# COMPUTER-AIDED SYSTEM FOR THERMAL AND VENTILATION DESIGN - DESIGN SUPPORT FOR AUTOMATICALLY ATTAINING TARGET ROOM TEMPERATURE -

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## ABSTRACT

In designing thermal and ventilation systems in buildings, an examining process of exchange between the designers and analysts is needed. This study aims to expand the simulation system of thermal and ventilation into an automated process for the design of optimum thermal and ventilative conditions, based on the expertise of analysts, the analysis of the thermal environment and the modification of the design, by automating these functions. This paper describes the outline of the computer-aided system for thermal and ventilation design, the inferring method of design-modification parameters and the effectiveness of the system through the application results to the cases in which the room temperature in a multizone building is targeted as the thermal and ventilative conditions.

## KEYWORDS

Design support, Computer-aided design, Thermal design, Ventilation design, Ventilation analysis, Natural ventilation, Mechanical ventilation, Expert system, Multizone building

## INTRODUCTION

In designing thermal and ventilation systems in buildings, simulations of thermal and ventilative conditions are necessary to establish an intended thermal environment in a room. In this case, an examining process of exchange between the designers and analysts is usually needed. This process is very significant in the execution of design tasks. It demands a high level of expertise and is quite time consuming, while it offers the possibility of shortening the design procedure through increased efficiency of the design tasks.

This study aims to expand the simulation system of thermal and ventilation into an automated process for the design of optimum thermal and ventilative conditions. This would enable the development of an expert system which would realize the thermal environment targeted. This system, 'THERVISS', based on the expertise of analysts, the analysis of the thermal environment and the modification of the design, by automating these functions, will assist designers.

In the previous papers, the computer-aided system for thermal and ventilation design was applied to the cases in which the temperature of a single room1) and the room contaminant concentration in a multizone model2) were targeted as the thermal and ventilative conditions. The system outline and the method of inferring design-modification parameters were described and the execution examples mentioned. This paper discusses a multizone model in which the room temperature is taken up as the target environment and the method of inferring the effects of parameters of adjacent rooms on the room temperature to be designed is incorporated to allow the inference of design-modification parameters by using various methods. The execution example using such methods is described below, and inferential accuracies of room temperature and execution time required, resulting from the use of these methods, are also mentioned.

## THERMAL AND VENTILATION DESIGN SYSTEM

### *System Overview(Automated Design Procedure)*

Figure 1 shows the system's configuration and flow. Following the input of data, simulation of the thermal and ventilative conditions is done, and the results are checked. Failure to achieve the goal requires the further process of inferring which parameter(s) should be changed. Following the change of the data involved, simulation of the thermal and ventilative conditions is redone. This trial process is repeated until the target is attained. The simulation of the thermal and ventilative conditions is performed, by using a previously developed multizone ventilation simulation system named 'MULTI/VENTL'[3] (based on a

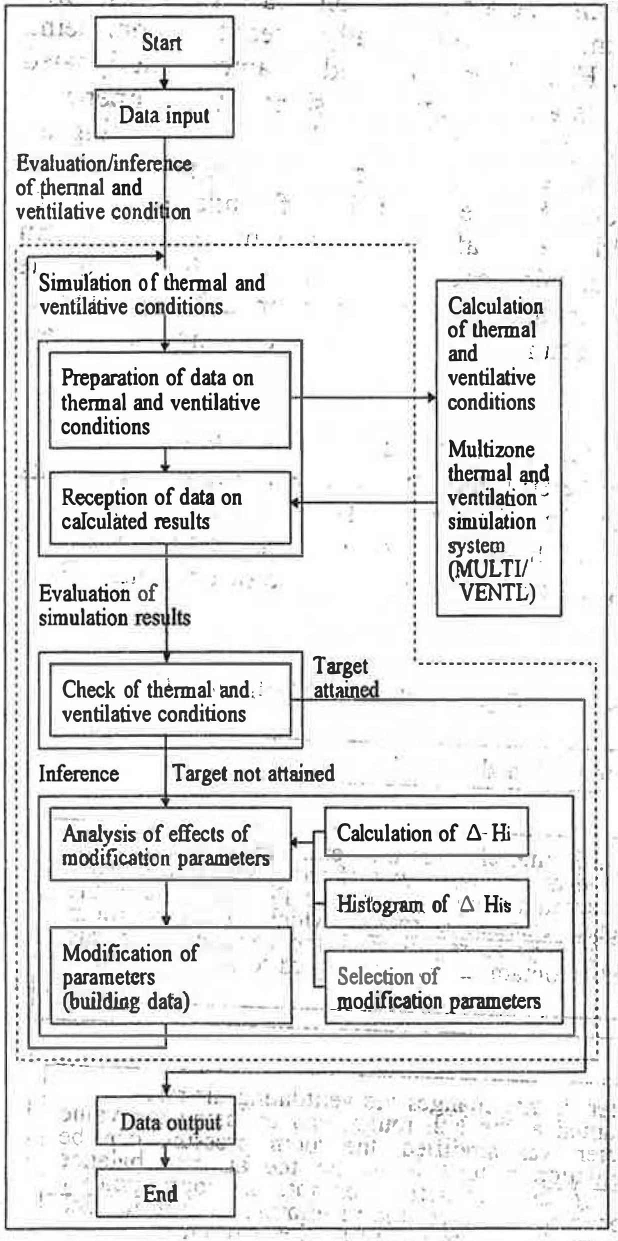


Figure 1: System's configuration and flow

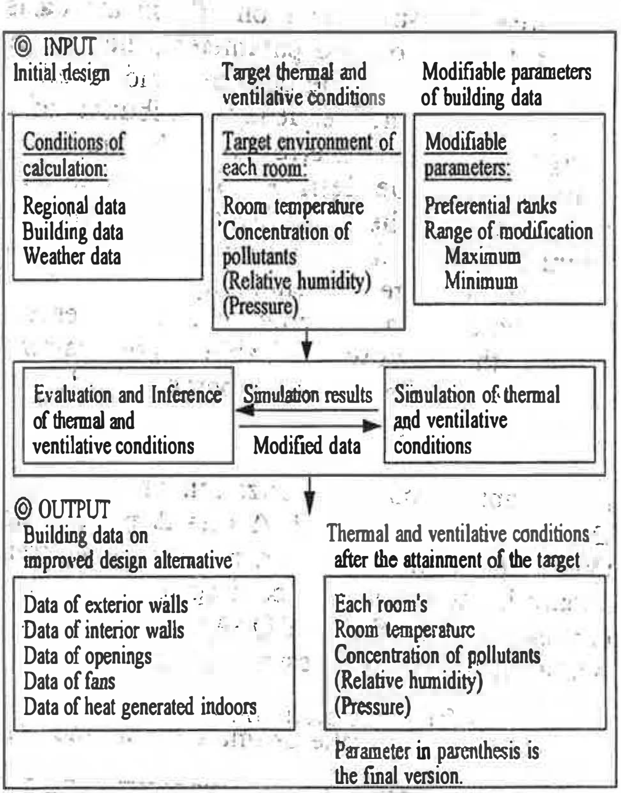


Figure 2: System input and output procedures

● Pi:Modification parameter of the room to be designed

$$\Delta H_i = \frac{\partial \Sigma H}{\partial P_i} \cdot \Delta P_i \quad \cdots\cdots\cdots ①$$

● Pi:Modification parameter of adjacent room

$$\Delta H_i = \frac{\partial \Sigma H}{\partial t_n} \cdot \frac{\partial t_n}{\partial P_i} \cdot \Delta P_i \quad \cdots\cdots\cdots ②$$

Pi : modification parameter i of building data (for example, area A of an opening)
tn : adjacent room temperature (℃)
Δ Hi : the estimator of an increase in heat gain, when modification parameter i varies by Δ P(W)
Δ Pi : range of modification of modifiable parameter i (for example, (=$P_{i\max}$- $P_{i\min}$)/ND)
ND : number of divisions
ΣH : heat balance equation of the room to be designed where H is a heat gain by building element(W)

heat balance equation applicable to each room coupled with an air rate balance equation) to analyze room temperature, room pressure, room humidity, room pollutants concentration and ventilating air rate. Figure 2 shows the input and output procedures of the system. The initial design, the targeted thermal and ventilative conditions, and design-modifiable data are inputted. The thermal and ventilative conditions in this paper are related to the room temperature. Following the execution, alternatives for an improved design, and the thermal and ventilative conditions after reaching the goal, are obtained. The modifying process of parameters to attain the target, variations in the room temperature and alternatives for ultimate design improvement are then output.

### *Inferring Design-modification Parameters*

Based on the simulation results of thermal and ventilative conditions, $\Delta H_i$, the estimator on increased heat gain by each parameter is calculated by using Equation ① and ②, with regard to the parameters which have been inputted as being able to be modified. For the modification parameters of the room to be designed, $\Delta H_i$ can be calculated by using Equation ①. For the parameters of rooms adjacent to the room to be designed, $\Delta H_i$ can be calculated by using Equation ②, on the basis that the temperature of adjacent rooms will change due to modified parameters, thereby causing the air ventilation and heat transmission between the room to be designed and its adjacent rooms to thermally affect the room being designed. Next, the frequency distribution of $\Delta H_i$ is determined and parameters designated as higher ranks are inferred as such parameters, as are effective to designate the temperature of the room to be designed. If the modification parameter $P_i$ related to the ventilating air rate, (such as the opening area(A), monitor area(A), flow factor of opening($\alpha$), and magnification of fan(m)), varies by $\Delta P_i$, it would be likely that the inferential accuracy of $\Delta Q_i$, the change of ventilating air rate, would greatly affect the efficiency of the system with regard to the number of trial processes. In this paper, based on such likelihood, the three methods shown in Table 1 are examined in terms of how to infer $\Delta Q_i$. Inferential accuracies of the room temperature and the execution time required resulting from these methods are compared.

In the approximate linearization of the calculation of the ventilating air rate($Q$ $[m^3/s]$), $\Delta p_1(=\Delta p - \Delta_1)$ and $\Delta p_2(=\Delta p + \Delta_2)$ are determined, and between these two points, $Q=f(\Delta p)$ is approximated by using the straight line $Q=A\cdot\Delta p+B$, in which $\Delta_1$ and $\Delta_2$ should be determined according to ventilative conditions (Figure 3). For a monitor, it can be expressed in the form of $Q=A\cdot pr+B$. Here $\Delta p$ is the pressure difference of opening $[Pa]$, while pr, the room pressure $[Pa]$

TABLE 1:Calculation of $\Delta H_i$
(the estimator of an increase in heat gain for each Method(A-C))

| | |
|---|---|
| Method A | Calculation of $\Delta H_i$ using Equation ① and ② |
| Method B | Method A +<br>For design-modification parameter $P_i$ that changes the ventilating air rate: With the room temperature attained at the Nth round of trial used as a known, and through the air rate balance equation using the value of $P_i + \Delta P_i$ after the parameter was modified, a nonlinear calculation routine which solves the room pressure is added. By using the room pressure obtained, the ventilating air rate in each opening can be calculated to obtain $\Delta H_i$ with regard to N + 1 round. |
| Method C | Method A +<br>For design-modification parameter $P_i$ that changes the ventilating air rate: With the room temperature obtained at the Nth round, and by using the value of $P_i + \Delta P_i$ after the parameter was modified, the room pressure can be obtained through a linear calculation routine based on the air rate balance equation in which calculation of the ventilating air rate is approximately linearized. By using the room pressure obtained, the ventilating air rate in each opening can be calculated to obtain $\Delta H_i$ with regard to N + 1 round. |

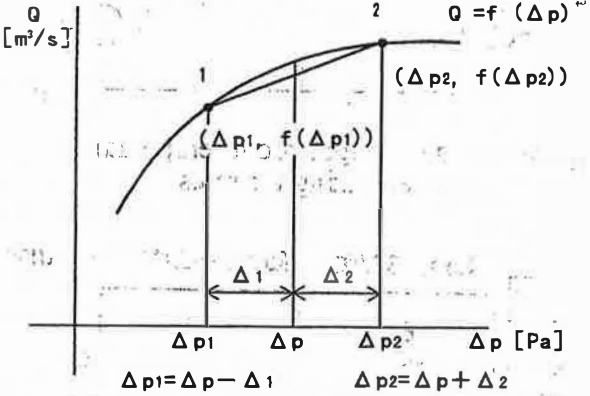
## EXECUTION EXAMPLE

### *Executing Conditions*

Table 2 shows the executing conditions and Table 3 shows the initial design alternatives, modifiable parameters and their modifiable limits for the building examined. Here, the first room has the target thermal and ventilative conditions, with the target temperature of 37 ℃. The inside temperature of the first room under the initial design alternative is 41.2 ℃(Figure 4), or 4.2 ℃ higher than the target room temperature.

TABLE 2:Executing conditions

| | | |
|---|---|---|
| Calculation site | Tokyo(35.68° N.L. and 139.77° E.L.) | |
| Calculation time and date | 12:00 hrs, August 24 | |
| Outside temperature and humidity, Wind direction and velocity | 30.0 ℃ and 55%, SWS and 5.0m/s | |
| Rate of total horizontal solar radiation | 814W/m² (direct:640, sky :174) | |
| Rate of horizontal nocturnal radiation | 58W/m² | |
| Target room and temperature | Room 1, 37 ℃ or less | |
| Amount of sensible heat generated indoors | Room 1<br>290.7kW | Room 2<br>290.7kW |
| Amount of latent heat generated indoors | Room 1<br>58.1kW | Room 2<br>58.1kW |



Q = f(Δ p) can be approximated between two points (1 and 2) by using Q=A · Δ p+B. A and B are determined by using pr(which was obtained in the previous calculation step and corresponds to the Δ p). Δ 1 and Δ 2 are variable and should be determined according to ventilative conditions.

Figure 3:Linearization of the calculation of ventilating air rate

TABLE 3:Modifiable parameters and possible range of modification

| Building data | Modifiable parameters | | | | Initial value | Changeable range (%) | Range of modification |
|---|---|---|---|---|---|---|---|
| Opening 1 | OP1 | Area | (m²) | A | 23.0 | 75 ～ 200 | 20% of Changeable range |
| Opening 2 | OP2 | Area | (m²) | A | 23.0 | 60 ～ 110 | |
| Opening 3 | OP3 | Area | (m²) | A | 23.0 | 75 ～ 200 | |
| Monitor 1 | MO1 | Area | (m²) | A | 23.0 | 75 ～ 200 | |
| Monitor 2 | MO2 | Area | (m²) | A | 46.0 | 96 ～ 116 | |
| Exhaust fan 1 | EF1 | Magnification* | (−) | m | 1.0 | 50 ～ 300 | |
| Exhaust fan 2 | EF2 | Magnification* | (−) | m | 1.0 | 50 ～ 300 | |
| Roof 1 | RF1 | Heat transfer coef. | (W/m² K) | U | 3.07 | 62 ～ 100 | |
| Roof 2 | RF2 | Heat transfer coef. | (W/m² K) | U | 3.07 | 62 ～ 100 | |

*) The exhaust fan is approximate, in its characteristic curve, to the quadratic equation ($p=a \cdot Q^2+b \cdot Q+c$). The fan's magnification m means the fan's revolutions in percentage, in which its characteristic curve is ($p=a \cdot Q^2+b \cdot m \cdot Q+c \cdot m^2$).

p: fan's static pressure (Pa) Q: fan's air rate ($m^3/s$)

### *Results*

Figure 5 shows the results of design improvement alternative ultimately obtained through the execution of the system based on methods A, B and C. For method C, examining the changes in the pressure difference Δ p of each opening, Δ 1=0.294Pa and Δ 2=0.196Pa were applied to obtain the results shown. Figure 6 shows the room temperatures and the selected design-modification parameters such as the opening area, monitor area, fan's magnification and heat transfer coefficient of roofs that evolved in the process of changing the design by means of the individual methods. In the ultimate design alternatives, the results differed slightly by method.

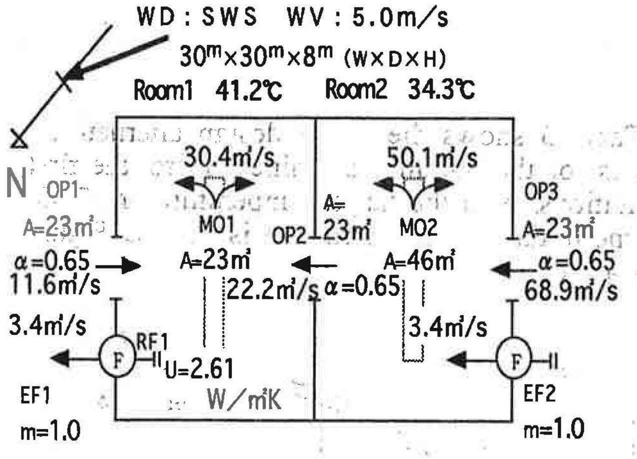


Figure 4:Initial design, room temperatures and ventilating air rates

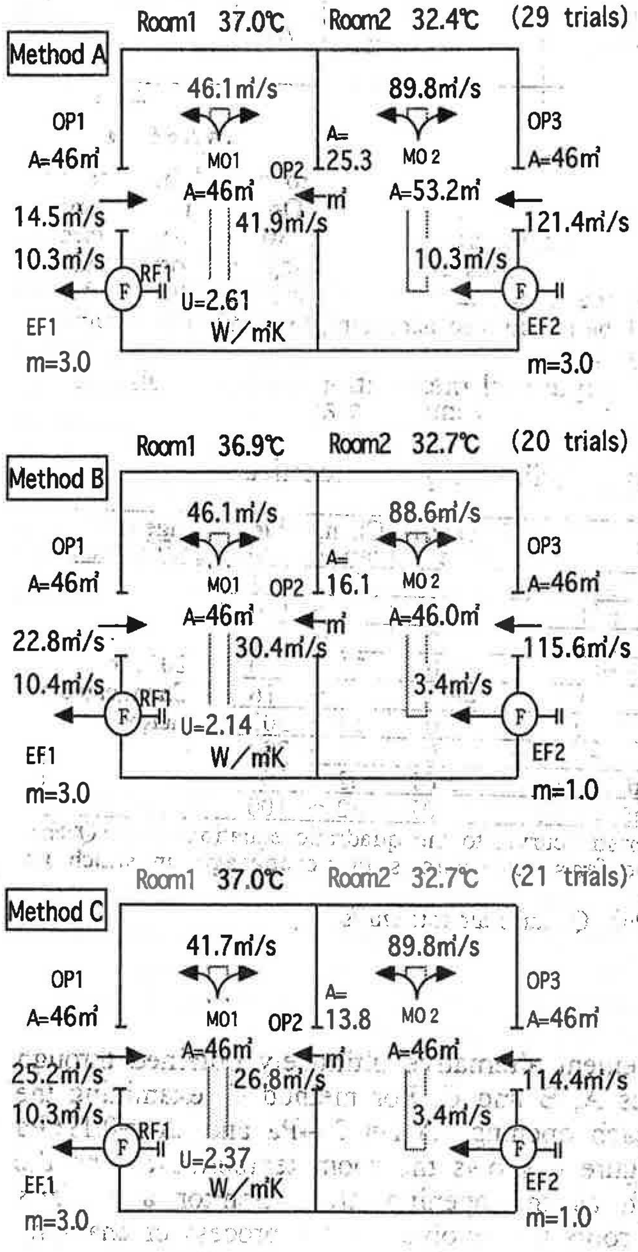


Figure 5:Improved design alternatives, room temperatures and ventilating air rates

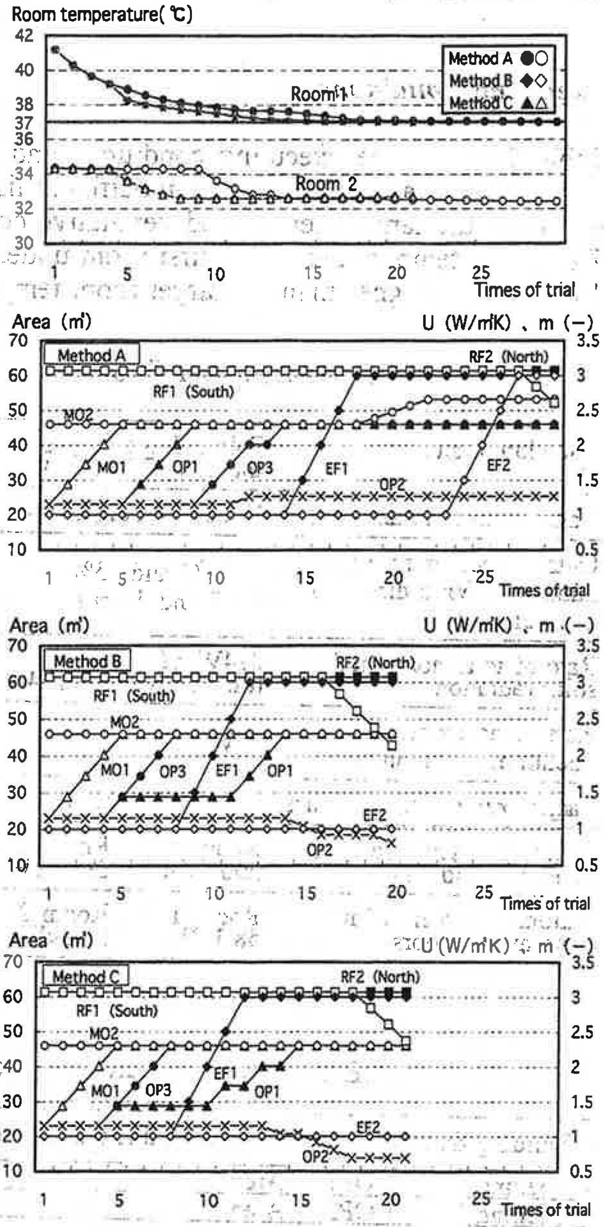


Figure 6:Changes of room temperatures and modification parameters

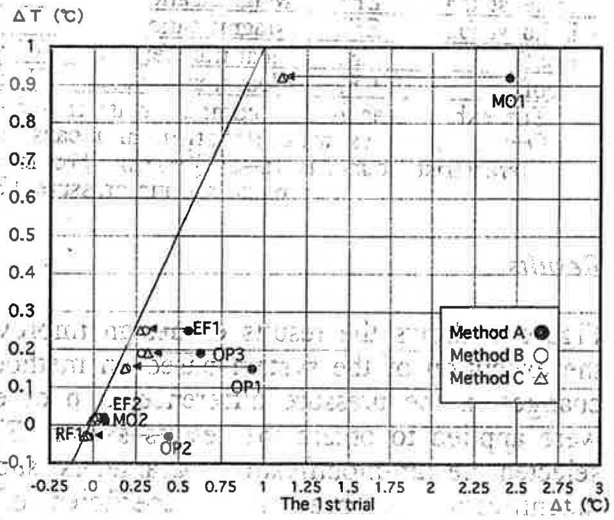


Figure 7:Inferential accuracies of room temperature change

### *Considerations*

Here, the accuracies of the first room's inside temperature inferred by methods A, B and C respectively are examined. Figure 7 plots the examined results of accuracies of the first-round inference conducted in the trial process of attaining the target room temperature. The estimator of the room temperature change calculated from $\Delta$ Hi is set as $\Delta$ t. The room temperature difference before and after modifying the parameter, obtained through the simulation of the room temperature carried out by using MULTI/VENTL, is hereby set as $\Delta$ T. ($\Delta$ t is taken to be positive when the room temperature is predicted to drop, while $\Delta$ T is taken to be positive when the room temperature dropped.) In the methods A, B and C, both $\Delta$ t and $\Delta$ T are indicative of positive correlation. However, correlation is greater in methods B and C than in method A, hence the accuracy of inferring design-modification parameters increased. Furthermore, with the area of opening 2 increased, in method A, the room temperature changed ($\Delta$ t>0 and $\Delta$ T<0) contrary to the inference, but in methods B and C, it turned out to be as inferred ($\Delta$ t<0 and $\Delta$ T<0). With this, the number of trials to attain the target room temperature amounted to 29 in method A, 20 in method B and 21 in method C. Methods B and C maintain the same level of inferential accuracy. Concerning the execution time, methods A:B:C =1:3.58:0.98, or method B took a longer time due to the effect of convergent calculation of the room pressures in each trial. From this execution example, the effectiveness of method C was the greatest from the viewpoints of inferential accuracy and execution time.

## CONCLUSIONS

In this paper, in a multizone model, the computer-aided design system for attaining the target room temperature of a particular room to be designed, has been discussed. In the inference of effectiveness of design-modification parameters, an examination was conducted by the methods of inferring the ventilating air rate when it was changing as a result of the parameter modification, and these methods were applied to the execution example for comparison. The results indicated that the method of inferring $\Delta$ Hi, which was based on the approximate linearization of calculating the ventilating air rate, was the most effective in the accuracy of inferring the room temperature and execution time. In the case of this method, the values of $\Delta_1$ and $\Delta_2$ affected the number of trials (convergency), so it is necessary to determine the best set of $\Delta_1$ and $\Delta_2$. In order to further improve the convergency, it is necessary to vary $\Delta$ Pi, a range of modifications and to simultaneously change related parameters by building up the knowledge available.

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