DeST——A Simulation Tool in HVAC Commissioning

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Introduction

DeST, named 'Designer's Simulation Toolkit', is a tool developed for aiding HVAC engineer to realize 'design by analysis, design by simulation'. It can also be used to help architect to optimize their thermal performance of fabrics.

DeST is developed by Institute of Building Environment and Building Services, Department of Building Science, School of Architecture, Tsinghua University, Beijing, China. The process of DeST developing started in early of 1990s, and has lasted more than 10 years.

Building simulation initiated from 60s of last century, and many building simulation programs have been developed and some are widely used in research and education. Some of these programs have very detailed building model but relative simple and hardwired system template as DOE-2 and BLAST. These programs are used more to analysis building fabrics performance. Some of these have very detailed system models but relative simple building models such as HVACSIM+ and TRNSYS, and used more in system dynamic process emulation. However, there is still a big gap between simulation and design.

How a design process is performed? 'Air-conditioning system design manual, ASHRAE' describes the design process as several stages or phases:

> *Program Phase →Schematic Design →Preliminary Design →Final Design →Post Design Phase →Commissioning Phase →Post Occupancy Service*

According to subtask 2 of IEA BCS ANNEX 30 (Design Process Analysis), a design process can be divided as:

> *Conceptual Design →Preliminary Design →Detailed Design →Commissioning Phase →Facilities Management →Renovations*

Although there can be different methods to describe different periods of design process, the common opinion is that design process is performed stage by stage. The total information of the designed system can only come out at earliest after 'final design' or 'detailed design'. It is impossible for a designer to know the detail data of an AHU or a FCU during the stage of schematic design or preliminary design.

The simulation software for load calculation only required a template system. Therefore, it can be used by designers as load calculation tool rather than tool helping people to design a HVAC system. In the other hand, all of the current system simulation tools required detailed system information as the input data of the simulation. It prevents the designers to use it in the early stage of design because they don't know the detailed information, which the program required.

A good computer aided design tool should be a slave of the designer. It can take the simply repeated work and complicated calculation from people, and give more space to designers for exerting their talent in every stages of the design process.

DeST is design to pursue this purpose. It is an annual building energy consumption analyze software doing simulation hourly for HVAC designers, applying simulation into different phases of design: *Design by stage, simulation by stage*.

How DeST can be used in building and HVAC system design

The structure of DeST is shown in Fig. 1. Each part of DeST stands for a module with specific function served in specific design stage. The figure of man with wide arrow stands for a manual input by user.
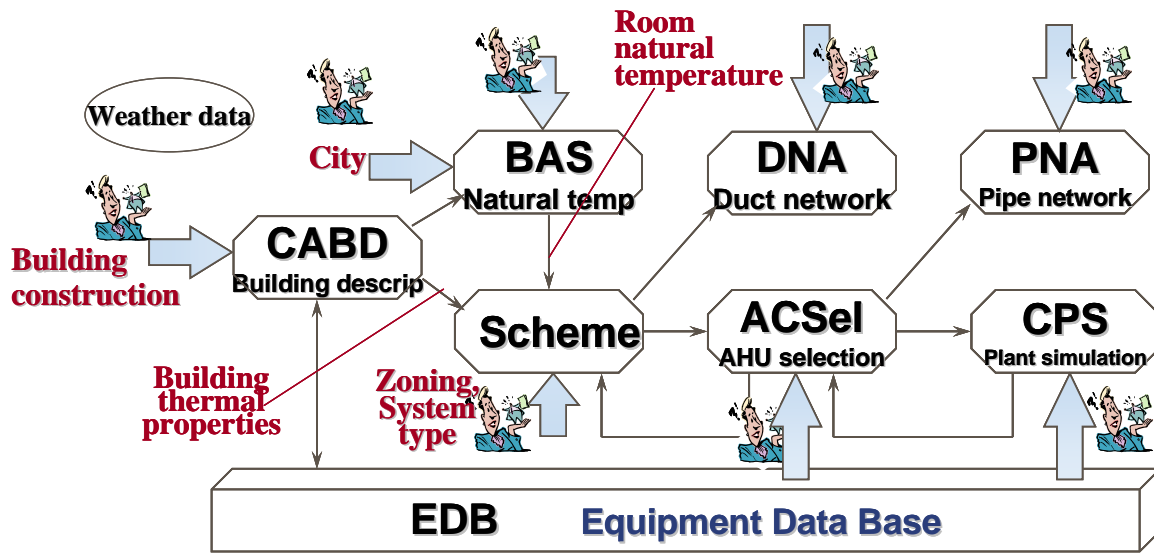

Fig. 1 Structure of DeST

1. In the Building Design Stage or in the Conceptual Design Stage

In the stage of building thermal property design, an architect may hope to know the thermal performance of the building he designed. The 'natural temperature' —— the room temperature without HVAC —— of each room can represent better the thermal performance than cooling/heating load, because the cooling/heating load depends on the set-point temperature of the air-conditioned rooms. Therefore, it is the natural temperature rather than load that can reflect exactly the thermal properties of the building.

In the stage of building thermal property design, the natural temperature can provide the designer a quantified description of how good or bad the thermal performance of the building he designed is. Then he would like to change some thing, such as to change the position and size of the windows to improve night ventilation, to change the insulation material or to add some shading components. Then he hopes to see the resulted natural temperature get better or not.

In the HVAC conceptual design stage, the HVAC engineer needs the maximum total heating/cooling load of the building (kW) and the total heat quantity should be removed or added through one year (kJ or kWh) for the purpose of the primary technical and economical analysis. Such maximum load and total heat quantity can be easily obtained from the natural temperature in case that the temperature set points are given.

Therefore, corresponding to the first design stage, the first stage using DeST is to acquire building information and calculate the natural temperatures of all of the considered rooms in

the building. In this stage, two main modules in DeST will be used. One is CABD, a building construction input module, and BAS, the natural temperature simulation module. An auxiliary program can estimate the maximum heating/cooling load and the total heat quantity from the resulted natural temperature according to the input indoor temperature set point if the user needs the load for conceptual design.
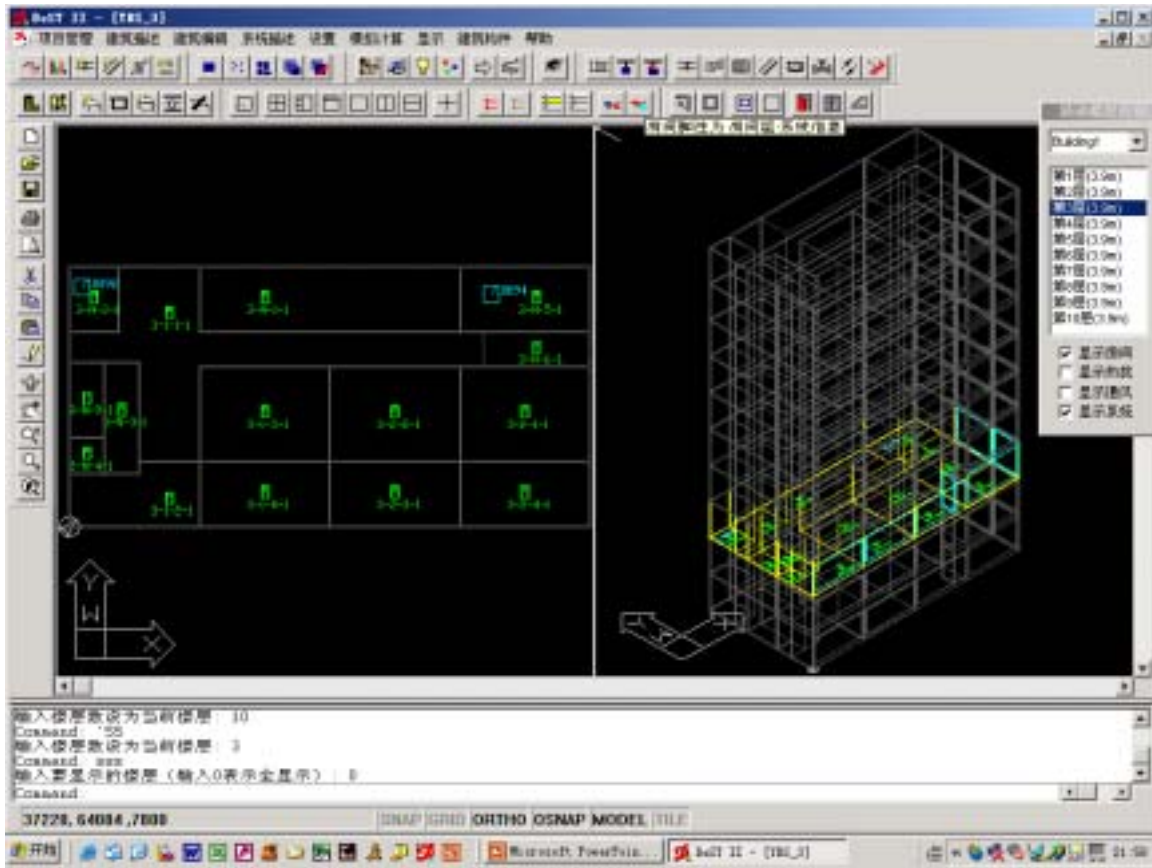
CABD

CABD is a module providing user the graphical interfaces for the sake that they can describe a building easily. This module is AUTOCAD based, because it is a graphical tool that designers are very familiar with and also has been installed in their computers. The user can change space layout, opens, shading, glazing area, etc., and he can also pick up different kind of fabrics components or different kind of materials from the database (Fig. 3) and add to the building to see how the building thermal properties will be changed.

The interior heat gain with its schedule and infiltration rate will be input manually. Some connections have been made for inputting data from some auxiliary programs, such as a under developing program for simulate the natural ventilation rate using multi-zone network model, and a shading simulation program for providing the hourly shading area on the building external surface which has been developed. User can designate the result of natural ventilation rate simulation instead of the manually input infiltration rate.

The output of this module is all of the data related to building thermal properties and the description data of the building configuration. In the later stage, this data will be used in natural temperature calculation, air handling processes determination, detailed design stage and so on.

Fig. 2 is an example of a building configuration input. A user who familiar to AUTOCAD and building drawing will take 1~3 hours to describe such a building.

(a) Floor plan and 3-D display of YBS 10 stories building (Chinese version)
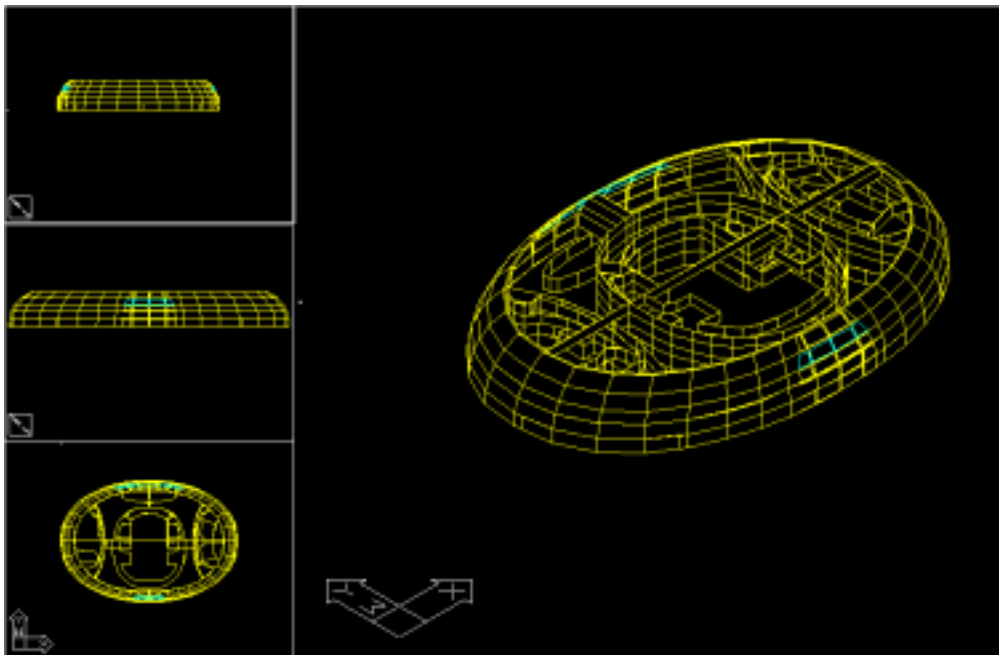
(b) Building with complicated shape can also be described
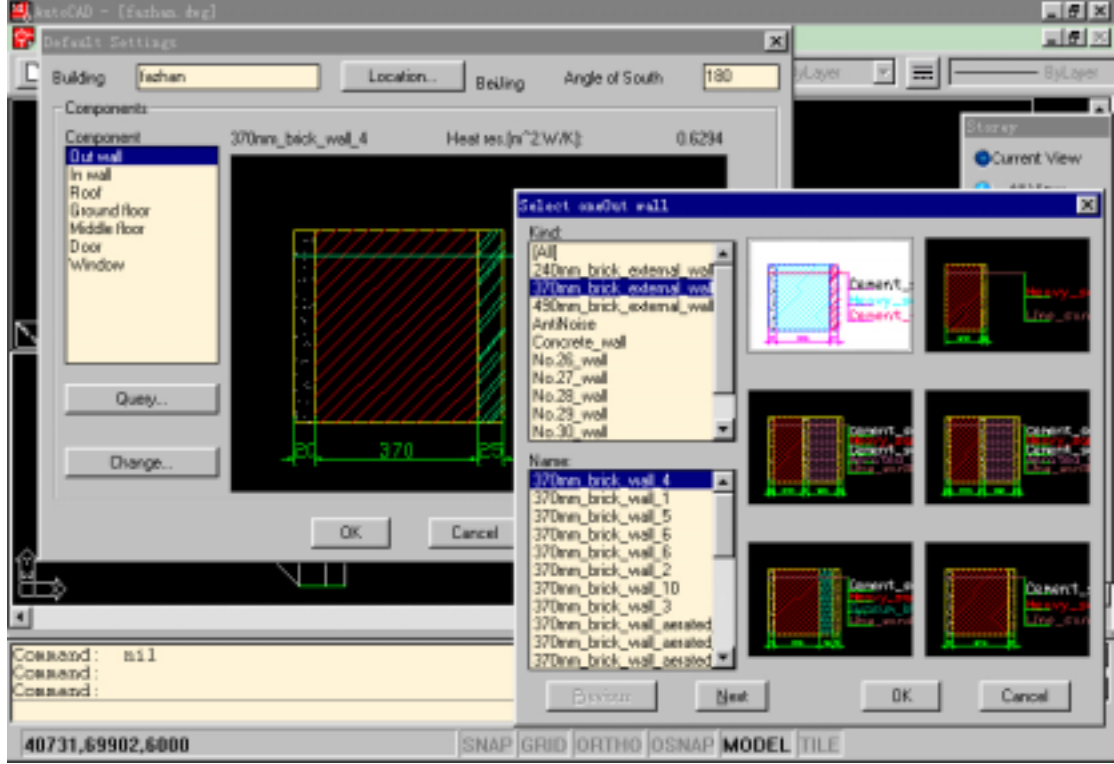
Fig. 2 Interface of CABD

Fig. 3 Materials and building components database and its interface

BAS

BAS is the module used to simulate the natural temperature of each room of the inputted building. State space method is used to solve the differential equations rather than transfer function method. The room air temperature can be considered composed two parts: natural temperature without the effect of HVAC system, and the temperature increment caused by the effect of HVAC system. Using State space method, the room air temperature can be expressed as:

$$t_k(\tau) = \int_{-\infty}^{\tau} \sum_{j=1}^{m} \sum_{i=1}^{n} \varphi_{ij} \cdot e^{\lambda_i \cdot (\tau - \eta)} \cdot q_j(\eta) \cdot d\eta$$

Where $t_k(\tau)$ is the air temperature of the kth room, q_j is the jth interior heat gain of the room, λ_i is the ith element of the eigenvector of the room, φ_{ij} is the ith effect factor of jth heat gain to the room air temperature, n is the eigenvalue dimension of heat gain, m is the number of interior heat gains.

Thus, the room natural temperature can be expressed as:

$$t_{k,natural}(\tau) = \int_{-\infty}^{\tau} \sum_{j \in Z_p} \sum_{i=1}^{n} \varphi_{ij} \cdot e^{\lambda_i \cdot (\tau - \eta)} \cdot q_j(\eta) \cdot d\eta$$

$$= W(\tau - \Delta\tau) + \sum_{j} \psi \, q_j(\tau - \Delta\tau) + \sum_{j} \psi_{oj} q_j(\tau) \qquad (j \in Z_p)$$

where $W(\tau - \Delta\tau) + \sum_{j} \psi \, q_j(\tau - \Delta\tau)$ is the historical effect of heat gain on the room air

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temperature. It stands for the thermal mass of the room, ψ_{1j} and ψ_{oj} is the effect of ith unit heat gain on room air temperature at the time $\tau\text{-}\Delta\tau$ and τ.

BAS has an option for user to choose if they just want to do the building thermal property design or continue to do system program design. For the latter who want to acquire the information for technical and economical analysis for primary determining the type of cooling/heating plan, the auxiliary connection program of BAS will require the user to input the set point temperatures of every rooms, and then according to the natural temperature output by BAS, the maximum load and the total heat quantity removed or added to the building are calculated and outputted.
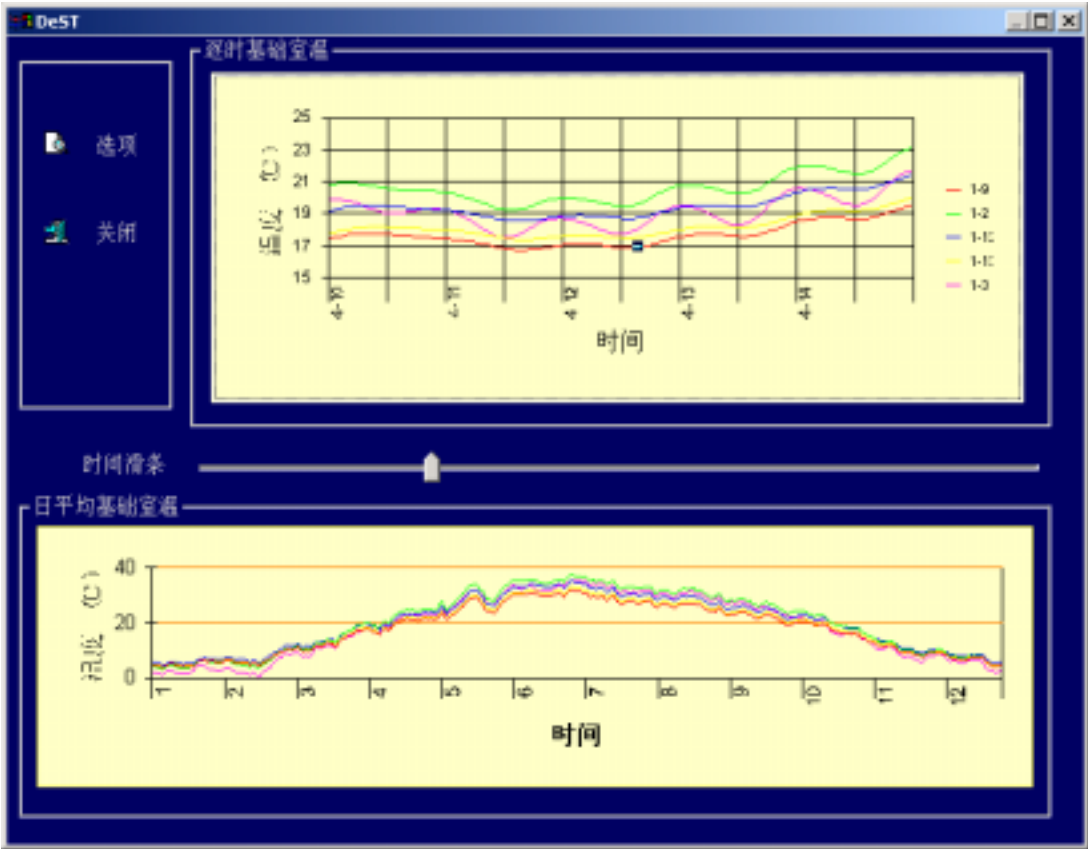

Fig. 4 Output natural temperatures of BAS

2. Preliminary Design or Schematic Design Stage

In this stage, the most important task is to determine the scheme of air handling process. Fig. 5 shows the flow chart of this stage.

SCHEME requires the designer input his intention to the system design. First, he has to input his intention on zoning and system types such as all-air system or water- air system? CAV or VAV? If in some zone all-air system is chosen, the maximum permitted supply air temperature difference should be declared. According to the maximum cooling/heating load and the maximum permitted supply air temperature difference, SCHEME suggests the maximum supply air flow-rate for this zone and asks the user for confirm. If CAV is chosen, the hourly simulation will result required supply air state, required air handling processes, the resulted hourly air states of all rooms of this zone and the ratio of satisfaction. If it is a VAV system, the hourly supply air flow-rates will be outputted as well.

The constant air flow-rate and the hourly varied air flow-rate of VAV system will be outputted as the input data of DNA, the duct network analyses module.

According to the output result, user can modify his original design, e.g. change the zoning to make sure that only the rooms with similar indoor environment standard will be put in the same zone, or change a CAV system to VAV to see whether the ratio of satisfaction of that zone increase or not.
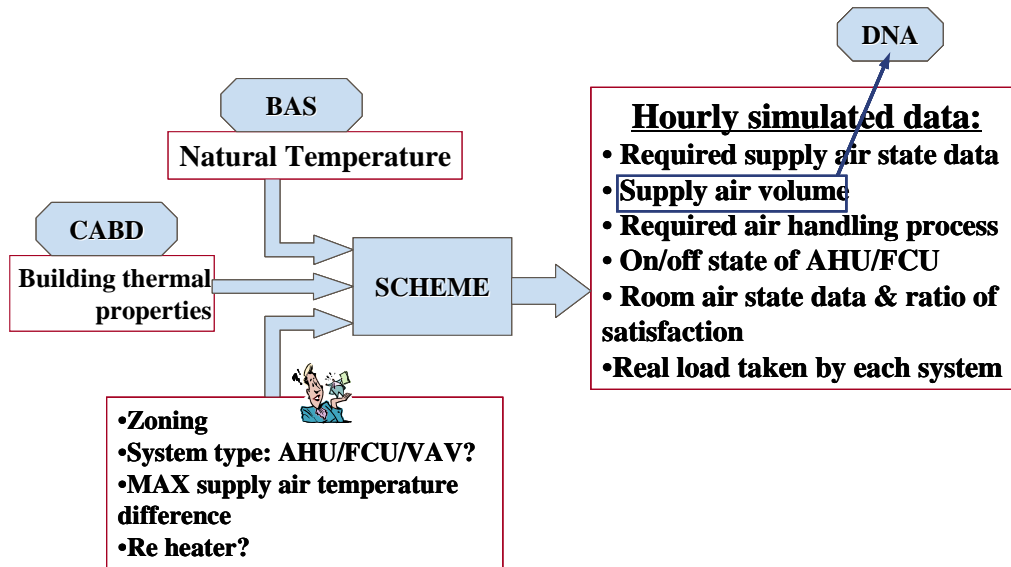

Fig. 5 Relationship between SCHEME and other modules

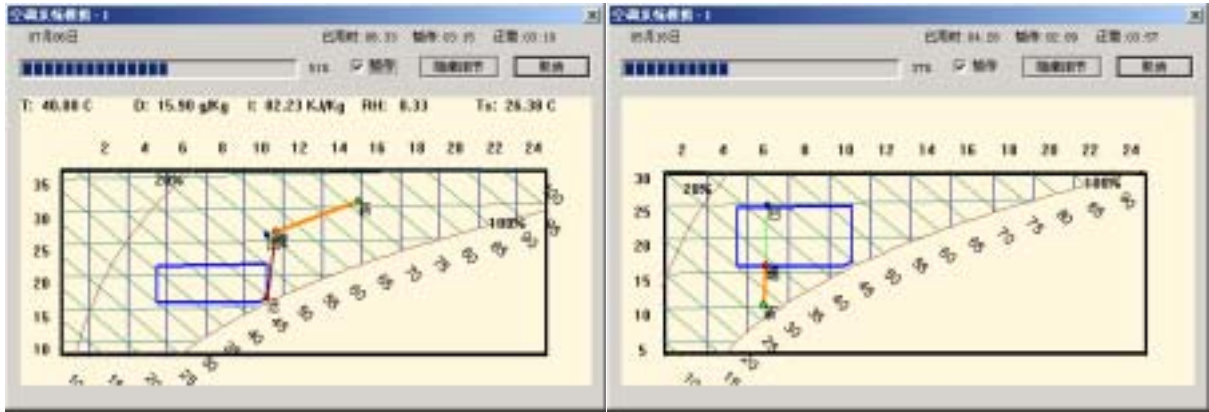Fig. 6 Input interfaces of SCHEME: zoning and system types

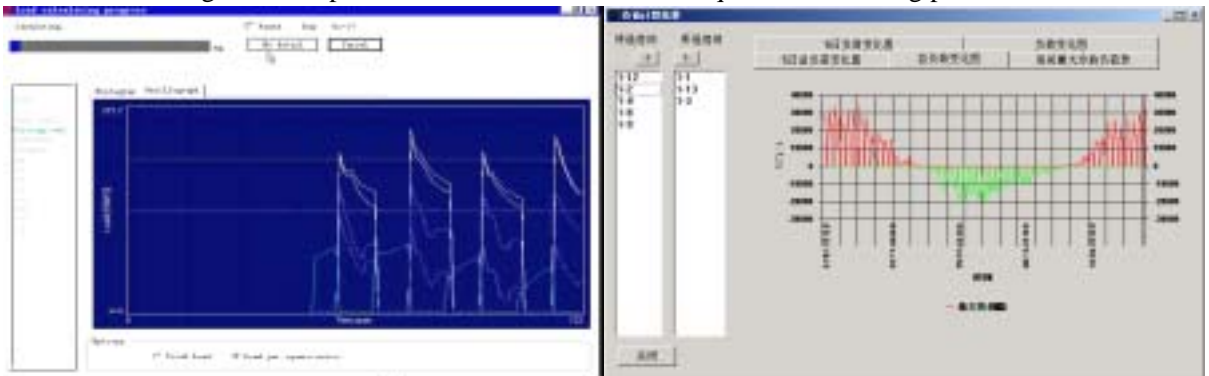Fig.7 The output interfaces of SCHEME: the required air handling processes

Fig.8 The output interfaces of SCHEME: hourly load taken by each AHU and the hourly load of each room

3. Detailed Design or Final Design Stage

In the detailed design/final design stage, all of the detailed information related to the system configuration and components will be determined. Therefore, there will be 3 main tasks in this stage.

(1) According to the requirement from simulation results of SCHEME, selecting the air handling equipment such as AHU, FCU, air economizer, and the annual operation strategies such as outdoor air flow-rate control or supply air dew point control. This work will be done by ACSel.

(2) Determining the duct and piping system configuration, determining the fan and pump, and analyses the ratio of satisfaction of the selected fan or pump. These works will be done by mentioned above DNA and PNA.

(3) Determining the type, number and the operation data of heating/cooling plant, and giving the energy consumption through one year.

There are 4 main modules in DeST for accomplishing these works. ACSel is used for air handling equipments selection and simulation, DNA is used to analysis the duct system, CPS is used to do detailed design of the heating/cooling plant, PNA aims at piping system analysis.

ACSel

Fig. 9 gives the scheme of ACSel. It acquires data from SCHEME's output. Besides, it requires the user to select air handling equipment from the database considering the required air flow-rate of each zone from SCHEME. Then simulation is started to result the outlet air state data. Compared with the required supply air state data, the ratio of satisfaction will be obtained. It also gives the hourly possibility of utilizing outdoor fresh air to reach the required supply air state and decreasing the energy consumption. If the user indicates to use a intake

air/exhaust air heat exchanger, the hourly maximum possible recovered heat will be given.

Furthermore, ACSel gives the required hourly chilled/hot water flow-rate and temperature. The constant water flow-rate and the varied hourly water flow-rate of VWV system will be outputted as the input data of PNA, the pipe network analyses module. The maximum cooling /heating load should be taken on by chiller and heater will be given to the users, in order to provide them the necessary information for select heating/cooling plants in the next step.
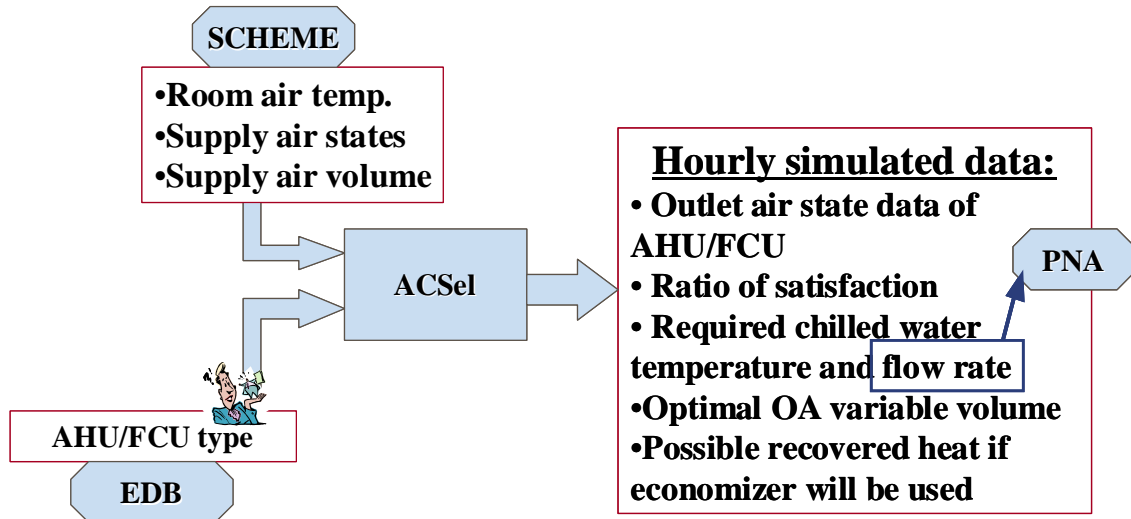

Fig. 9 Detailed design 1: Air handling equipment selection

CPS

CPS is a module used for the detailed design of cooling/heating plant. The model of chillers from ASHARE Primary Toolkit is used in CPS.

CPS acquires the water data such as flow-rate or water temperature from ACSel, and requires the user to select chiller or boiler from the equipment database as well as the number of each kind of the components.

Outputs of CPS include hourly outlet water temperature and flow-rate which the selected machine can provide. Compared with the required hourly water data, the ratio of satisfaction is obtained. The user can modify his design considering the ratio of satisfaction. The operation state such as the on/off ratio or part load operation hours, and the COP and all year energy consumption will be given too.
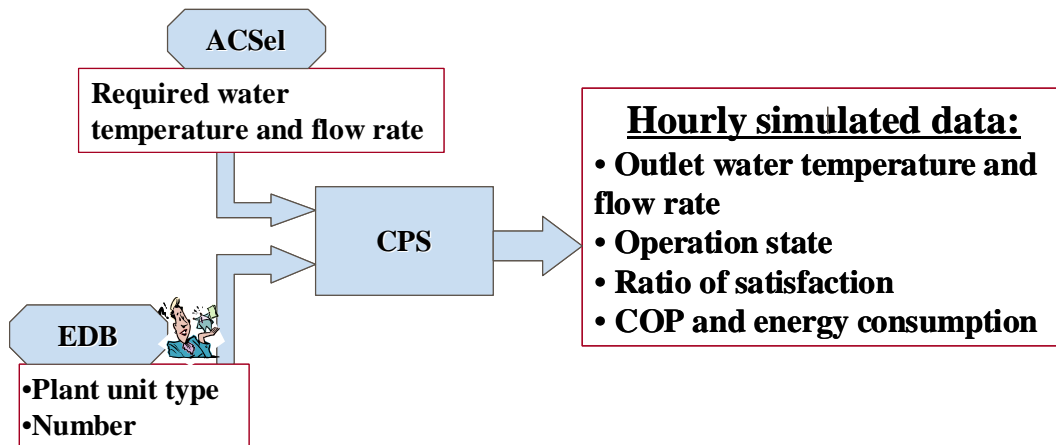
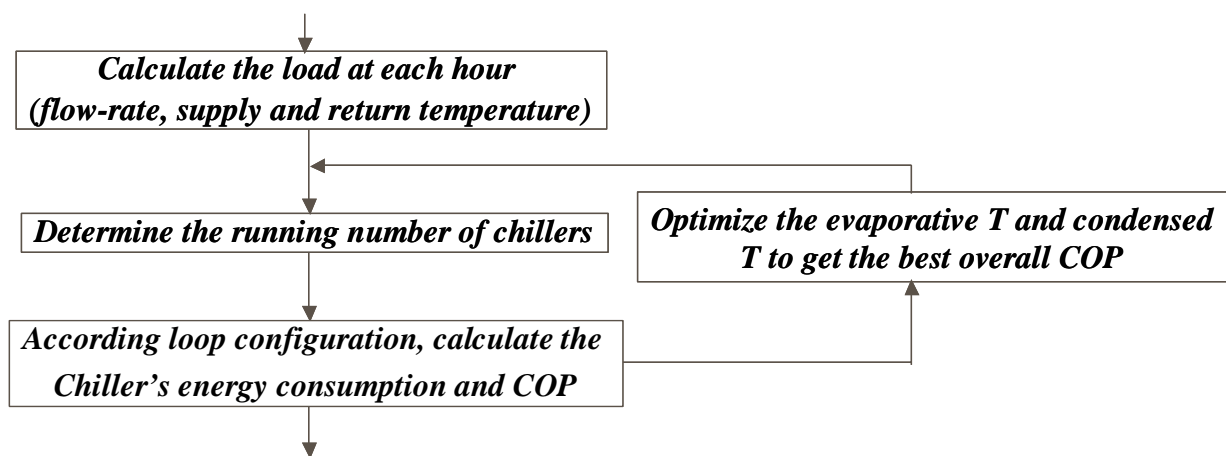Fig.10   Detailed design 2: heating/cooling plant selection

Fig. 11   Flow chart of chiller modeling, CPS

DNA and PNA

The modules of DNA and PNA have very similar functions. The only difference is that the former is for duct network and the latter is for the pipe system. The required air or water flow-rate is determined in the former modules, these modules requires the user to describe the network configuration, then hourly simulation on pressure drop of each branch is carried out. According to the maximum head or pressure requirement, the user will select fans or pumps. Then it will give out the ratio of satisfaction on both the pressure and flow-rate of each branches or terminals. Hourly and all annual energy consumption will be provided as well. So that user can modify his design according to the situation of satisfaction and energy consumption.

More information

There is not a real simulation on control stage. However, during each stage, some control strategies have been included such as VAV control, FCU control, AHU control and chiller control. The simulation only concerns the control strategies rather than the dynamic response of the sensor or controller, i.e., if DeST finds the fresh air ratio should be 32.5%, it comes to 32.5%, it does not simulate how the damper moves to 32.5% nor if the rate can be 32.5%. In

every stage, it believes that the optimal control strategies have been adopted in the former stages. For example, when pumping system is designed, it is believed that the hourly chilled water flow rate is optimized in the former stages by designers aided by DeST, so that the task in this stage is to optimizing the pump capacity, operation strategy and energy consumption to provide the optimal flow rate. In this way, it does hourly simulation rather than second by second or minute by minute simulation. Therefore, DeST cannot be used as a HVAC system emulator as HVACSIM+ or TRNSYS.

Current situation of DeST development

Both Chinese and English version of DeST 1.0 have been issued before 2001, and Chinese version of DeST 2.0 has been issued in 2001, and the English version of DeST 2.0 is just accomplished in August 2002 and still need test. The weather database still mainly includes the weather data of Chinese cities and newly added data of Tokyo, and need to add new data from other countries. It is very easy to add new information to all databases of DeST because they are opened to the users.