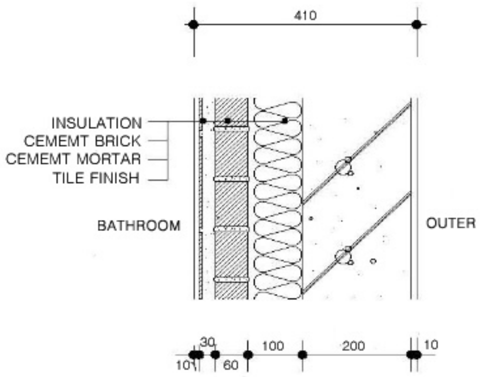

Figure 1 Typical structure of the outer wall

In the case of the intermediate floor structure, there are different upper and lower finish material compositions around the concrete floor slab depending on the usage of the upper space. In other words, there are differences in the compositions of the intermediate floor structure depending on the type of interior finish materials, availability of XL pipe as floor heating equipment and sound-blocking material, and type of insulation material.

The base floor structure carries similarity in compositions among the apartments that were investigated. Specifically, it consists of "lean concrete-PE film-steel reinforced concrete-liquid-proof/dewatering plate-non-reinforced concrete-epoxy coating."

Like the base floor structure, the roof structure also has a similarity. It consists of insulation material and interior finish material for the thermal insulation of the interior space, roof slab, waterproof materials placed right above the roof slab, and exterior finish materials. The structure in general has "gypsum board/ceiling paper-empty space-roof slab-waterproofing membrane-insulation material-PE film-press concrete-epoxy coating.

For the structure of windows and doors, the material itself is almost the same even though the shape and size are different depending on the usage and location. In general, it has paired glass (24mm, 16mm), and the frame is made of aluminum in most cases.

Setting the support system's composition and flow chart

Based on the analysis in the preceding chapter and in consideration of the purpose, feature, and requirement of the support system to be developed, 6 different modules were set for the factors making up the support system: input module for choosing or inputting the information of required variables for the estimation and interpretation of energy performance; estimation module for estimating the apartment's energy efficiency rating at Schematic Design; target setting module for determining the actual result based on the estimated efficiency rating and resetting the target in case the actual result is not satisfactory; energy interpretation module for estimating the total energy consumption required in the process of setting the performance improvement measure using EnergyPlus; improvement measure setting module for determining the performance improvement measure, and; output module for generating the analysis result based on the support system in an appropriate form.

Figure 2 shows the operation of the support system as determined based on the 6 modules cited and the purpose of this research. As shown in Figure 2, the support system will be operated stage by stage, with each module corresponding to each stage. At stage 1, information on all of the apartment households was entered. Changeable variables were directly entered by the user, and fixed variables were developed by the database in the course of developing the support system. At stage 2, the calculation method proposed in the "Building Energy Efficiency Rating Certification System" was accepted, the changeable variables required for the calculation were directly entered, and the fixed variables obtained by analyzing the values suggested in the abovementioned system and the values collected in the course of this research were saved in the database. If the values obtained as a result of the analysis in stage 2 were satisfactory, system operation ended after the information was generated at stage 6. Otherwise, if the results at stage 2 were not satisfactory, the system was operated in stage 3 wherein the user can set the desired target energy performance for the apartment building. At stage 4, building energy performance was interpreted based on the household chosen at stage 3, variables, etc. Stage 4 was performed using the engine of the EnergyPlus program, one of the energy interpretation programs. To achieve the target rating set in the preceding chapter, the amount of targeted saving (MJ/year) was set based on the interpretation result of EnergyPlus and analysis results of stage 2. At stage 5, the performance improvement measure for achieving the targeted efficiency rating and the targeted saving set in stage 4 was established. Before establishing such measure, the order of priority among the various parts of the envelop structure should be determined first. The appropriate structure was determined by changing the materials of each part according to the order of priority of the parts as established based on the logical method of setting the order of priority; the amount of energy saved was then calculated through the interpretation of the EnergyPlus Program, which was repeated based on the set order of priority among the various parts of the envelop structure until the user was satisfied with the interpretation result.

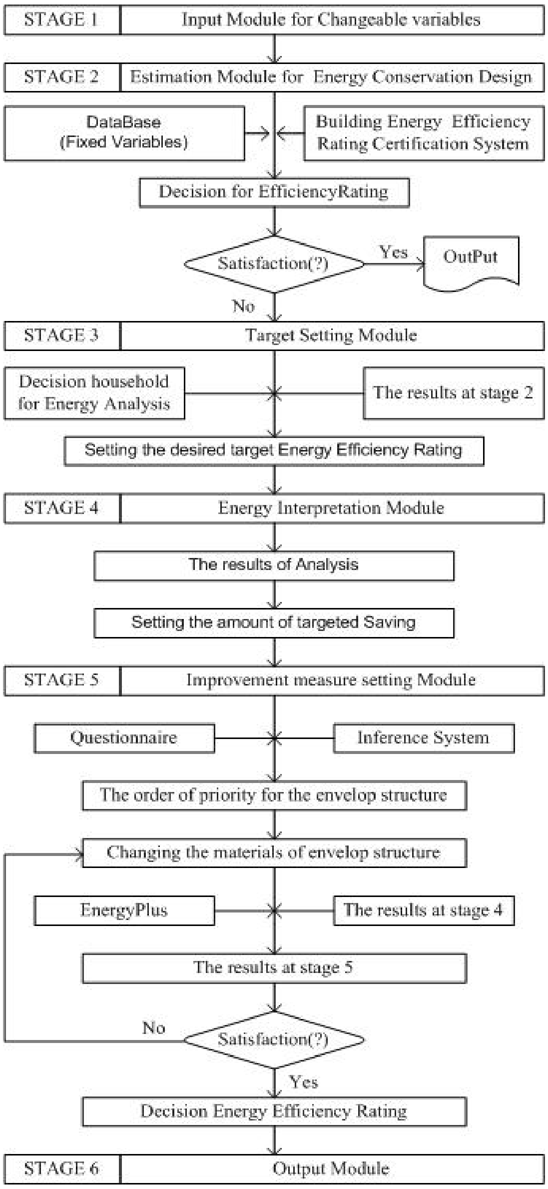

Figure 2 Flow chart of the support system

Once the user was satisfied with the interpretation result, the efficiency rating for the apartment with the appropriate envelop structure was calculated by applying the calculation method in the Building Energy Efficiency Rating Certification System of stage 2 on the basis of the information used in the interpretation of the EnergyPlus Program and the interpretation result. At stage 6, the results obtained from the analysis process of the support system and the final results were generated in a form that could be easily understood by the user.

Development of inference model to determine the order of priority

In changing the materials of the envelop structure parts for the improvement of energy performance as one of the major features of the support system, an inference model for determining the order of priority for the envelop structure parts should be developed. To develop the abovementioned inference model, AHP (Analytic Hierarchy Process) and Fuzzy logic-based technology were used. In other words, Fuzzy logic was applied to reflect the conditions of the apartment complex covered on the change of the envelop structure in setting the order of priority; the Analytic Hierarchy Process was introduced to reflect the general degree of importance of the determining factors related to the change of the envelop structure.

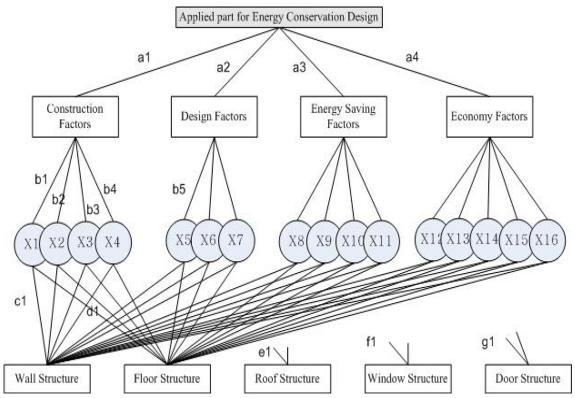

Figure3 Inference model for the order of priority

Table 2
Determining Factors affecting the order of priority

CONSTRUCTION FACTORS	the ease of construction (x1) the mutual relation of process(x2) the ease of material procurement (x3) the application of new technology(x4)
DESIGN FACTORS	the complexity of elevation (x5) the ease of design change (x6) the influence of APT's identity (x7)
ENERGY SAVING FACTORS	Energy efficiency (x8) the importance of ventilation (x9) the importance of direction (x10) the importance of insulation (x11)
ECONOMY FACTORS	Initial investment cost (x12) Construction cost (x13) Labour cost (x14) Material cost (x15) the ease of maintenance (x16)

The result of the development of the inference model for setting the order of priority can be illustrated Figure 3. As shown in Figure 3, there are 4 different layers among which the highest layer 1 represents the determining factor, the sector to which "energy conservation design is applied" and by which the appropriate structure is set; the lowest layer 4 represents 5 factors including the wall structure, floor structure, roof structure, window structure, and door structure as the subject of the order of priority. Based on the references and survey/interviews with experts, the determining factors affecting the order of priority are shown in Table 2 (representing layers 2 and 3).

Development of support system module

Using the programming language DELPHI and MS ACCESS on the basis of each module of the support system as set in the previous chapter, the support system whose development was targeted by this research was developed in a standalone type as shown in Figure 4. The programming language DELPHI as used in the development of the support system uses the object-oriented structure called VCL and offers a visible development environment as its biggest advantage. MS ACCESS was used in the development of the database since it demonstrated the best performance in a local condition without a server.

Figure4 Initial screen of support system

CASE STUDY

In this chapter, a case study is performed to examine the support system developed in the previous chapter and to secure reliability.

Introduction to application subject

To secure the reliability of the developed support system, the estimation of the energy efficiency rating and analysis of improvement measure for energy performance were performed for the apartment under construction. Interviews with working-level persons were also conducted based on the analysis result and process.

Table 3
Introduction to the apartment covered in the analysis

LOCATION	FLOOR AREA	NUMBER OF HOUSEHOLDS
Seoul, South Korea	111,283 m^2	659

The apartment covered in the process is shown in Table 3. A total of 5 working-level persons in charge of architectural equipment design (professional engineers and construction field office chiefs) and another group of 5 architects in charge of architectural design were selected to examine the analysis result and the process.

Analysis process of the apartment covered

In the developed support system, a variety of data required for the analysis are saved in database and editing tools are provided; accordingly, the data can be edited or supplemented depending on the user's condition. In particular, the physical properties of the apartment envelope structure materials are not only saved in the database but can also be revised and supplemented, if necessary.

Data such as structures and materials related to the envelope structures of the apartments subject to application are edited using the editing tool; general information such as the location of the apartment, floor, and heating method is entered for each apartment building. Once general information is entered, the plane for each household is prepared using the plane-generating module provided by the support system as shown in Figure 5. Information such as wall, window and door, heated area/non-heated area, etc., is entered.

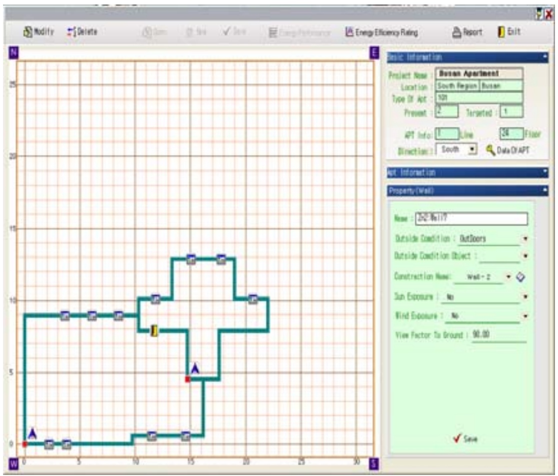

Figure5 Module through which plane and other information are generated

To estimate the energy efficiency rating for the entire apartment complex after the information for each household is entered, analysis based on the standard for the building energy efficiency rating mentioned in the preceding section was performed. The result of the analysis revealed 29.35% of the total energy saving rate (Grade 2 energy efficiency rating). To improve such energy efficiency rating, the rating target was set one notch higher (Grade 1).

To analyze the base data for establishing the improvement measure for the envelope structure so that the set rating target can be achieved, a household was selected; simulation was then executed for the household using EnergyPlus. The result of the analysis is shown in Figure 6, which suggests that the annual energy consumption for the household where analysis was performed was 644.23MJ/Y, and that up to 26.74MJ/Y in energy consumption needs to be saved to be rated Grade 1 as the rating target.

To determine the optimum envelope structure based on which energy consumption can be reduced by the abovementioned amount, the order of priority for the parts and components of the envelope structure subject to change should be reasonably set. A survey reflecting the condition of the analyzed apartment such as the inference model (Figure 7) developed in the preceding section should be performed, and the priority of order for the parts and components of the envelope structure subject to change should be set based on the result of the survey.

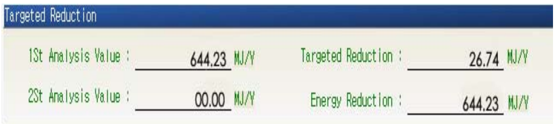

Figure6 Result of simulation using EnergyPlus

Figure7 Questionnaire for setting the order of priority

The result of the analysis of the order of priority for the envelope structure is shown in Figure 8, which allows users to understand easily the order of priority as a result of the analysis as well as change the order subjectively depending on their judgment.

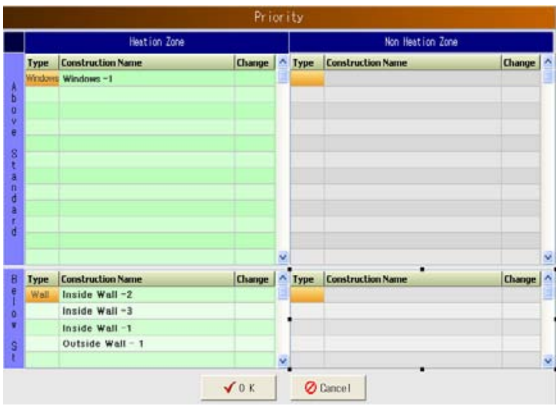

Figure8 Result of the determined priority order

The materials of parts and components in the envelope structure (Figure 9) are changed based on the priority order selected by users; annual energy consumption is re-interpreted using EnergyPlus. In the case of the analyzed apartment particularly the insulation layer, an insulation material with greatly improved insulating effect was used; as a result of such change, the power saving target was achieved.

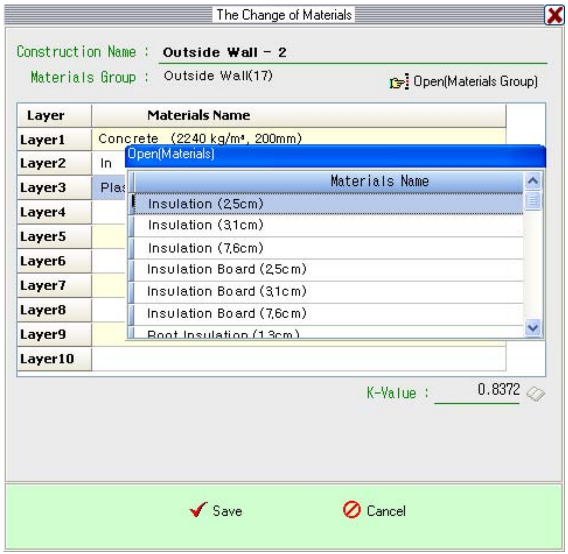

Figure9 Material change for envelop structure

If users are not satisfied with the result of the re-interpretation, the material change of the parts and components for the envelope structure continues until users are satisfied, in which case the estimation module for energy efficiency is used again to estimate the efficiency rating for the entire apartment complex before the work is closed. Since the result of the re-interpretation was deemed satisfactory, the energy efficiency rating for the analyzed apartment complex was measured using the efficiency rating estimation module and rated to be Grade 1. This means that the material change of the insulation layer in the envelope structure to a different material with greater insulation effect enabled energy efficiency rating to improve to Grade 1 even as it was rated Grade 2 based on the original design.

Result of the analysis of the apartment covered and examination

The output module of the support system offers results such as the estimated apartment energy efficiency rating, energy performance improvement measure, and estimated efficiency rating after the improvement of the apartment in a form that can be easily understood by the user.

The support system was finally completed by supplementing and correcting the system and reflecting the opinions obtained from interviews with the selected examiners based on the analysis result and process. The result of such examination process shows that the concept and methods used in this research can be utilized in proposing the criteria for judgment as to whether the architectural design satisfies the design standard for building energy conservation as well as how energy performance can be upgraded during the basic architectural design process or when architectural design drawings are reviewed by the contractors. Furthermore, the interpretation of building energy performance and performance improvement measure should be pursued in every single area related to building energy conservation design in addition to the envelop structure cited through continuous R&D.

CONCLUSION

The result of this research wherein the energy performance of the newly built apartment was estimated at the basic planning stage and the support system was developed to establish the improvement measure for energy performance based on the estimation can be summarized as follows:

First, the support system through which new apartment efficiency rating is estimated at Schematic Design and appropriate material composition is proposed for raising the efficiency rating by changing the materials of the envelop structure parts was developed. During the development process, the Building Energy Efficiency Rating Certification System as one of the design standards for building energy conservation, the energy interpretation program EnergyPlus, and the development language DELPHI and database MS ACCESS were used.

Second, the inference model for setting the order of priority was based on Fuzzy Logic System and AHP; a total of 16 different determining factors used in the development process for the order of priority were set on the basis of the relevant references, interviews with experts, and researcher’s judgment.

Lastly, the physical properties of materials and climate data as important elements of the development process of the support system were saved in the database for continuous revision and supplementation.

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