

COMPARISON OF REPRODUCIBILITY OF A REAL CAV SYSTEM BY DYNAMIC SIMULATION HVACSIM+ AND TRNSYS

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ABSTRACT

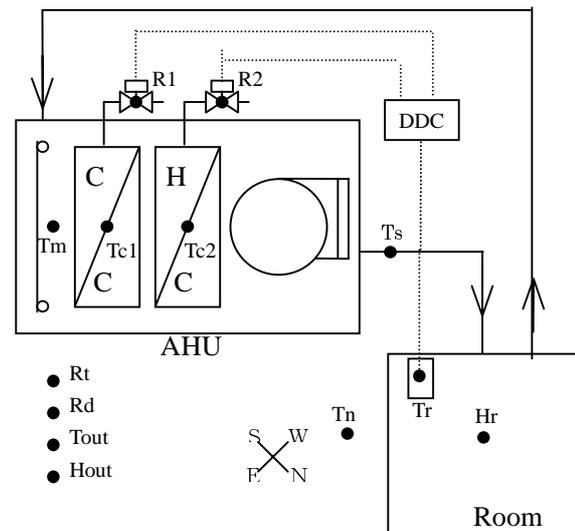
It is necessary to use the dynamic simulation program to evaluate the dynamic characteristic of the HVAC system. Some dynamic system simulation programs have been developed, but researches concerning the reproducibility of the dynamic HVAC system characteristic are not so much until now. In this research, HVACSIM+ developed by NIST, USA, and TRNSYS developed by Wisconsin University solar energy laboratory, USA, is discussed for this purpose. Reproducibility of two programs and possibility to use them to generate the database for Fault Detection and Diagnosis were verified by comparing the simulated results and the actual measurements. Moreover, some findings of convenience of program were obtained by comparing difference of calculation algorithm in two simulation programs.

INTRODUCTION

At the phase of research and development for schematic and preliminary design of HVAC system, if dynamic simulation technique is used, the system can be evaluated whether to meet the demands or not by comparing simulation models of various HVAC systems. Setting and adjusting control parameters and performance of equipment can be evaluated as well. In this research, the actual measurements and the simulated values using HVACSIM+ and TRNSYS in a real HVAC system with single duct and Constant Air Volume were compared on two different conditions, which are the normal and faulty conditions. The present paper discusses the dynamic reproducibility of the component model in two simulation programs and possibility to generate the database for Fault Detection and Diagnosis and then discusses the convenience and usefulness of two programs by comparing the calculation algorithm of them.

MEASUREMENT ON HVAC AND ROOM

The real CAV Air Handling Unit System of a



Ts, Tm: temperature of supplies air, and return air
 Tr, Hr, Tn: temperature in room, relative humidity in room, temperature in adjacent room
 Tc1, Tc2: temperature of supply water in cooling coil and heating coil
 R1, R2: valve-opening rate for chilled water and hot water
 Rt, Rd, Tout, Hout: global solar radiation, direct solar radiation, outdoor temperature, outdoor relative humidity

Fig.1 The outline of the object system and measured points

conference room in the research facilities in Tsukuba City was chosen as an object system. The outline of the object room and the object HVAC system are shown in Table1, Table2, and Fig.1.

A central monitoring system and a data logger were used for obtaining measured data. For simplification of the simulation model, the damper of outdoor air intake to AHU was closed. The measurement conditions for both states are shown in Table3.

The measured points are 13 and are shown in Fig.1, which include temperature and humidity of outdoor air, solar radiation at the site, temperature of each point around the AHU, and the room temperature and humidity. They were measured at the interval of three minutes. The weather conditions of the normal and faulty states are shown in Fig.2 and Fig.3 respectively.

Table 1 Outline of object room

Structure	RC
Use	Conference hall
Floor area	180 m ²
Ceiling height	3.0 m

Table 2 The HVAC system

Air-condition method	Single duct CAV method	
Fan	Supply air flow rate	2600 m ³ /h
	Static pressure	0.45 kPa
Chilled water coil	Cooling capacity	13.5 kW
	Chilled water flow rate	32 / min
	Chilled water temperature	7-13 °C

Table 3 Outline of measurement

State of system	normal	fault
Date	Aug 7, 1997	Aug 17, 1997
Weather	Fine, sometimes cloudy	cloudy
Measured time	7:00-17:30	7:00-17:30
Operating time	8:00-17:30	8:00-17:00
Set point temp. (adjacent room)	26 (24) °C	25(25) °C
PI controller	Proportional band=2 °C Integral time =4 minutes	Proportional band =2 °C Integral time =4 minutes
Lighting	2.88 kW	2.88 kW
Number of occupants in room	7 (16:00-17:30)	not

MODELING OF SIMULATION

In order to figure simulation models, it is necessary to combine component model given in each program. An example, diagram of the composed simulation model for HVACSIM+ is shown in Fig.11. An initial value of each variable should be given at the beginning of simulation, which were set by referring to the design values or the actual measurements of the real HVAC system. However, the following 1) – 4) were assumed in modeling.

- 1) The center point temperature of the room was supposed to represent the room air temperature.
- 2) As the heated water is not supplied in summer, it is not necessary for the simulation model to contain the heating coil. Therefore, the AHU is composed of merely two component, the fan and the cooling /dehumidifying coil.
- 3) For simplification, two windows in the southeast and northwest of the room were replaced by one window with the summed area of them.
- 4) A dedicated chilled water pump is not equipped for this AHU in the real building, so it was difficult to know the water flow rate accurately. Then, an assumed pump, which should be needed in HVACSIM+, was decided by the design water

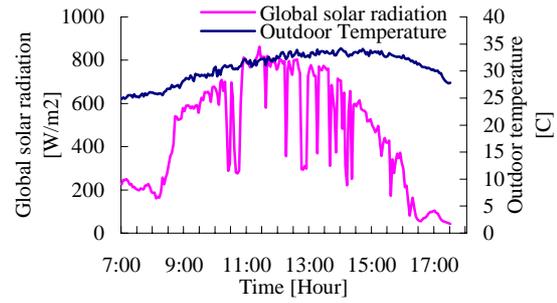


Fig.2 Weather at the normal condition

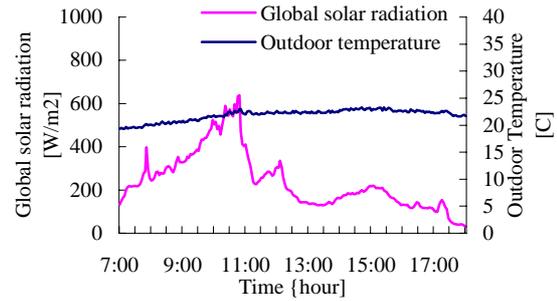


Fig.3 Weather at the faulty condition

pressure head and the design maximum water flow rate. The chilled water flow rate in the coil was obtained relying on the valve opening rate signal with the equal percent characteristic.

It is not necessary to assume the pump in TRNSYS; the chilled water flow rate was calculated as a function of the design maximum chilled water flow rate, the valve opening rate signal and the equal percent characteristic.

EXAMINATION OF COMPONENT LEVEL AND ADJUSTMENT OF PARAMETER

HVACSIM+ and TRNSYS have subroutines called TYPE. Each TYPE has given for calculating each subsystem of HVAC system. By combining TYPEs, it is possible to execute overall AHU systems simulation.

Reproducibility of the TYPE in both programs were evaluated by comparing simulated values, which were the outputs of the TYPE by inputting the measured data, with the measured one. And differences of the calculation algorithms between HVACSIM+ and TRNSYS were compared, and the method of adjusting the parameters was examined.

1) PID Controller

The actual chilled water valve was controlled with PI controller in the real system. PI control was reproduced by set the differentiation time in PID Controller TYPE to 0. Both PID Controllers in two programs are designed with the velocity form algorithm derived from the trapezoid approximation of error signal basically. But PID Controller TYPE

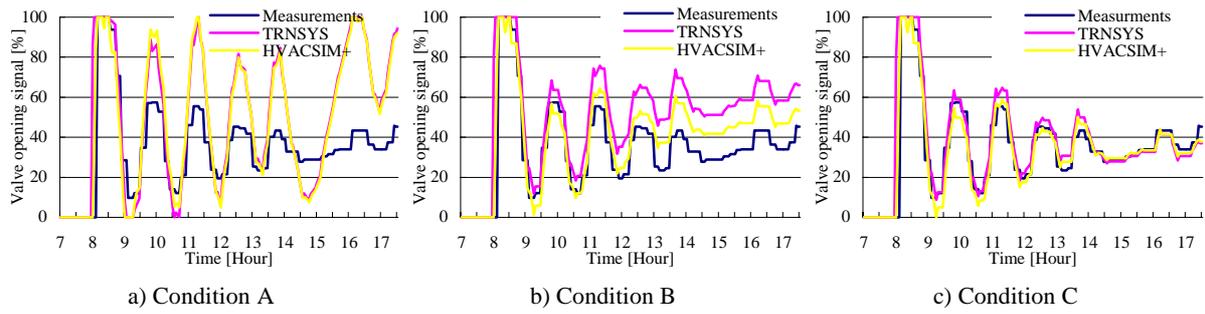


Fig.4 Valve opening rate (Nomal operation, component examination)

of HVACSIM+ have not dead band, but have set point kick up prevention algorithm, in which the calculation error when the room air temperature set point changes suddenly is considered. Fig.4a) shows the comparison of the actual measurements and simulated values of the chilled water valve opening rate signal, when a PI control parameter, dead band, and a mechanical error of the room air temperature set point are not considered (Condition A in Table4). The valve-opening rate of simulated values indicated much higher or lower at the max. and min. points of oscillation than the actual measurements. Because PID Controller TYPE in the current program of HVACSIM+ had not the dead band, it was added to one. The dead band is usually adjusted at the commissioning phase, therefore it is very difficult to obtain a real one. Therefore, it has been adjusted to 0.1 °C by the trial and error method (Condition B in Table4), and the calculated results were shown in Fig.4b). The cycle of the valve opening rate is getting smaller, and simulated values approach nearer to the actual measurements as compared to those obtained in condition A. However the difference of the actual measurements and the simulated values are growing with the passage of time. It may be because of accumulation of the mechanical error caused in the room air temperature set point value by a certain reason, and then it brought about errors between the actual PID Controller and calculation error due to integration function. Moreover, a little difference in the simulated values between HVACSIM+ and TRNSYS is seen. For to remove the difference of the actual measurements and the simulated values, a little error, which were 0.004 °C in HAVCSIM+ and 0.007 °C in TRNSYS (condition C in Table4), are given to the set point of the room air temperature, and the calculated results were shown in Fig.4c). Therefore, it is understood that the simulated values of the valve opening rate signal can both reproduce the actual measurements very well by adjusting dead band and mechanical error of the room air temperature set point in each calculation.

2) Chilled water coil and valve

The actual measurement does not contain the

Table 4 Parameter (component, normal condition)

Calculated condition	A	B	C	
			HVAC	TRN*
PID controller dead band [°C]	0.	0.1	0.1	
Set point error [°C]	0.	0.	0.004	0.007
Effective heat capacity in room [kJ/K]			6000	7500

*HAVC : HAVCSIM+, TRN : TRNSYS

chilled water flow rate. The measured returned air temperature, the measured valve opening rate signal and the measured chilled water temperature were inputted to examine the chilled water coil TYPE and the valve TYPE by comparing the simulated supply air temperature and the measured one.

The equations for the chilled water coil given in two programs are almost the same. However, while HVACSIM+ has a dynamic coil model, which takes the dirt of the surface inside the tube into consideration, a static model without considering it has given for TRNSYS. The parameters of the coil and the valve input in each TYPE are decided according to the design value. The simulated chilled water flow rate using two programs are shown in Fig.5, and the comparison of the simulated values and the actual measurements of the supply air temperature are shown in Fig.6. Fig.5 is clearly shown that chilled water flow rate simulated by HVACSIM+ and TRNSYS are almost same. Moreover, it is understand that both simulated supply air temperatures are corresponding to measured one very well, even if the calculation algorithm in the chilled water coil TYPE of HVACSIM+ and TRNSYS are different. There is not much difference between the simulated values and the actual measurements; therefore it could be concluded that both HVACSIM+ and TRNSYS have possibility to accurately reproduce the coil and the valve system.

3) Room calculation

It is necessary to combine several TYPEs, which are the zone model TYPE, the building surface TYPE, the shadowed fraction TYPE and so on, when the air temperature and relative humidity in

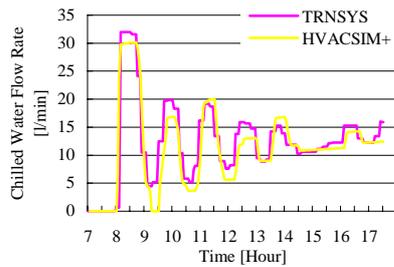


Fig.5 Chilled water flow rate

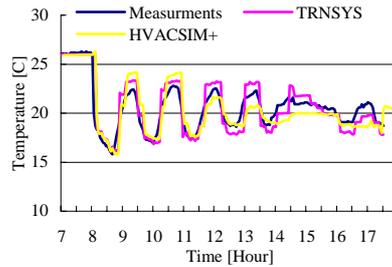


Fig.6 Room supplies air temperature

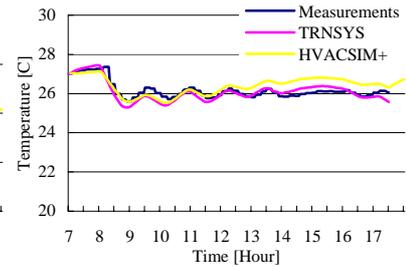


Fig.7 Room air temperature

the room are simulated in HVACSIM+. It is also essential the weather data for the weather input TYPE. On the other hand, TRNSYS serve one TYPE for the room simulation.

As for the building surface, various building wall materials with some thickness had offered, however several building materials data has been appended for the actual building. The effective heat capacity of the office equipment and the occupants in the room are data necessary for calculating of the room air condition. At the beginning, it was calculated with the heat capacity of all equipment and furniture in the actual room, which counts about 500 (kJ/K) using size and heat characteristic of material of 20 desks and 80 chairs, existed in the actual room. However, it was disclosed that the calculation algorithm of building surface model did not include heat capacity of the column. Counting a part of the heat capacity of column within the room space, the sum of heat capacity becomes about 7000(kJ/K). As it was difficult to identify how much heat capacity of the column clearly influences the room air temperature, it was adjusted within the range of about 3000-7500(kJ/K).

Because the room air calculation in both programs are based on the perfect mixing algorithm, the influence of the temperature distribution and the location of the temperature sensor in the room were not considered. It must be one of the causes, which considerably contributes to produce difference of the room air temperature between the simulated values and actual measurements. It was tried to compensate the error by adjusting effective heat capacity in room. Finally, it became the optimum value, 6000(kJ/K) in HVACSIM+ and 7500(KJ/K) in TRNSYS respectively, as a result of the trial and error method to bring the simulated values of the room air temperature close to the measured one, which were shown in Table 4. The difference of both room effective heat capacity of the equipment can be brought out of the different calculation method on the room air condition above mentioned.

The calculated values of the room air temperature, which were calculated using two programs with adjusted optimum parameters on the normal condition, and the actual measurements of one are

shown in Fig.7. Because the simulated values of the room air temperature are close to the measured one, the room air calculation offered in both programs have enough reproductively within the absolute 1 °C nevertheless actual measurement must contains measurement absolute error of the temperature sensor about 0.5 °C.

4) Application to the faulty condition

The simulation of the faulty condition using the same parameters as the normal condition was examined as the application to the fault database generation. However since a set point of the room air temperature was changed from 26 °C at the normal condition to 25 °C in measurement, the mechanical error of a parameter of PID Controller TYPE was also adjusted. The adjusted parameters on the faulty condition are shown in Table5. The comparison of the simulated results and the actual measurements of chilled water valve opening rate signal, room supply air temperature, and room air temperature on the faulty state are shown in Fig.8a)-c), and are stated as follows.

1) The simulated values of chilled water valve opening rate signal in Fig.8a) are almost corresponding to the actual measurements as a result of the adjustment of the mechanical error regarding the set point of the room air temperature.

2) The simulated values of the room supply air temperature in Fig.8b) have a little vibration during 10:30-12:00, which is brought from the vibration of the chilled water temperature shown in Fig.9. But the actual measurement is the steady because the valve opening rate signal is constant in this period. Dynamic property of the heat exchange in the coil TYPE must be more sensible than the actual one. However, because the change performance of simulated value is corresponding to actual measurement, enough reproducibility can be admitted.

3) It is understandable that the simulated values of the room air temperature bring close to the actual measurements in Fig.8c). There is a tendency that the simulated value of the room air temperature using HVACSIM+ becomes higher than that of the measured one as the time goes by.

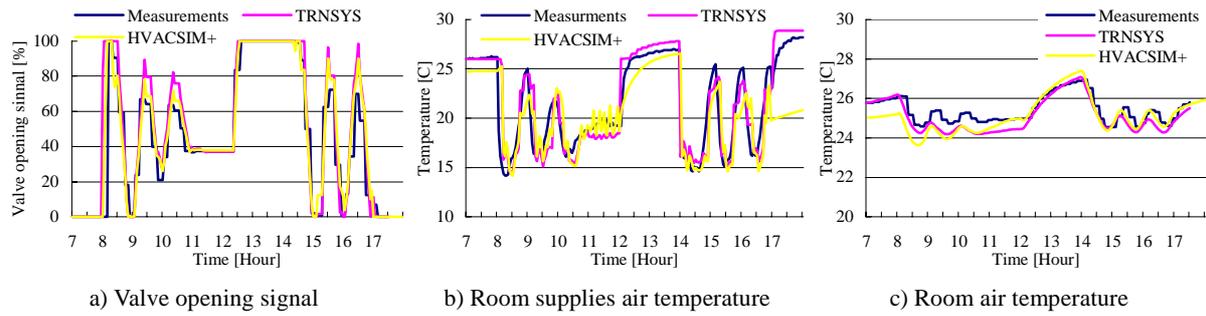


Fig.8 The comparison of simulated results and the actual measurements of the faulty condition

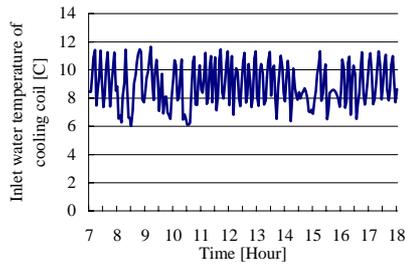


Fig.9 Inlet Chilled water temperature of the coil

Though there is a little difference between the simulated results and the actual measurements, it could be stated to obtain acceptable reproducibility even in faulty condition. Therefore, it is examined that component models in both programs could be used to generate the database for Faults Detection and Diagnosis.

SIMULATED RESULTS AND CONSIDERATION OF OVERALL HVAC SYSTEMS

1) Verification of overall systems

The overall HVAC systems were verified by using parameters obtained at the component examination. The simulated values and the actual measurements of the room air temperature, the room supply air temperature, the chilled water valve opening rate signal and the room relative humidity on the normal condition are shown in Fig.10a)-Fig.10d). The simulated results of the room air temperature became an almost corresponding to the actual measurements. The vibrations of the actual measurements of the valve opening rate signal in Fig.10b) and the room supply air temperature in Fig.10c) have attenuation pattern at 14:00-17:00. But the simulated results of both using HVACSIM+ have constant amplitude, and the simulated results of TRNSYS became a constant value in this period. One of the contributions must be the difference of PID Controller calculation algorithm between two programs. The simulated results of the room supply air temperature and chilled water valve opening rate signal came off the actual measurements, which must be caused by the room air calculation

Table 5 Parameter (component, fault condition)

Program	HAVCSIM+	TRNSYS
PID controller dead band [°C]	0.1	0.1
Set point error [°C]	0.012	0.008
Effective heat capacity in room [kJ/K]	6000	7500

algorithm as mentioned before. The simulated value of the room air relative humidity using HVACSIM+ is about 5-10% lower than the actual measurement in Fig.10d), Supposedly, dehumidification at the chilled water coil seems to have been much more remarkable than in the real system. However, the calculated values can be said that it simulates the real system very well, considering measurement errors of a relative humidity sensor.

2) Discusses the applied possibility of the fault simulation to overall systems

To examine the applied possibility to generate fault database of overall systems, the programs decided verifying the reproducibility on the normal condition shown in Table4 were input. The simulated values and the actual measurements of the room air temperature are shown in Fig.10e). When the same parameter as at a normal condition is used, the oscillation cycle of the room air temperature became bigger. This must be caused by different weather condition of the normal and faulty condition shown in Fig.2 and Fig.3. Therefore there must be the difference of the heat storage in building structure and the room air temperature distribution between the two condition. Then, it has readjusted that the effective heats capacity of the room showing in Table6.

The comparison of the simulated results after adjusting parameters and the actual measurements of the room air temperature, the room supply air temperature, the chilled water valve opening rate signal, and the room air relative humidity are shown in Fig.10f)-Fig.10i). It is understood that the simulated results and the actual measurements are corresponding well from these figures.

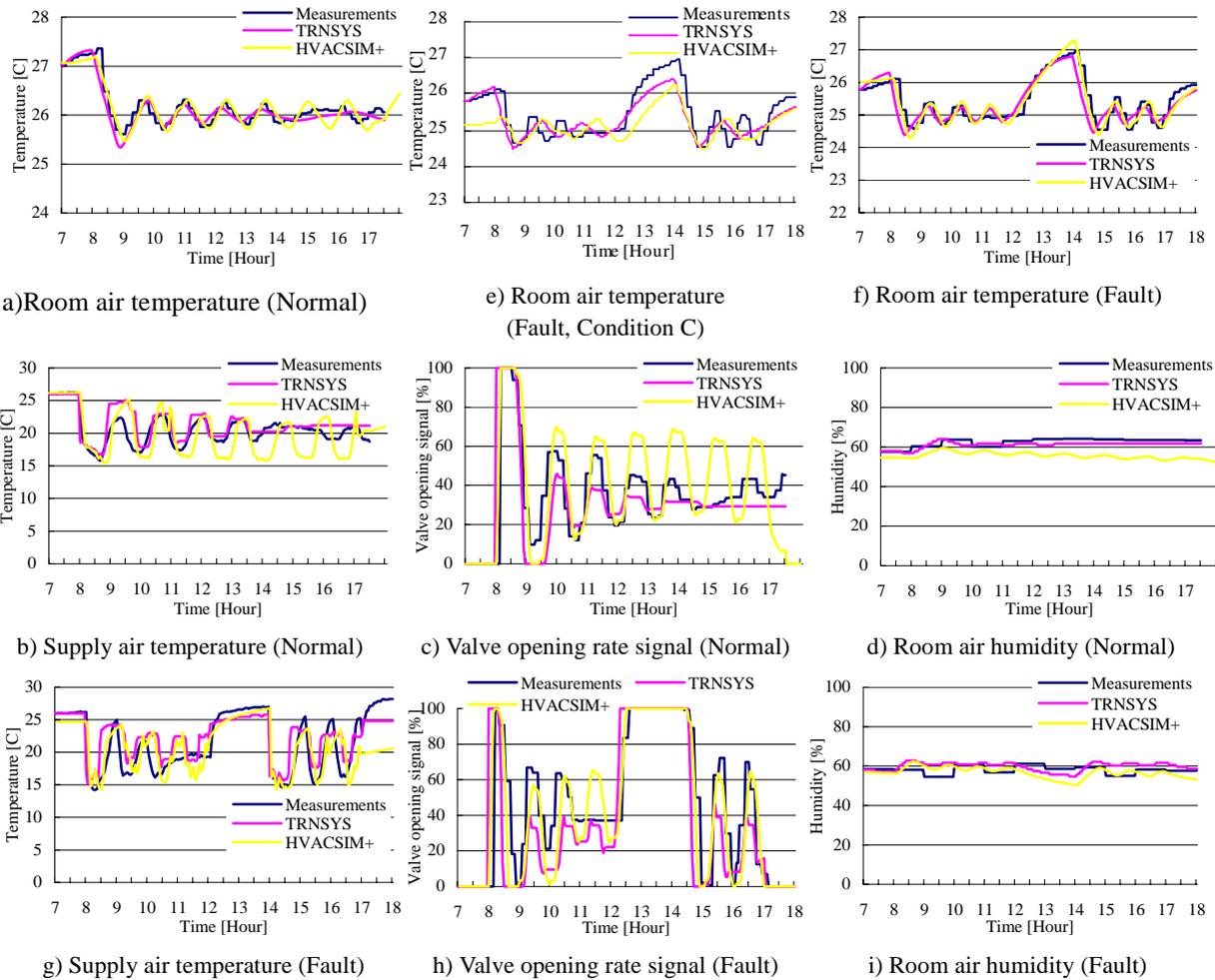


Fig.10 The comparison of the simulated results and the measurements

However, the simulated values of the chilled water valve opening rate signal in Fig.10h) and the room supply air temperature in Fig.10g) during 10:30-12:30 just before the fault was generated, kept vibrating while the actual measurements of them were the constant values. It can be influenced by the calculation error of the room air calculation as well as at normal condition. The simulated value of the room air relative humidity at the faulty condition using HVACSIM+ in Fig.10i) changes closer with the actual measurement than at the normal condition in Fig.10d). One of the reasons is explained by that the effect of dehumidification in the cooling/-dehumidifying coil is smaller, because the room air humidity on the faulty condition is smaller than at the normal condition.

Because the influences of the sensor position and the room air temperature distribution are not considered into the calculation algorithm of the room or zone model, even if the calculation error of each TYPE is small, a larger calculation distribution results after overall systems are combined. As a result, the simulated values of the room supply air temperature and the valve opening rate signal came off the actual measurements. Therefore, as the next

Table 6 Parameter (overall systems, fault operation)

Program	HAVCSIM+	TRNSYS
PID controller dead band [°C]	0.1	0.1
Set point error [°C]	0	0
Effective heat capacity in room [kJ/K]	3250	5500

step, a higher reliability simulation is expected by introducing the room air temperature distribution and the location of the temperature sensor to the room air calculation. So we may use both programs to generate the perfect database of the faults detection and the diagnosis for HVAC systems.

TIME PROGRESS METHOD AND CONVENIENCE

1) Difference of time progress method

In HVACSIM+, to improve the calculation accuracy and to shorten the calculation time, the changeable time step is adopted. However, the stability of the calculation worsens if the user does not appropriately set the value of the maximum and minimum time steps and the calculation might not

be able to perfectly be converged in some cases. On the other hand, the calculation time becomes longer though more steady calculation is obtained by adopting the fixed time step in TRNSYS. The comparison of calculation time of the progress method between fixed time and changeable time is shown in Table7 when using HVACSIM+. As a result, it is understood that the calculation time is greatly decreased with the progress method of changeable time.

2) Installation of boundary condition file

Because the changeable time step is adopted in HVACSIM+, the algorithm to which the value of time dependent boundary variable is interpolated by a third-order Lagrangian method. Therefore, before begging the simulation, it is necessary to make the boundary condition file, in which the value of time dependent boundary variable is a rapid change, two data at the same time step and at least three data near this period on very small time step are needed. Because the fixed time step is adopted in TRNSYS, making a special boundary condition file is unnecessary, and it is possible to read the value of time dependent boundary variable by using a reading data model.

3) Variety of composition of component model

In HVACSIM+, the component model is almost limited to the element equipment. On the other hand, in TRNSYS, various calculation processing processes are built in as TYPE, in which contains the tool necessary for reading and processing the data, to display the calculation result in graph on the screen while calculating.

4) Convenience of system simulation modeling and input work

In HVACSIM+, overall system simulation model is composed of the combination of each TYPE in which parameters input a subprogram HVACGEN with man-machine interaction. On the other hand, the input work of the simulation modeling can be done on interface, TRNSHELL in TRNSYS, the input work, when the simulation model is constructed, is more convenient than HVACSIM+. Moreover, the equipment or the system characteristic can be described using various internal functions besides the composition element on TRNSHELL in TRNSYS.

SUMMARY

In present paper, the reproducibility of two dynamic simulation programs, HVACSIM+ and TRANSYS, and the possibility to generate the Faults Detection and Diagnosis database were verified by corresponding the simulation results to the actual

Table 7 Calculation time

Time step	Time(sec)	Calculation time*(sec)
Regular	10	32.52
Variable	10-60	13.84

*With Pentium 150 MHz CPU in PC

measurements. It is necessity for adjusting some parameters in addition to input schematic and preliminary design values of the real HVAC system into current programs. The result is written as follows.

1) When considering PID Controller calculation, the simulated results approached the actual measurements by the addition of dead band and the appropriate adjustment of some parameters.

2) As for the chilled water valve-opening rate, tendency of change in simulation was caught well though the heat exchange characteristic of the chilled water coil was more sensitive than that of the real system.

3) The influence of the temperature sensor location and the room air temperature distribution are not considered in the calculation algorithm of the room model. Therefore when overall system are calculated, the simulated results of the room supply air temperature and the chilled water valve opening rate signal became a bit away from the actual measurement value.

4) If the error of the humidity sensor is considered, the simulation results of the room air relative humidity using the two simulation programs corresponded very well though the effect of dehumidification of the cooling/dehumidify coil of HVACSIM+ is higher than that of the real one.

5) In HVACSIM+, for decreasing the calculation time, the changeable time step was adopted. However, convenience is worse than TRNSYS.

6) When using HVACSIM+, a lot of working hours and the experiences for the understanding of the program algorithm and making the simulation model. Therefore, HVACSIM+ can be a program of the research level at the present stage. Some improvements should be needed for inexperienced convenience in the future.

7) For the possibility to the generation of the FDD database of two programs, at the component level, it was confirmed. But when the calculation of the overall systems, leave something to improve.

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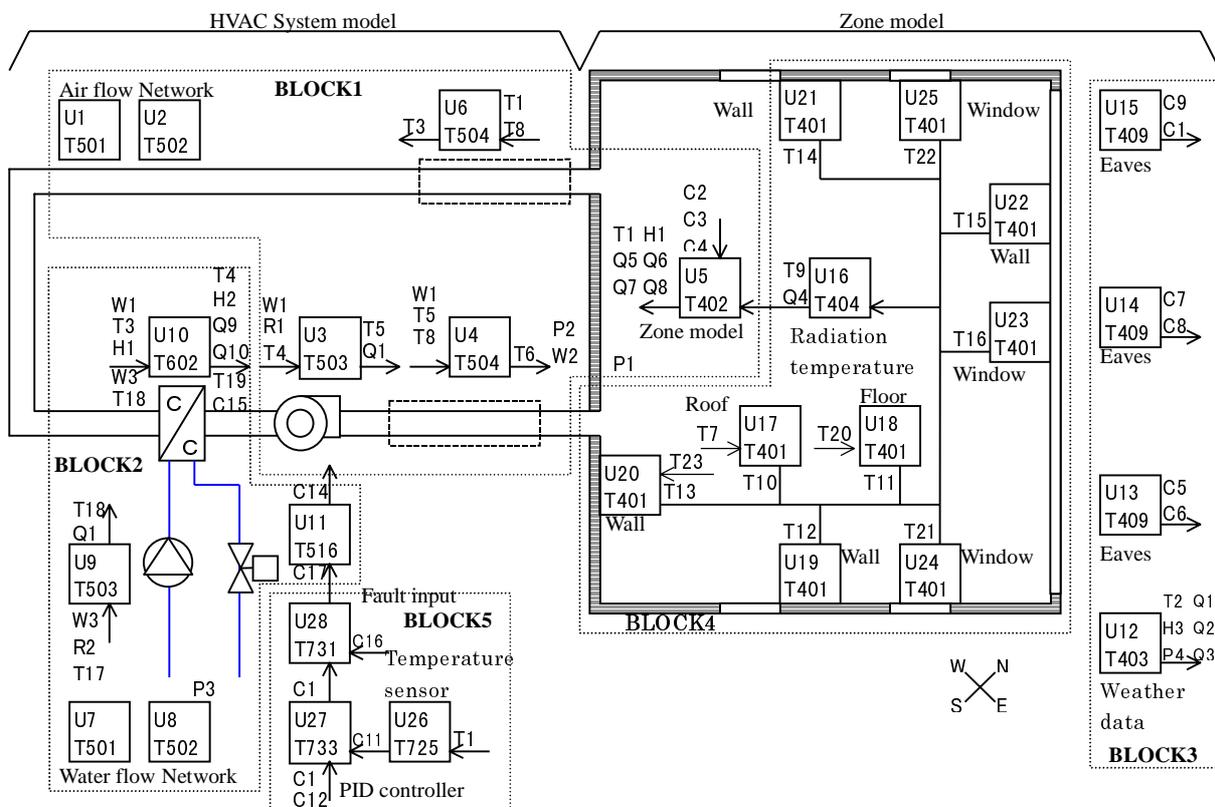


Fig.11 Diagram of the composed simulation model for HVACSIM+