A WINDOWS-BASED PC-SOFTWARE TO DESIGN THERMAL ENVIRONMENT IN RESIDENTIAL HOUSES

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ABSTRACT

We developed a PC-software to estimate thermal environment of a residential house. To make the software practical for non-technical people, the easiness of operation was our main interest in this development. This led us to adopt a fully graphic interface, dynamic database of the structural walls and a comparative output of the thermal estimation. As a result of error comparisons within various numerical methods, we decided to use the full implicit finite element method to calculate the transient heat flow in the walls.

INTRODUCTION

The thermal resistance of residential houses in Japan has increased steadily in recent years as a result of increased concern over energy-savings and comfort of residents. Traditionally, the wall of Japanese house was a paper. We had had no thermal resistance in the house envelope. In winter, we had gotten localized warmth by burning small fires in a chilly room, rather than heating the whole room, which is standard practice in North Europe and America. Thus, the recently solution from the northern countries has led us not only to change the envelope performance, but also to reform our life style. Moreover, Japan spreads from a cold northern area to a warm southern area. House design changes somewhat to the condition of the locality and the life style of the residents. This means we should design the environment within these conditions. As one theme of the HOUSE JAPAN project, we are developing PC software for designing residential houses with the best solution for thermal comfort and energy-savings based on the resident's life style and the locality. The main feature of the software which runs on Windows-95 is easy operation with a graphical interface.

This software has three type of the way to estimate thermal performance of the house. The first is based on the steady state heat transfer process and it shows the thermal resistance of whole house. The second is based on the transient heat transfer process and it shows the annual variation of the room temperature and energy consumption for heating. The last estimation is based on the CFD analysis and it shows the temperature distribution in a room to visualize the thermal comfort in a short while. What we have spent some efforts to develop this software are selection of the numerical model which estimates transient heat transfer by means of calculation error and how easily we get the temperature distribution.

GRAPHICAL INTERFACE DESIGN

We decreased the work load by the original way to define the room shape and setting defaults for each parameter. It is very normal to use a CAD system to design a house. But, CAD software is made specifically for planning, which means the space definition and the outward appearance of the building depend on the materials used. Nowadays, various functions can be added to CAD, like walk-through capabilities that take the user on a virtual walk through the house being planned. The features we intend to realize can be considered as an added functions, but the environment in the residential house is more personal than an office building. It requires more substance.

Figure 1 shows a PC screen from our software. This is the main area for planning the physical environment. In order to make operation easy enough for people who are unfamiliar with PCs and house planning, the interface is fully graphical and suitable graphical symbols are used to show the character of each room.

We decided to compose a plan of each unit room for drawing rooms. Figure 2 shows the way how rooms are drawn in comparison with the normal CAD way. The numbers in the figure are the work step numbers. The basic shape of the room is limited to a rectangle in order to decrease the workload. User can easily edit the room shape, for example, to add extra corner or to change the room scale, after drawing the basic shape.
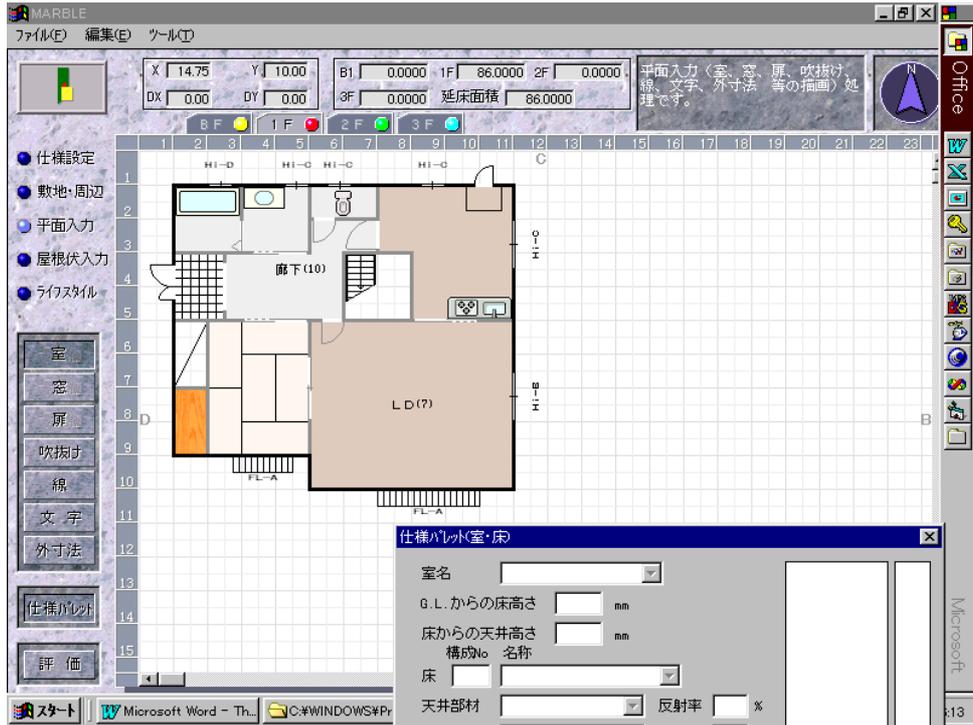
Figure 1.　Software screen for drawing floor plans

This scene is drawing the plan. There are menu buttons on the left side to select function and what to draw. The functions are specification setting, land & neiboughers, drawing of plan, drawing of roof and life style.
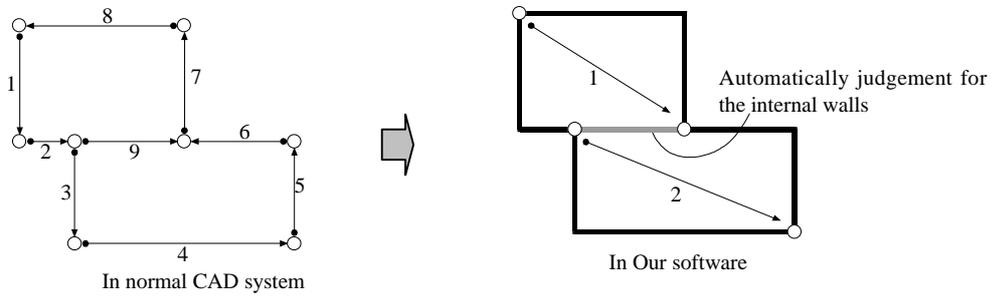

In normal CAD system

In Our software

Automatically judgement for the internal walls

Figure 2.　How rooms are drawn

Number of type 3		
Name: Out wall 1		
Number of layer : 2		
	material code	Thickness
1	32	25.0
2	17	50.0
3	46	12.5

List of structure

Number of point 9	
Coordinate	
X	5.5
Y	8.0
Z	3.0

List of point

Number of room 2		
Space volume 50.0		
Number of wall 6		
Code	Number	Area
1 1	2	20.0
2 2	1	20.0
3 3	3	7.5
4 3	4	10.0
5 3	5	10.0
6 3	6	7.5

List of rooms

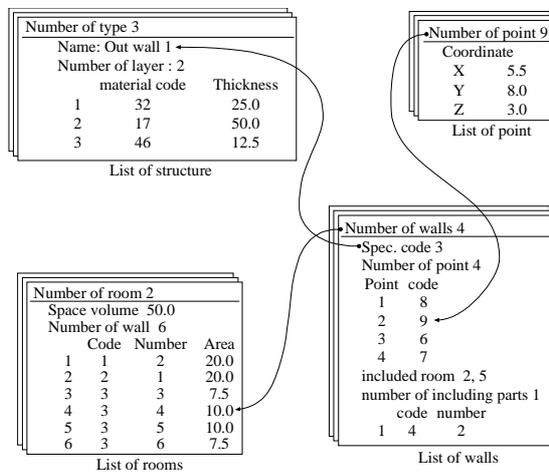| Number of walls 4	
Spec. code 3	
Number of point 4	
Point	code
1	8
2	9
3	6
4	7
included room 2, 5	
number of including parts 1	
code	number
1 4	2

List of walls

Figure 3.　Database structure

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DATABASE OF WALL STRUCTURES

The software handles the information on space definition and the index of wall construction used for calculations of thermal behavior. Generally, the walls of a house are nearly uniform in structure except for some walls like a facade with decorative tile. Thus, the user does not have to set the specifications or the structure for each wall he creates; he needs only to set the default value in the first step. Figure 3 shows the structure of the dynamic construction database used in our program. The wall data must have information on space location, size, shape, structure and so on. The relational database consists of four parts.

The first part is a list of points. This defines the space location of each point which is the definition of a wall. The point data is composed of coordinate values from the x, y and z axes, and the wall number which contains the point. The second part is a list of walls. This is composed of various sets of points which form the wall and the number of the specification in the structure list. Point sets also show the shape of the wall. The third part is a list of spaces. The spaces include the room and any structural space like an attic space. This is composed of a wall number list and space volume. The last part is a list of structures. Each has a number of layers and a code for each layer. From these lists, we are able to calculate the thermal performance in each wall. If the user draws a room, the program adds a new room to the spaces list, some walls to the walls list, and many points to the points list. If the user edits or deletes one of the rooms, the same procedure is performed automatically by using the rules of RDB.

These data sets can also be used to translate data sets of the other CAD systems. We have already been able to convert output in DXF file format. Most CAD systems have translation capabilities so as to accept data sets in DXF file format. So, our software also provides an easy way to input the plans of a house into all CAD systems.

CALCULATION OF BASIC THERMAL BEHAVIOR

The software shows the total heat loss of the house being planned and the heat flux from each of the walls, which is compared with the other insulation levels.

The method for estimating the thermal environment in a residential house is divided into two parts. One is done in the steady state in order to present the thermal performance of the house easily. The other is based on the transient transfer state to predict the temperature variation and energy consumption. The former estimation gives us the total heat loss value ('Q-value' called in Japan) defined by the next equation, which is almost the international standard output for thermal resistance.

$$Q = \{\Sigma(K_i A_i) + C_a V_n\} / S \qquad (1)$$

Here,

K_i: Specific heat conductance of a wall [J/m^{2}sK]

A_i: Specific area of a wall [m^2]

C_a: Heat capacity of air [J/m^{3}K]

V_n: Volume of ventilated air [m^3/s]

S : Total floor area [m^2]

Subscript i indicates the wall number.

Figure 4 shows the Q value compared to the different insulation sets. This allows us to confirm the performance of the planned house and any weak points in the house in terms of thermal environment.

According to each room temperature and thermal resistance of the wall, we can get the surface temperature of each, and the proportional volume of heat flux transmitted by each. The software also gives us the seasonal heat loss and the running cost which is converted in the unit cost of petroleum and the efficiency of the standard oil heater as shown in table 1.

Table 1. Energy cost

System		Unit cost	Unit heat	Efficiency
Fan heater	Petroleum	40 yen/l	9.8 kW/l	0.9
	City gas	33 yen/m^3	3.8 kW/m^3	0.9
	Propane gas	146 yen/kg	14 kW/kg	0.9
Electric heater		23 yen/kW		1.0
Air conditioner		23 yen/kW		2.5

We analyzed the degree of numerical error from the various numerical methods for transient heat flow processes. We tested the finite difference method (FDM) and the finite element method (FEM) for the space scheme, and the full implicit/explicit and the Crank-Nicholson formula for the time scheme. Each method is applied to a one-dimensional axis, vertical to the wall surface. The governing equation is as follows.

$$\{ A \} [X]^m = \{ C \} [dX^m/dt] + [B] \qquad (2)$$

Here,

[X] Scalar of temperature

{A} Weight matrix of space

{C} Weight matrix of

[B] Weight scalar of heat source

[dX/dt] Variation of temperature within delta time

m Suffix of the time scheme, n: full explicit, n+1: full implicit, n+1/2: Crank-Nicholson

We used a linear approximation for the interpolate function in the FEM.
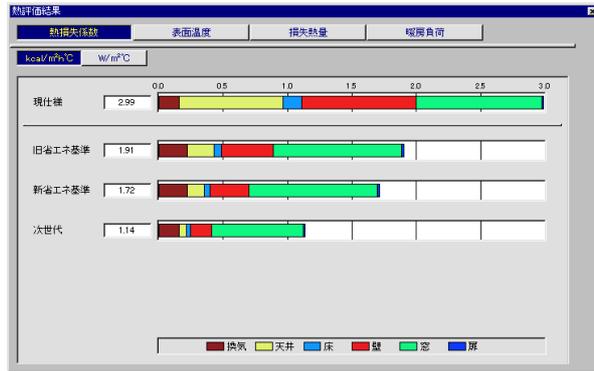
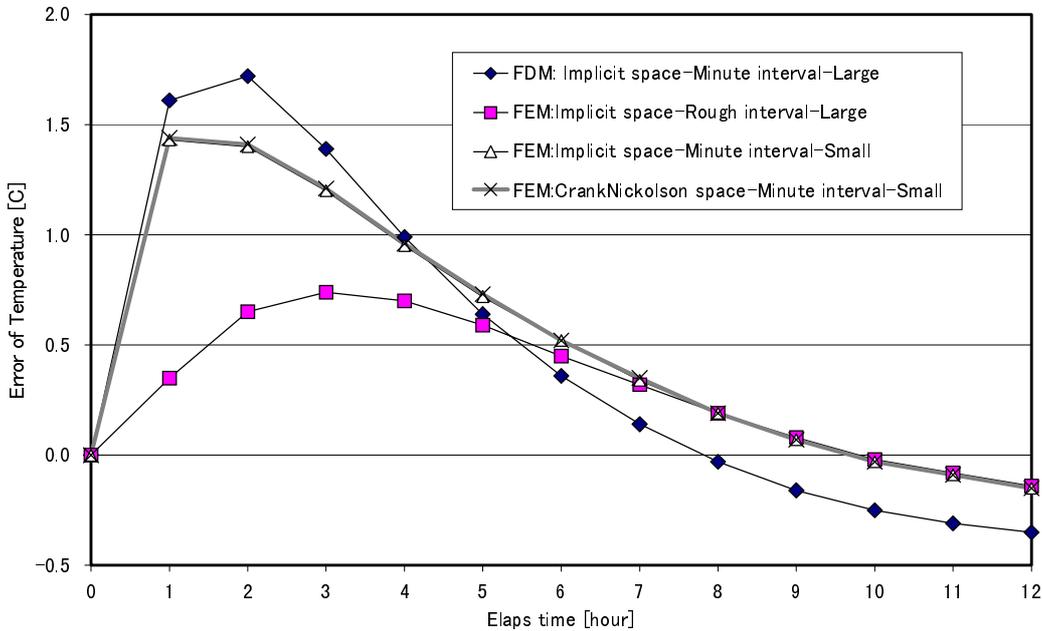Figure 4. Example output estimate (Q-value of the house)

Figure 5. Numerical error of temperature variation

Figure 5 shows the numerical error in the in-door surface temperature variation corresponding to 10 degree centigrade increase in adjacent air temperature at the start. Since we use in-door surface temperature to calculate the heat flux which is flown through the wall, this figure shows the numerical error of the heat flux. The wall is made of three layers: 100 mm thick concrete, 30 mm insulation and 10 mm gypsum board which is at a uniform 10 degree centigrade temperature in the initial state. The boundary conditions at the both surface of the wall are the third type, which uses specified values of ambient air temperature and heat transfer coefficient.

We confirmed that all results converge on the steady state value. We obtained that a solution using the finite difference method with minute space divides, and a minute time interval was the most accurate. The figure shows the temperature difference between the various solutions and the accurate solution which is obtained by the explicit FDM with minute division of the space and time as mentioned above.

The implicit FEM with rough division and big interval is accurate enough to be taken as the correct solution. In contrast, the implicit FDM with big interval, which is usually used in Japan to estimate thermal performance of the house, has large error.

SIMPLIFIED CALCULATION METHOD FOR TEMPERATURE DISTRIBUTION

On addition to information about energy consumption, we need degree of thermal comfort in order to design the thermal performance of walls and openings. From our field researches, temperature difference between near floor and near ceiling is very large in a room. In typical case, it is more than 10 degree Celsius. It is clear that the thermal comfort depends on various factors, such as surrounding temperature, air velocity, wall temperature, humidity, activities and so on. But our field research results show that the temperature distribution is so big that the other factors except the surface temperature do not affect the comfort especially in winter. Thus, it can be said in our objects, thermal comfort is mainly effected by the temperature of surrounding air. In order to decide the optimal plan, the distribution of air temperature and velocity must be taken into account. We think the humidity is another problem which should be estimated together with the human health and building durability. In this paper, we think simply the less distribution is the better space.

In our software, the time to express the distribution should be shorter. As well known, the normal way to calculate the temperature distribution by CFD needs long time. We are developing the numerical method for expressing the distribution of temperature and air velocity in a short time. Naturally enough, we sacrifice the accuracy in exchange for speed.

We tried the zero equation model. According to the measurement results in the test laboratory (Hanibuchi et al. 1997), we obtain the linear relation between turbulent diffusivity and average velocity in case of forced convection heating equipment. Chen et al. reported same result. In our zero equation model, the turbulent diffusivity depends only on the average velocity as follows.

$$v_t = C_v r\, l_m V \qquad (3)$$

here,

v_t : Turbulent diffusivity
C_v : Constant parameter = 0.1
r : Density [kg/m^3]
l_m : Length scale [m] (constant)
V : Average velocity [m/s]

The heat transfer coefficient adjacent to the wall in the boundary condition is constant. The numerical calculation is based on the SIMPLE algorithm (Patanker 1980). Figure 6 shows the calculated room. Room shape is 7m x 5m, 2.5m height. Table 2 shows the numerical conditions of calculations and elapsed time for the calculation in our PC.

Table 2. Numerical condition and elapsed time

Name	Divide scale	Number of division	Total points	Time
Rough	50cm	12 × 12 × 10	1440	30 sec.
Minute	20cm	45 × 34 × 29	44370	240 Sec.
k-e				450 Sec.

Hardware spec : same as Pentium II(450 MHz)　+　RAM 256 MB

Figure 7 shows the result of zero equation model for turbulence. In case of minute division, both distributions of temperature and diffuisivity show good agreement with the result of k-• analysis. In case of rough division, results are too bad to make us abandon this model in spite of the too short calculation time. In case of minute division, the calculation time is about half of k-• model. 4 minutes is short enough to wait the operator who is designing one's house.

Of course, there is no theoretical basis of this model. We limit application of this model to forced convection field in a room since we have not yet tested the other condition.

CONCLUSION

This software would be successful if users take to the easy operation and wish to live in a comfortable saving-energy room. To improve the easiness and reliability of operation, we start monitor test in corporation with experts.

The structural database in this software allows us estimate other performance such as day lighting and acoustic property, and so on.

ACKNOWLEDGEMENTS

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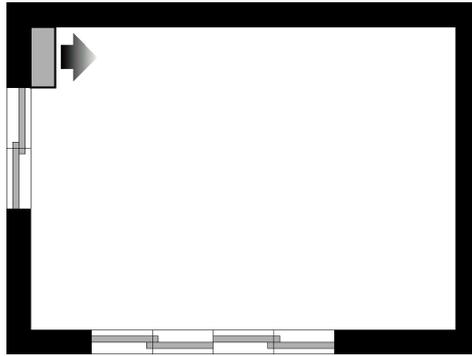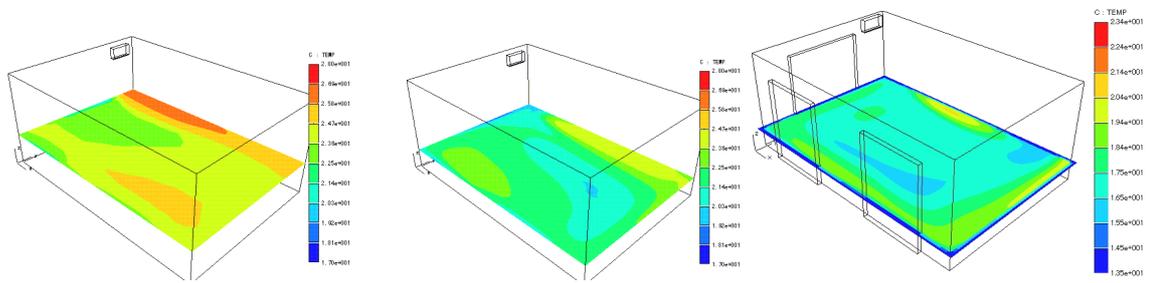
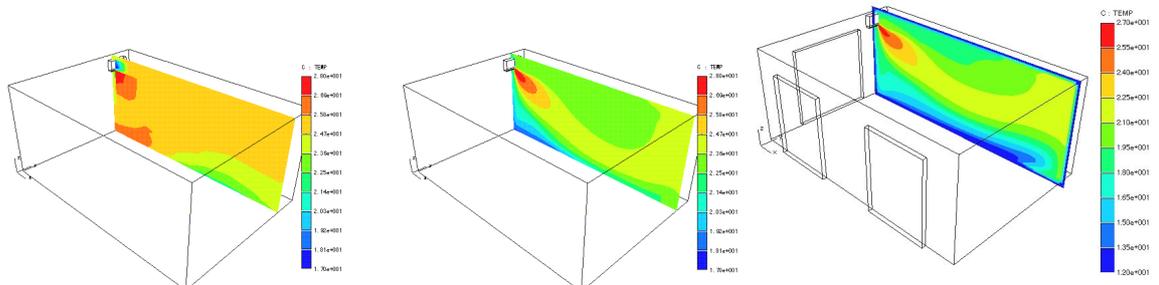Figure 6. Calculated room

(1) Rough division　　　　　　(2) Minutes division　　　　　　(3) k-e model

(a) Horizontal temperature distribution (60cm height from floor)
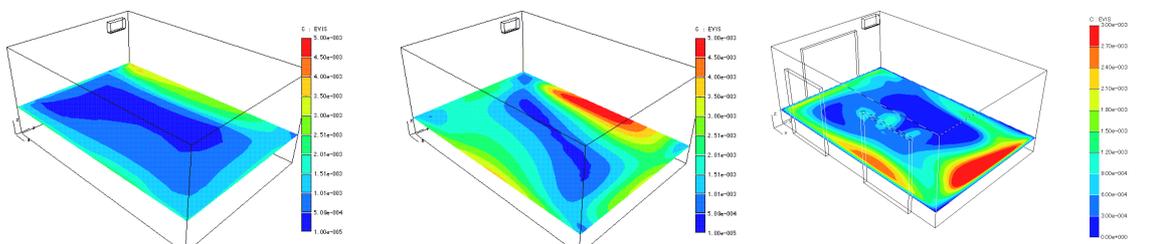

(1) Rough division　　　　　　(2) Minutes division　　　　　　(3) k-e model

(b) Vertical temperature distribution

(1) Rough division　　　　　　(2) Minutes division　　　　　　(3) k-e model

(c) Horizontal distribution of turbulent diffusivity

Figure 7. Numerical results