DEVELOPMENT OF HVAC SYSTEM SIMULATION TOOL FOR LIFE CYCLE ENERGY MANAGEMENT
PART 1: OUTLINE OF THE DEVELOPED SIMULATION TOOL FOR LIFE CYCLE ENERGY MANAGEMENT

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ABSTRACT

The importance of LCEM (Life Cycle Energy Management) has been recognized from the view of life cycle energy saving of sustainable buildings. The purposes of this research are proposal of an LCEM framework and development of prototype HVAC system simulation tools for LCEM. In this paper, necessity of energy simulation tools for LCEM is discussed, and the outline and solution method of the simulation tool are shown.

KEYWORDS

Life Cycle Energy Management, Simulation, HVAC System

INTRODUCTION

Everyone can easily recognize the importance of the maintenance and operation phase that consume much energy when sustainable construction is considered from the viewpoint of countermeasures against global warming. Proper management is indispensable, however, in the life cycle from the planning and design phase to the operation phase of the facility itself to realize truly appropriate maintenance.

This study is conducted to establish the concept of the basic framework of LCEM (life cycle energy management) and develop an energy simulation tool for required air-conditioning system (hereinafter referred to as "air-conditioning system simulation tool"). In particular, although the developed simulation tool is limited to calculation of water amount, air flow amount, temperature and energy, the same type of analysis results (DOE-2 2001, DeST 2004, Yanagihara 2004) can be obtained as from the familiar spreadsheet software.

This paper describes the framework of the LCEM tool, the necessity of the air-conditioning system simulation tool, and the outline of the tools.

BACKGROUND

The concept of the basic framework of LCEM (life cycle energy management) has been established and an energy simulation tool has been developed for required air-conditioning system (hereinafter referred to as "air-conditioning system simulation tool") from 2003 under the LCEM Examination Committee (Chairman: Shuzo Murakami, Keio University) of the Public Buildings Association for contribution to countermeasures against global warming. This paper summarizes some achievements (Tokita et al. 2005, 2006) of the LCEM Examination Committee.

Figure 1 shows the current organization where one study group and four working group are located under the Committee. The Study Group manages and adjusts the whole organization, and working groups are in charge of the following works:

1) The Equipment Performance Survey Working Group surveys and organizes characteristics formulae for air-conditioning equipment.
2) The Air-Conditioning Simulation Tool Development Working Group develops the entire tool including equipment.
3) The Case Study Working Group specifies concrete manner of utilization in each phase from the planning phase to the operation phase.
4) The Input Condition Setting Working Group organizes and offers the thermal load conditions required for the tool.

This organization is managed through cooperation between the Land, Infrastructure and Transportation Ministry, academic experts, energy companies, consultants, construction companies, etc. The completed tool is distributed for free through the Land, Infrastructure and Transportation Ministry in principle. Distribution of the prototype tool was started for the first time in July 2006.

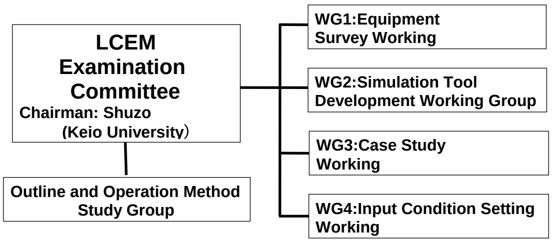


Figure1 Committee configuration

CURRENT SITUATION OF ENERGY MANAGEMENT

Energy management is performed mainly for the operation phase currently, but the following unsolved problems remain:

1) Inefficient operation is performed daily using excessive equipment unsuitable to the actual status of operation in many cases.
2) In equipment manufacturing and trial operation, what is checked is mainly whether the rated specifications are satisfied. The performance in the off-peak period and the energy-saving performance throughout all periods are not checked.
3) Operation is continued without reflecting the design intent and construction intent in many cases.

It is estimated that the above problems are caused because the settings of energy-saving targets throughout the life cycle, corresponding control indicators, check methods, etc. are not made clear.

NECESSITY OF LCEM

Consistent energy management from the planning phase to the operation phase is indispensable to solve various problems related to energy management described above. Figure 2 shows the concept of entire LCEM including planning, operation and modification. Essential points in each phase are as follows:

1) Planning phase
It is important to clearly indicate the concrete requirements and targets of the client for energy saving (target setting). Target setting forms the start point of energy management throughout the life cycle.
2) Design phase
Various examinations are performed for energy saving based on the requirements of the client. The contents of design should meet the targets at the end. Target values are modified if necessary.
3) Construction phase
Construction is performed to meet the contents of design. Performance verification is especially important in equipment manufacturing, trial operation and adjustment, and acceptance in this phase. Essential points in executing performance verification are to confirm the performance not only in the peak load period but also in the off-peak period.
4) Operation phase
Operation data are accumulated and analyzed in accordance with energy control indicators and control items, and it is confirmed whether the energy-saving targets set in the planning phase and design phase are achieved in actual operation. If the energy-saving targets are not achieved, required corrective actions are taken including operation improvement.

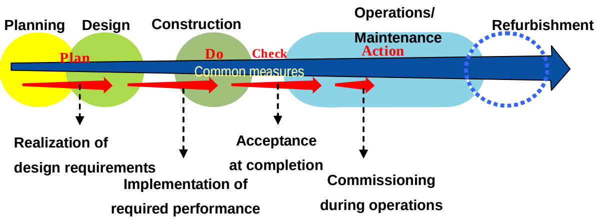


Figure 2 Conceptual diagram of LCEM

IMPORTANT PURPOSES IN LCEM

Essential points of important purposes extracted in LCEM are as follows:

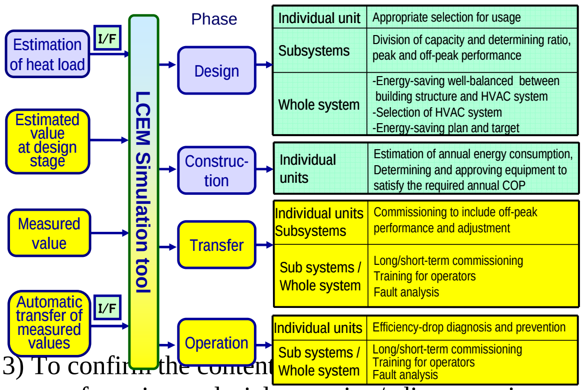
1) To make clear performance requirements among which currently only the peak performance is made clear in many cases.
2) To perform management with consideration of the operational status in the off-peak period instead of the currently performed management of design, construction, and operation where the main focus is on peak performance.
3) To quantitatively support plan, design, and operation where seat-of-the-pants techniques are often adopted currently except for the peak performance
4) To perform continuous performance assurance and performance evaluation using consistent indicators throughout the life cycle, and perform the PDCA cycle instead of the intermittent performance evaluation and performance confirmation performed currently
5) To detect and analyze potential defects missed currently
6) To securely perform the operator training considered to be performed seldom or never currently

The object of LCEM can be the entire energy consumption system in a broad meaning, but is limited to the air-conditioning system here. The indoor environment is regarded as the restraint condition, and it is assumed that the required indoor environment condition is satisfied.

NECESSITY OF SIMULATION TOOL IN LCEM

It is necessary for performing LCEM to prepare a "measuring rule" as shown in figure 4 that measures the energy-saving target attainment level throughout the life cycle. We are developing the air-conditioning system simulation tool in this study as a "measuring rule" related to air-conditioning facilities. Targets in the development are as follows:

1) To predict and evaluate not only the energy consumption but also the system status values
2) To be always available in all phases from design to operation



3) To confirm the content manufacturing and trial operation/adjustment in light of the contents of design
4) To evaluate the performance during acceptance, operation, etc. by comparing and collating design values with operation status values (actual performance values)
5) To predict and evaluate not only the performance in the peak load period but also the performance in the off-peak period
6) To be applicable to various levels with high degree of freedom including the entire system, sub systems and individual equipment units
7) To be easily tried and tested on a personal computer

Figure 3 Role of Simulation Tool for LCEM

POSITIONING OF SIMULATION TOOL IN LCEM

Figure 4 shows the relationship among the existing performance assessment tools, existing air-conditioning system simulation tools, and the simulation tool required to be developed from the viewpoint of LCEM.

1) Building performance assessment tools developed recently

Building environmental performance assessment tools such as CASBEE and LEED have been developed recently. These tools macroscopically evaluate the performance of the whole building, and are not intended to execute detailed system evaluation and quantitative evaluation of energy consumption and others.

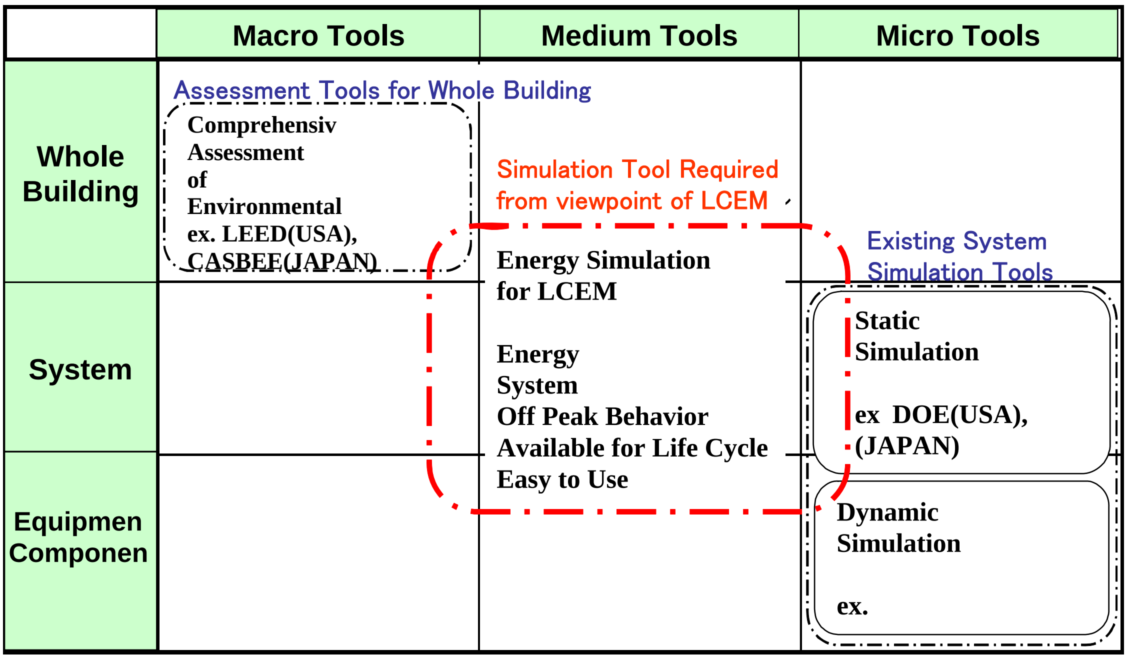


Figure 4 Mapping of Simulation Tool for LCEM

2) Existing air-conditioning system simulation tools

Existing air-conditioning system simulation tools are roughly classified into relatively macroscopic system simulation tools including HASP/ACSS, BECS/CEC/AC and DOE and microscopic tools including HVACSIM+. The former group evaluates the entire system and sub system, and the latter group evaluates equipment and components comprising equipment. Each group is intended to quantitatively evaluate the air-conditioning system. Tools in each group are highly advanced, however, and only limited numbers of engineers and researchers are using these tools actually (Niwa 2004).

3) Simulation tool required to be developed

The simulation tool required to be developed from the viewpoint of LCEM is an energy simulation tool for the air-conditioning system that connects the tools and above.

The required simulation tool should macroscopically predict and evaluate the energy performance of the air-conditioning system, be able to grasp defects of the air-conditioning system with rough sieve, and be easily handled by workers including operators in each phase in the life cycle. The following three points are regarded as important especially from the viewpoint of LCEM:

a) The user can easily handle the tool, understand the contents, and modify and expand the contents.

b) The table calculation method is simple, and calculation processes are not black box in most cases.

c) The tool can calculate status values in the partially loaded status, and the user can understand the annual and periodical performance of each equipment/sub system.

FEATURES OF DEVELOPED TOOL

The developed tool emphasizes the practical utility. Accordingly, most of equipment characteristics consist of experimental formulae to facilitate comparison and collating with actual equipment. The user can manipulate the GUI (graphical user interface) using only the basic functions of general-purpose spreadsheet software, and obtain the equilibrium state among equipment using the "repeated calculation" function.

Other features are summarized in 1) to 5) below:

1) Can evaluate the performance of equipment single unit.

The tool can clarify the operation status in a temperature/flow rate condition different from the rated condition when verifying an individual equipment unit.

2) Can evaluate the performance of arbitrary sub system.

Heat source equipment

- A set of cooling tower + Pump + Refrigerator
- Refrigerator + Chilled water primary pump + Chilled water secondary pump
- Combination of heat sources of different models and different capacities

Air-conditioning equipment

- Air-conditioner + Fan + Indoor
- Combination of "Several sets of refrigerators + Air-conditioner + Fan"

3) Can evaluate the performance of the entire system.

The tool performs simulation using the load calculation results (sensible heat and latent heat) calculated separately as the boundary condition in annual energy calculation.

4) Can be used in each phase from the planning/design phase to the operation phase.

The tool can be used in the life cycle from the planning phase to the operation phase by arbitrarily combining the features 1) to 3) above.

5) Has high operability and expandability.

a) The tool offers high operability. Workers related to air conditioning can easily handle the tool.

b) The simulator is not black box, and the user can easily understand the contents of the tool. The user can easily change and extend the functions.

c) The user can adopt diversified inputs (including manual input, off-line input of thermal load calculation results and on-line input of measured values).

d) The user can easily process results.

The general-purpose spreadsheet software "Excel" is used for creation and solution of these programs. The solution includes not only simple calculation but also convergent calculation that utilizes the convergence offered by "repeated calculation" contained in the spreadsheet software. Macro programs are to be used only in annual calculation in principle.

SOLUTION USING OBJECT CELLS METHOD

The developed tool obtains the operation status values of the air-conditioning system using a solution called object cells method.

Table calculation is generally performed while mathematical formulae and numbers are input to cells on the sheet as shown on the left in Figure 5. In this technique, mathematical formulae constructing an equipment model are input to two or more cells as shown on the right in Figure 5, and such cell group is handled as one equipment (that is, object).

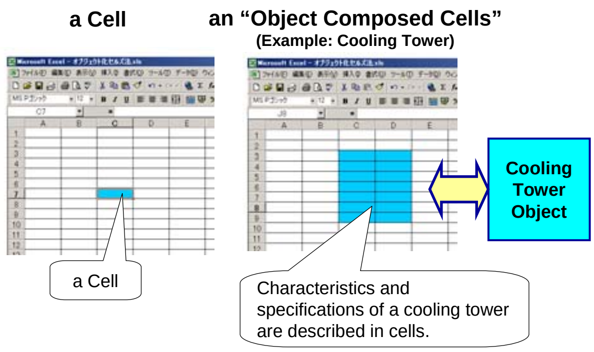


Figure 5 Cell and object consisting of cell group

CONSTRUCTION OF AIR-CONDITIONING SYSTEM

At first, prepare required objects in the object menu shown on the upper left in Figure 6. Next, "select", "copy" and "paste" required objects using the Excel functions to construct the air-conditioning system. As soon as required objects are pasted, the tool starts calculation among the objects. They are graphical operations. This form of individual, distributed, and mutual calculation without using the main program is regarded as object-oriented programming using the GUI. Figure 7 shows an example of objects. An object is composed of "Communication section", "Control section", "Method section (Calculation)" and "Property section (Specification)".

Figure 8 (1) shows a construction example of individual chiller unit. When the temperature and flow rate of cooling water are given as the boundary condition on the left and the temperature and flow rate of chilled water are given on the right in the same way, the tool calculates the data as the individual chiller unit.

Figure 8 (2) and (3) shows a heat source sub system where the outside air object, cooling tower object, cooling water pump object, refrigerator object and chilled water pump object are connected in the same way. When the outside air wet-bulb temperature and the temperature and flow rate of chilled water are given as the boundary condition, the tool simulates the sub system.

In the case of Figure 8 (1) and (2), the cooling water supply temperature and the cooling water return temperature are referenced to each other by each cell in table calculation. These items perform circular reference with each other, and can cause an error. The tool allows circular reference and offers convergent solution by repeated calculation, however, when the user selects "Tools" -> "Options" -> "Calculation Method" in table calculation, and turns ON the "Repeated calculation" check box shown in Figure 10.

All the user has to do is to connect objects when constructing a system using the object cells method. As a result, the user can easily create a large system as shown in Figure 9.

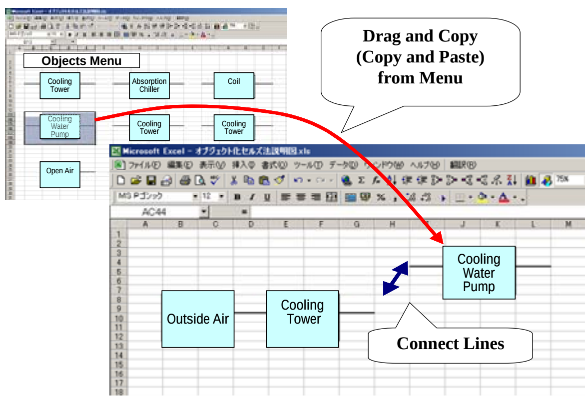


Figure 6 Object menu and system construction method

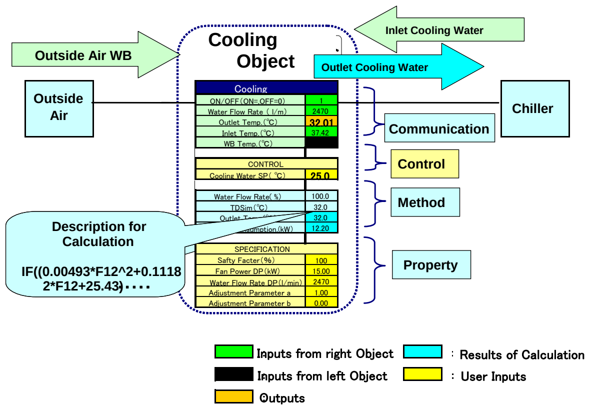


Figure 7 Example of object (Cooling Tower Object)

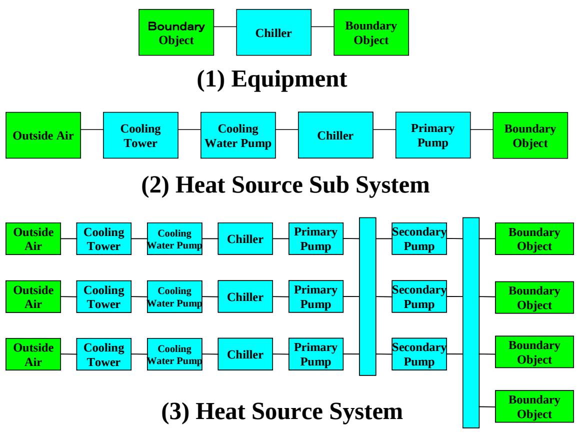


Figure 8 System construction example

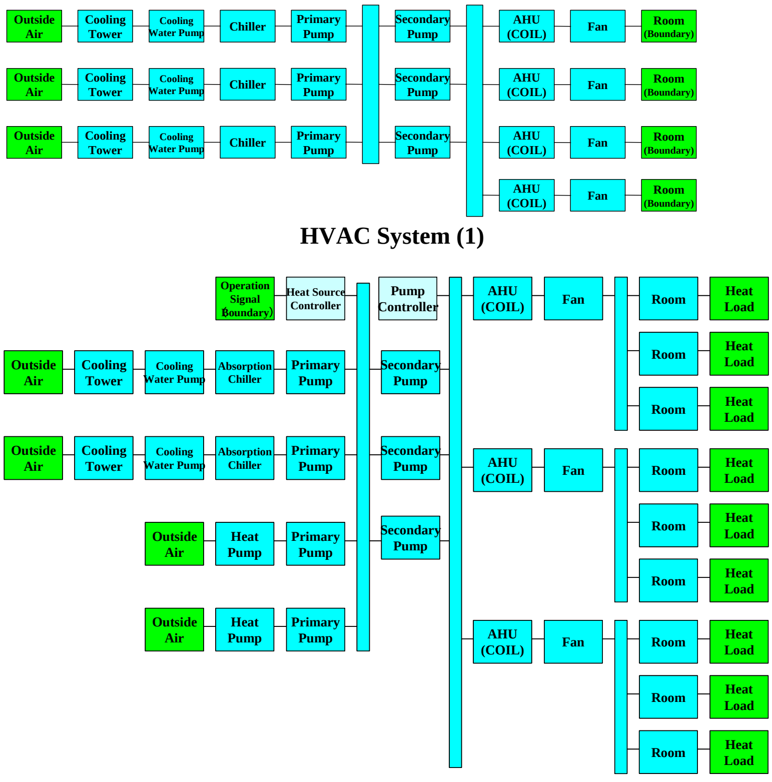


Figure 9 Construction example of entire system

CONCLUSION

This paper describes the basic framework of LCEM (life cycle energy management), and the necessity, positioning, role, etc. of the air-conditioning system simulation tool in LCEM.

It is considered that LCEM can be effective measures against global environmental problems and urban environmental problems considerably related to the building field (for example, COP3 and heat island).

In addition, this paper indicates the outline of features of the developed LCEM tool, solution used in the tool and air-conditioning system construction method in the tool.

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