FACES (FORECASTS OF AIR-CONDITIONING SYSTEM'S ENERGY, ENVIRONMENTAL, AND ECONOMICAL PERFORMANCE BY SIMULATION)

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ABSTRACT

FACES is a simulation tool for selecting an appropriate heat source system in the early building design stage.

Heat source systems have to be studied at an early design stage, because they are closely related to the floor plan. However, in an early design stage, most of the problems are unsolved, so that there is insufficient data for system simulations.

In order to enable detailed and accurate studies for various kinds of buildings and heat source systems, FACES utilizes full-scale programs for heat load calculation and system simulations. However, these programs themselves require numerous input data.

To bridge the gap between "insufficient data available" and "numerous input data required," automatic designing algorithms and numerous background data are built into FACES.

FACES makes it possible to appropriately study the amount of information available in any design stage, providing easy operation and accurate results.

KEYWORDS

Simulation, Heat source system, Automatic designing, Energy saving, Environmental evaluation, Economical evaluation

INTRODUCTION

FACES estimates energy, environmental, and economical performance of heat source systems by means of annual system simulation; it facilitates the study of the reduction of primary energy consumption, greenhouse gases emission, and annual owning and operating costs as well as leveling of electrical power load curve.

FACES contains five building simulation models: office, store, hotel, hospital, and hall; and 13 heat source system models including: thermal storage system, non-storage system, distributed air conditioning system, co-generation system and etc.

FACES is a tool for selecting the appropriate heat source system and for making a proposal to clients at an early designing stage. In order to design buildings, it usually requires stages of master planning, schematic design, and design development. Heat source systems have to be studied at an early stage, because they are closely related to the floor plan. However, in early stages, most of the problems are unsolved, and thereby the data are insufficient for system simulations.

Therefore, ordinary simulation programs often consist of a simple algorithm based on statistical data from old buildings. These simple programs, however, are not suitable for buildings that don't belong to those categories of old buildings. Furthermore, these programs don't permit detailed studies in later design stages.

To cope with these problems, FACES utilizes full-scale programs for heat load calculation and system simulations. These programs are adaptable to almost all buildings, but require numerous input data.

To bridge the gap between "insufficient data available" and "numerous input data required," automatic designing algorithms and numerous default input data based on many buildings (about 10,000 buildings in total) we designed in the past are built in FACES. This enables us to perform an appropriate study for the amount of information available. The automatic designing algorithms are based on our know-how, and automatically provide a proper building model and heat source system model.

FACES features are as follows:

(1) Interactive user-interface

(2) Various ways to input

(3) Automatic designing

(4) Accurate calculation

(5) Intelligible report

Interactive user-interface

The graphical and user-friendly interfaces, shown in Figure 1 to Figure 3, facilitate the program operation.

Anyone concerned with building equipment can use FACES and get results by easy operation. Only five input items such as building location, building function, total floor area, the number of stories, and type of heat source system are necessary to run FACES, because all other input items have default values.

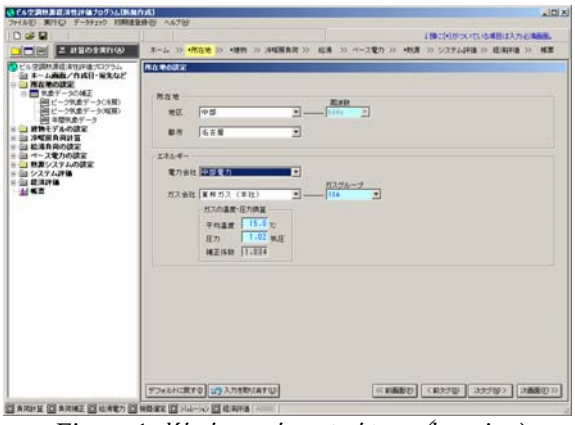


Figure 1 Minimum input item (location)

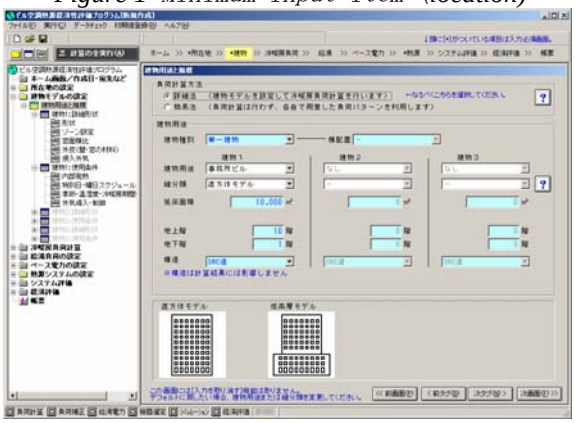


Figure 2 Minimum input items (building function, total floor area, and the number of stories)

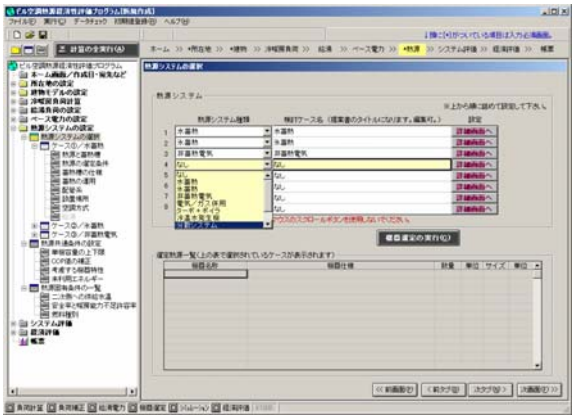


Figure 3 Minimum input item (heat source system)

Various ways to input

As a designing work goes on, detailed data can be added and modified in various ways in FACES.

Professional building equipment engineers can study various cases by the use of optional menus, such as proportion of building, heat insulating materials, window glasses, window area, air conditioning area, preset temperature, air conditioning term, internal heat gain, outdoor air intake rate, and so on.

Automatic designing

The Automatic designing algorithms create the building model, and specify architectural input data for FACES_ACLD that calculates peak and annual cooling and heating loads.

The Automatic designing algorithms also create the input data for heat source equipment, pumps, fans, air handling units, and so on for FACES_ACSS: energy simulation program.

Accurate calculation

FACES_ACLD(improved HASP/ACLD/8501) is based on HASP/ACLD/8501 and simulates the status of each machine under hour-by-hour cooling and heating loads in a way similar to BECS.

FACES_ACSS (improved HASP/ACSS/8502) takes into account the thermal and partial load characteristics of heat source equipment, operation schedules, and automatic controls in a way similar to HASP/ACSS/8502.

Because FACES_ACLD and FACES_ACSS output the simulation results of 8,760 hours in CSV format, users can handle data in spreadsheets.

Intelligible report

Figure 4 shows the results of peak load calculation. Figure 5 shows the results of automatic system designing. Figure 6 shows the results of system evaluation. Figure 7 shows the results of economical evaluation.

FACES creates a tabular and graphical output report consisting of summaries and breakdowns of energy, environmental, and economical performance of heat source systems for proposal. Figure 8 shows a sample of summary report. The summary report is in the form of an Excel book with VBA programs, so that users can customize the report.

As mentioned above, FACES automatically completes almost all the input data required for simulation and calculation, so that FACES creates the summary report at the early stages of design.

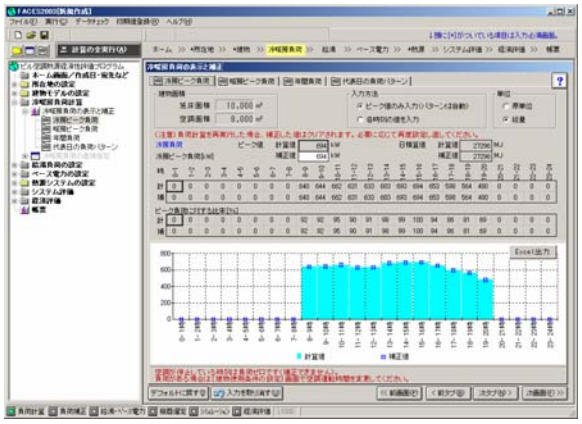


Figure 4 Peak load calculation results

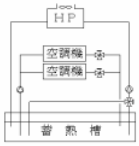
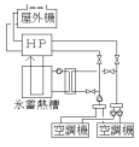
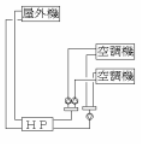
Figure 6 System evaluation results

Figure 5 Automatic system designing results

Figure 7 Economical evaluation results

Ⅰ．総合比較表　　2004/5/29

件名	テスト機材				
所在地	大阪				
建物種別	単一建物　10,000 ㎡				※　分母のmは延床面積です
建物用途	建物1 事務所ビル 個方体モデル	熱負荷とベース電力	冷房	暖房	給湯	ベース電力
延床面積	10,000 ㎡	ピーク負荷	835 kW	512 kW	0 kW	416 kW
空調面積	8,000 ㎡		83.5 W/㎡	51.2 W/㎡	0.0 W/㎡	41.6 W/㎡
階数	地上 10 階 地下 1 階	日積算負荷	32,577 MJ	18,932 MJ	0 MJ	5,279 kWh
構造	SRC造		3,258 kJ/㎡	1,893 kJ/㎡	0 kJ/㎡	527 W/㎡
空調期間	冷房 05/01～10/31 暖房 12/01～03/31	年間負荷				
空調時間	パターン1 8～20時 パターン2 8～18時		1,759 GJ 176 MJ/㎡	710 GJ 71 MJ/㎡	0 GJ 0 MJ/㎡	1,413 MWh 141 kWh/㎡

ケース名	A案 水蓄熱	B案 水蓄熱	C案 非蓄熱電気	D案
システム図				
イニシャルコスト	238,849 千円	238,679 千円	229,502 千円	千円
ランニングコスト	32,755 千円/年	32,132 千円/年	37,256 千円/年	千円/年
蓄熱槽容積	632 m3	64 m3		
熱源容量合計	411 kW	476 kW	835 kW	kW
選定機器	種類 kW 台数 空気熱源HP-R(R407C) 206 2	種類 kW 台数 空気熱源HP-R水(R407C) 238 2	種類 kW 台数 空気熱源HP-R(R407C) 278 3	種類 kW 台数
契約電力	653 kW	632 kW	790 kW	kW
電力消費量	1,798 MWh/年	1,851 MWh/年	1,835 MWh/年	MWh/年
ガス消費量	0 千m3/年	0 千m3/年	0 千m3/年	千m3/年
油消費量	0 kL/年	0 kL/年	0 kL/年	kL/年
LPG消費量	0 t/年	0 t/年	0 t/年	t/年
用水使用量	0 m3/年	0 m3/年	0 m3/年	m3/年
一次エネルギー消費量	1,779 MJ/(㎡·年)	1,832 MJ/(㎡·年)	1,831 MJ/(㎡·年)	MJ/(㎡·年)
TEWI kg-CO2/(㎡·年)	47	49	49	

対象範囲　：　建物全体　（消費税抜き）　　TE WI　：　総合等価温暖化影響（Total Equivalent Warming Impacts）　　FACES2003 Version 4.11.9

Figure 8 Summary report Simulation and experiment

Program Configuration

Figure 9 shows that FACES consists of a main program, custom files, five solvers, and databases. The main program provides the user-interfaces and controls the solvers. FACES features CSV format custom files that define the default input data for each screen, data check algorithms, and relational expressions between related input data. By defining algorithms in the files outside of the programs, it became possible to change algorithms without updating programs.

Execution Flow

Figure 10 shows major screens and solvers. The rectangles with PC icon show input screens, and the shaded rectangles are solvers: subprograms for calculation.

The solid screens show five minimum input items: building location, total floor area, building function, the number of stories of the building, and the type of heat source system.

The dashed screens show optional input items that enable detailed simulation. FACES has many optional input items, where entry is not required, since the program contains default values related to building function or type of heat source system.

The major solvers are the cooling and heating load calculator, hot-water and base-electrical-load generator, automatic heat source system designer, system evaluator, and economical evaluator. Each solver consists of many subprograms and is associated with numerous background data.

Upon execution, the main program activates solvers sequentially, and each activated solver runs using the input data, databases, and former solver results.

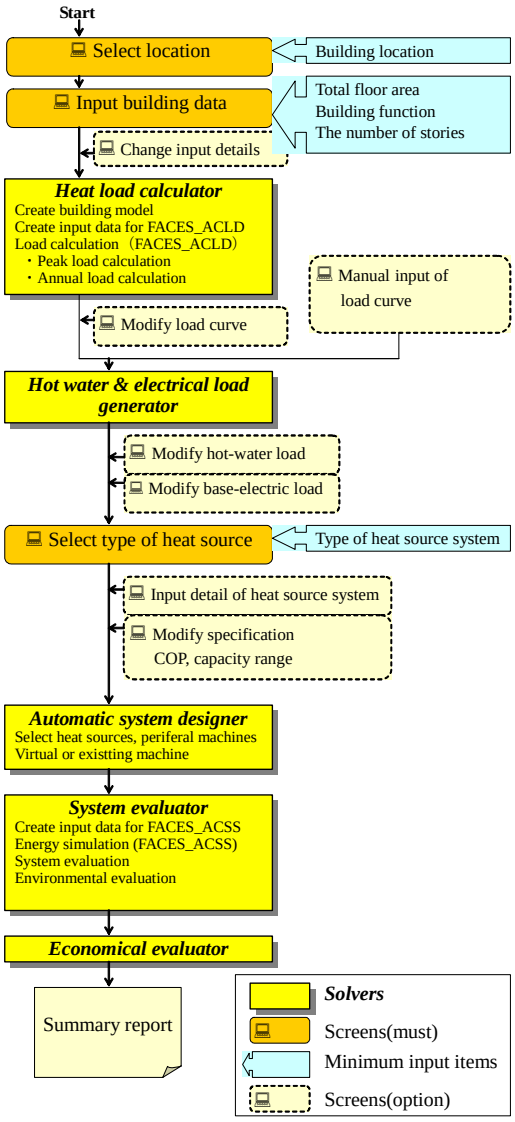


Figure 10 Flow of execution

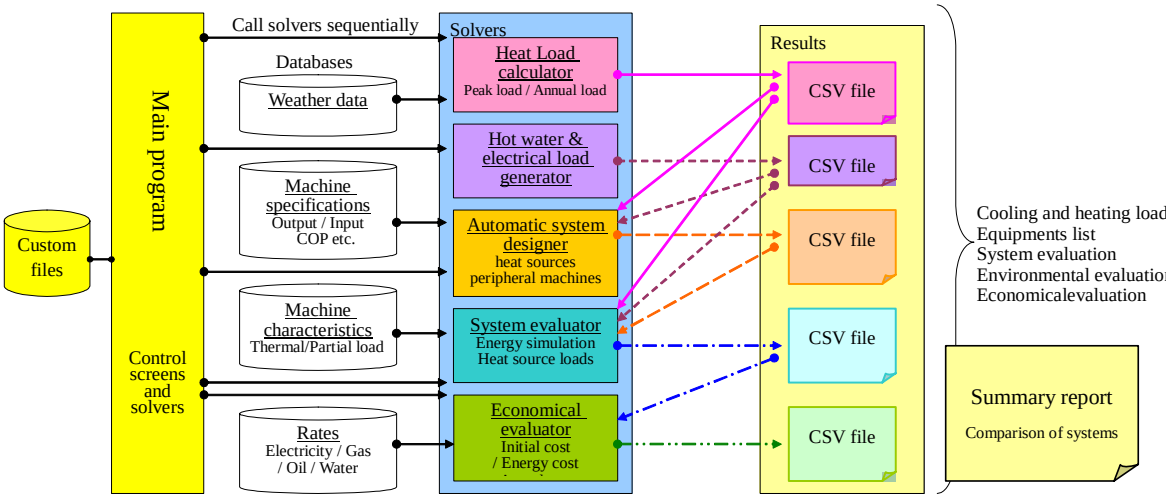


Figure 9 Configurations of FACES

Main program and major screens

The main program, written in Visual Basic, provides the input and output screens. The followingss are explanation of major screens shown in Figure 10.

(1) Selection of location

Location is one of the minimum input items. This factor affects cooling and heating load and energy consumption, costs, etc.

(2) Input of building data

Building function, total floor area, and the number of stories are also minimum input items. Office, shop, hotel, hospital, and hall are options for building functions. Each function model is equipped with default data such as proportion, internal heat gain and so on. These factors primarily affect cooling and heating loads.

(3) Input of details of building

Details of building (for example proportion and operating conditions such as interior heat gain) can be designated, but are not required. On selection of building function, all input items are automatically filled out with default data.

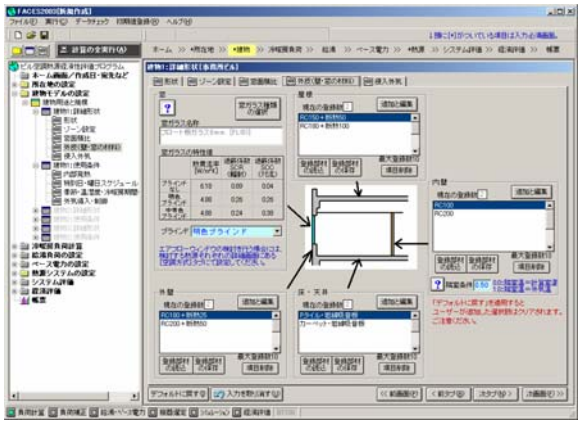


Figure 11 Details of wall, roof, and window

(4) Modification of cooling and heating loads

Calculated cooling and heating loads: hour-by-hour peak load, monthly load, and hourly load curve of each day, can be seen on the screen shown in Figure 4. The peak load and monthly load can be modified on this screen.

(5) Modification of hot-water heating load and base-electrical-load

Hourly and monthly hot-water heating load and base-electrical-load can be designated by users. The default values for hot water heating loads are based on measurements of several buildings. The hourly base-electrical-load curves are quoted from statistical data, but peak values were determined by the FACES consortium. We define base-electrical-load as the electrical load not related to air conditioning and hot-water supply, such as lighting, outlet, elevator, etc.

(6) Selection of type of heat source system

FACES contains 13 heat source system models including: water thermal storage system, ice thermal storage system, non-storage system, electrical and gas combined refrigerating system, turbo refrigerating system, absorption refrigerating system, co-generation system, and distributed air conditioning system. A maximum of eight heat source systems can be simulated at one time.

(7) Input of details of heat source system

Users can designate conditions of heat source systems in detail, but if detailed conditions are not clear, user input is not required. In selecting heat source system, input items are automatically filled out with default data. These data affect heat source capacity, energy consumption, and costs.

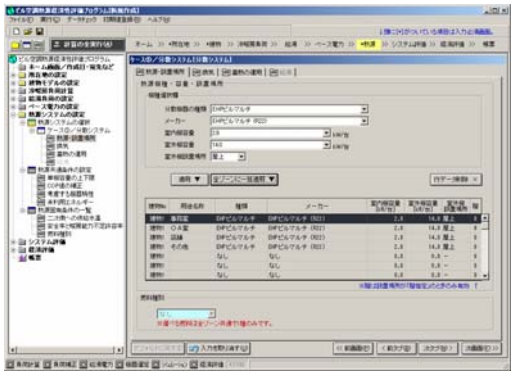


Figure 12 Details of heat source system

(8) Modification of heat source specification

Users can modify specification (for example COP and range of capacity, etc.).

(9) Results of system evaluation

The results of system evaluation can be seen on the screen. It shows the amount of energy consumption, the results of environmental evaluation, and the load curves of each heat source.

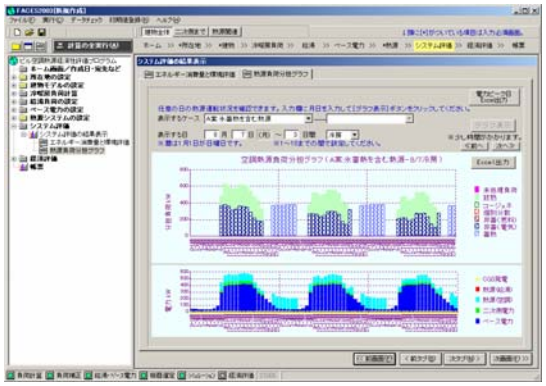


Figure 13 Heat source load

(10) Results of economical evaluation

On this screen, users can designate initial costs and running costs in detail. Users don't need to input data, because FACES fills out default data. Users can also see the result of the economical evaluation.

The relationships between the screens are very complicated especially in complex buildings and for complex heat source systems. The custom files control these complicated relations, and can be modified by building equipment designers themselves without the help of programmers.

Solvers

The details of the solvers shown in Figure 10 are as follows.

Solver-1 Cooling and heating load calculator

(1) Automatic building modeling

This solver, written in FORTRAN, creates input data for FACES_ACLD. Its input form (text file) is compliant with HASP/ACLD/8501, but not compatible, because FACES_ACLD has more functions than HASP/ACLD/8501. Besides, for peak load and annual load calculation, HASP/ACLD/8501 requires two kinds of input data, but FACES_ACLD requires one common input data.

(2) Cooling and heating load calculation (FACES_ACLD)

FACES_ACLD, written in FORTRAN, can calculate peak load and annual load. FACES_ACLD is an improved version of HASP/ACLD/8501. The added functions include the calculation of peak load, the calculation of intermittent air conditioning, and the air flow window. FACES_ACLD calculates the hourly cooling and heating load of peak days, and the annual hourly cooling and heating load, and then outputs the results in CSV format.

In order to calculate peak load, FACES_ACLD mainly applies the weather data belonging to MICRO-PEAK2000. If the proper location can not be found, users should select a nearby city and modify the data, or convert "Expanded AMeDAS Weather Data" to MICRO-PEAK2000 compliant form.

In order to calculate annual load, FACES_ACLD mainly applies the standard weather data of SHASE (The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). If the proper location can not be found, users should select a nearby city or apply "expanded AMEDAS weather data".

Peak load dominates the total capacity of heat source equipment, and annual load is applied in the annual energy simulation.

As described above, peak load calculation and annual load calculation respectively use different weather conditions, and also use slightly different internal heat gain. As a result, peak values of each result don't coincide. Usually, the peak value of the peak load calculation is greater than the peak value of the annual load calculation.

Solver-2 Hot-water-load and base-electrical-load generator

This program generates hourly hot-water and base-electrical load according to screen data. This program, written in Visual Basic, is included in the main program.

Solver-3 Automatic system designer

This program, written in C programming language, determines the size or capacity of ducts, fans, air handling units, secondary pipes, secondary pumps, storage tanks, heat source equipment, primary pipes, primary pumps, cooling towers, cooling water pipes and cooling water pumps in order.

In the FACES computation, heat source capacities are set mainly depending on the peak loads and so they usually are non-existent odd values, but those of existing machines are also available.

The specifications of heat source machines and peripheral machine designing algorithms are stored in the databases.

Solver-4 System evaluator

(1) Creation of input data for FACES_ACSS

This program, written in FORTRAN, creates input data for FACES_ACSS. The form of this data is compliant with HASP/ACSS/8502, but not compatible, because FACES_ACSS has more functions than HASP/ACSS/8502.

(2) Energy simulation (FACES_ACSS)

FACES_ACSS simulates the operation of machines on an hourly basis. This program, written in Fortran, is an improved version of HASP/ACSS/8502, adding ice thermal storage system, co-generation system, distributed air conditioning system, and detailed conditions. FACES_ACSS neglects over loads in order to reduce processing time.

(3) System evaluation and environmental evaluation

This program sums up annual energy consumption, heat source loads, environmental loads, and so on. This program is written in Visual Basic, and included in the main program.

Solver-5 Economical evaluator

This program calculates initial costs, energy costs, and annual costs. This program, written in Visual

Basic, is also included in the main program.discussion and result analysis

Prerequisites

With regard to energy consumption in offices, shops, hotels and hospitals, we compared simulation results with measurements.

The measurements are quoted from "Building Energy Consumption Reserching Report in 2002" of The Building-Energy Manager's Association. These data are classified only by building functions, but not locations, completion date and heat source systems.

We run FACES with minimum input data as follows:

- Location : Nagoya, Japan
- Bulding functions : office, shop, hotel, hospital
- Total floor area[m2] : 2,500 5,000 10,000 50,000 100,000
- Hot water supply : hotel and hospital only
- Heat source system :
  1. Water thermal storage system
  2. Ice thermal storage system
  3. Non-storage electrical system
- Others: default

Results of simulation

Figure 14 to Figure 17 show the results of simulation and measurements. The values of FACES results are taken as average of three heat source systems.

These figures show FACES results are considerably close to measurements in each building function.

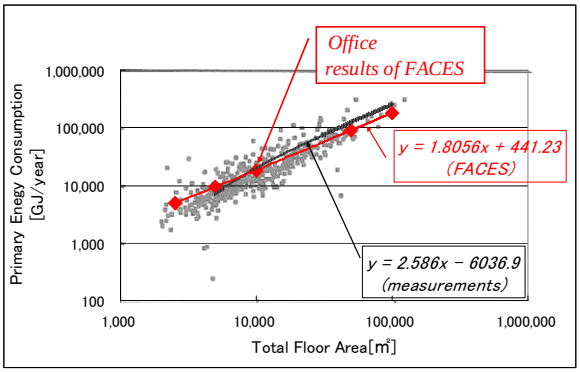


Figure 14 FACES results and measurements: office

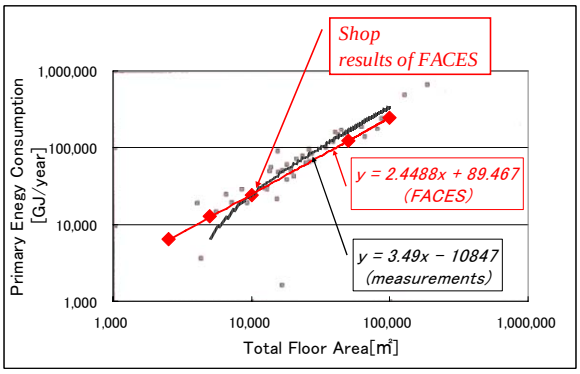


Figure 15 FACES results and measurements: shop

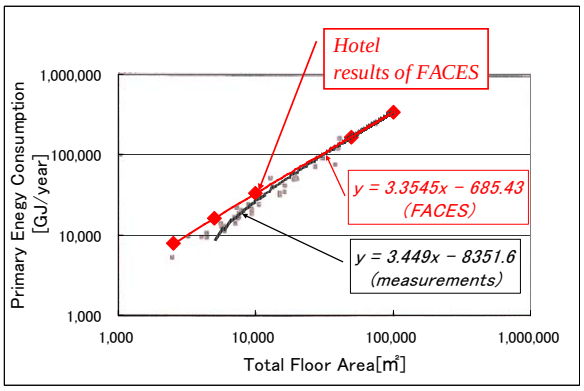


Figure 16 FACES results and measurements: hotel

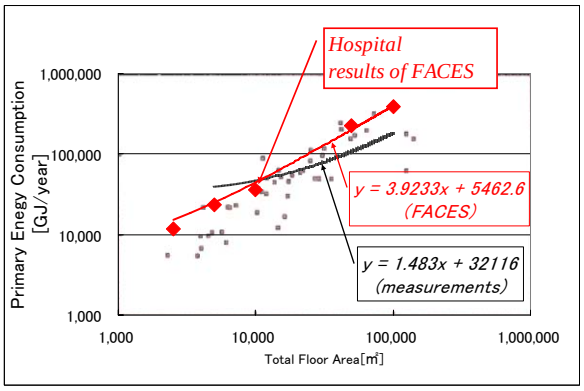


Figure 17 FACES results and measurements: hospital

CONCLUSION

The authors developed FACES as a simulation tool for selecting an appropriate heat source system in the early building design stage that enables accurate simulations even if building data is insufficient.

Figure 18 shows the targetted position of FACES.

HASP/ACSS/8502 is suitable for detailed studies, but it requires numerous input data and is difficult to use.

On the contrary, a simple program is easy to use but its accuracy is low. Even if a certain condition is changed, the result does not change accordingly and the same answers are issued.

It can be concluded that we have developed this easily operable energy simulation program to produce satisfactory accurate calculation results.

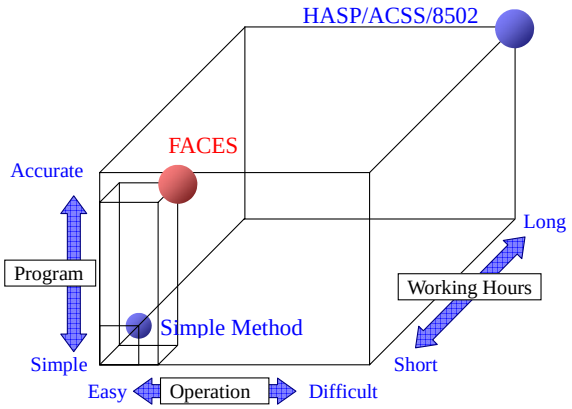


Figure 18 Position of FACES

ACKNOWLEDGMENTS

This research was made in close cooperation from each company of the Hokkaido Electric Power Co., Inc., the Tohoku Electric Power Co., Inc., the Tokyo Electric Power Company, the Chubu Electric Power Co., Inc., the Hokuriku Electric Power Company, the Kansai Electric Power Co., Inc., the Chugoku Electric Power Co., Inc., the Shikoku Electric Power Co., Inc., the Okinawa Electric Power Co., Inc, the Tokyo Electric Power Services Co., Ltd., and the Kandenko Co., Ltd. The authors hereby express their gratitude for their thoughtful cooperation.

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