The Development of the Database of the Equipment Characteristics for the Building Energy Simulation Tool

Kohichi Shinagawa
Member ASHRAE

Shuzo Murakami, PhD
Fellow ASHRAE

Hisaya Ishino, PhD
Member ASHRAE

Takashi Yanai, PhD

Yukihiro Kawazu, PhD

ABSTRACT

The database of the equipment characteristics provided by the BEST (Building Energy Simulation Tool) program is a flexible and expandable data set in which interactions among building equipments are well considered. These characteristic databases are always maintained in the neutral and fair way by the five subcommittee which are not affected by any specific manufacturer. The BEST program is designed to express every model in modules and can create various system configurations like major simulation tools such as TRNSYS and EnergyPlus. In this paper, the importance of modifiability of equipment databases, the expandability of the BEST program's equipment databases, and the details of developing equipment characteristic databases are explained.

And, the methods to apply equipment characteristics based on other standards are also introduced. This database has three data sets (nominal performance characteristics, part load performance characteristics, and dynamic performance characteristics) which are solved by applying two modelling methods (empirical model and/or physics-based model) to represent equipment characteristics to provide shorter calculation cycles in the coupled calculation within the entire building calculation. Users will be able to run the simulations just by choosing and entering general informations of the equipments which are available from catalogs. In addition, more advanced equipment characteristics (e.g. heat pump utilizing renewable energy) are also prepared in this development.

INTRODUCTION

One of the factor which makes simulation tools become obsolete is not updating the equipment characteristics after the release of the program. The solution for this problem, the BEST program committee hold regular workshops to update equipment characteristics continuously. There are groups among the type of equipments having sectional meetings to collect informations of equipments in cooperation with industry associations.

The policy of developing database is as follows:

1. The major HVAC equipments that are used universally in Japanese commercial buildings must be investigated preferentially.
2. High efficiency HVAC equipments (both of nominal and part load characteristics data) must be investigated.
3. Automatic controllers that affects the energy consumption (e.g. cooling tower with variable speed fan and condenser loop with variable speed pumps) must be investigated.
4. Equipment characteristics under various operations for better efficiency (e.g. raised room temperature or raised

Kohichi Shinagawa and Yukihiro Kawazu is a Senior Project Engineer at Environmental & MEP Engineering Division in Nihon Sekkei, Inc., Tokyo. **Shuzo Murakami** is a president at Institute for Building Environment and Energy Conservation, Tokyo. **Hisaya Isihno** is a professor emeritus at Tokyo Metropolitan University, Tokyo. **Takashi Yanai** is a Principal at Environmental & MEP Engineering Division in Nihon Sekkei, Inc., Tokyo.

chilled water temperature at low load operation) must be investigated.

The wolrdwide climate datas such as EPW and WEDAC are already available, but the English version of the BEST program is currently under development. The equipment characteristics examined by the other standards (e.g. ASHRAE standard 205P) will be available if the BEST's sub working groups modify these informations in modules because the BEST program is designed to express every models in modules like other major simulation tools such as TRNSYS and EnergyPlus.

THE BEST'S SUB-WORKING GROUP FOR EACH EQUIPMENTS

For HVAC system, the five categories of sectional meetings have been organized in consideration with modelling and classifying equipment characteristics. The diagram of the BEST's equipment sub-working group is shown in Figure 1. The sectional meetings are held for respective type of equipments such as, "central plant components", "condenser equipment", "variable refrigerant flow equipment" and "conveyance of heat, and air handling unit", in cooperation with relative industry associations (e.g. the Japan Refrigeration and Air Conditioning Industry Association (JRAIA), the Japan Society of Industrial Machinery Manufacturers (JSIM), the Institute of Electrical Engineers of Japan (IEEJ), and manufacturers). The database of equipments are developed by these sectional meetings among typical characteristics in each groups. Therefore, these equipment databases are maintained by adding new informations in neutral and fair way, not affected by any specific manufactures. It is important that the simulation database is expanded and renewed in neutral and fair way. Equipment characteristics for specific products can be provided by the manufacturers, but the database for the other typical equipment characteristics is useful in energy simulation for feasibility study at planning stage.

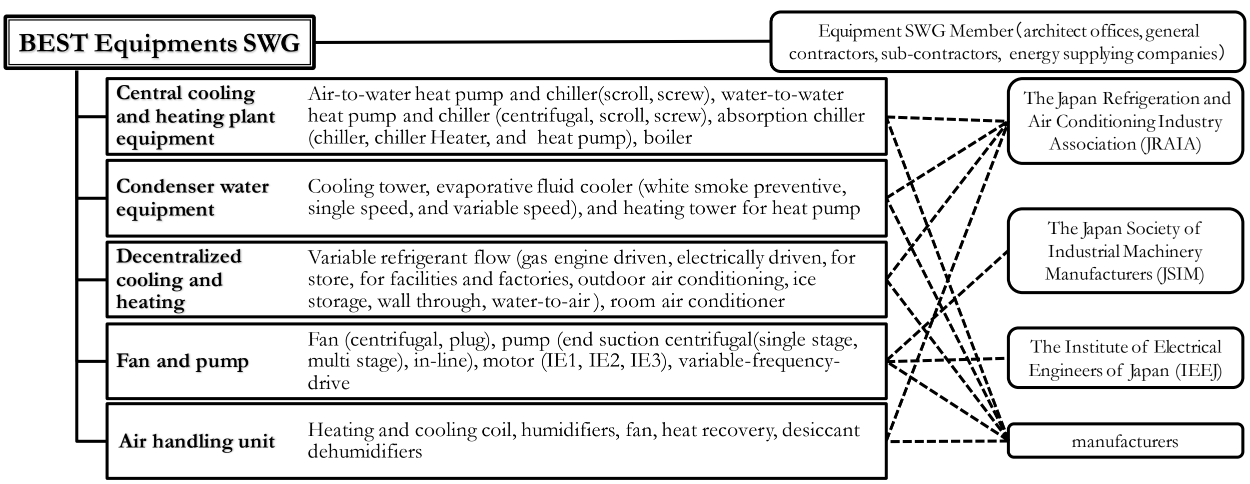


Figure 1 BEST equipment sub-working group diagram

MODEL OF EQUIPMENT CHARACTERISTICS

In the BEST program, equipment characteristics are based on two techniques, empirical model and physics-based model. The two techniques and equipment characteristic models are shown in Table 1. Empirical model is to calculate output data from input data by using the performance curves and performance table. Performance curves of equipment characteristics are often unavailable from manufacturers. The equipments that are controlled by variable-frequency-drive have optimum part load ratio to perform at its maximum efficiency. The equipment's COP curves that have nonlinear characteristics are often modelled with the combinations of equations in each ranges of part load ratio, especially in the case when difficult sets of formulas are applied over the entire operating range. For example, variable refrigerant flow equipment have five equations. However, the performance table data are also applied for the versatility, because in some cases, only representative performance and boundary performance are needed. Each type of characteristics of equipments are approximated by polynomial equations (by linear, quadratic, cubic, etc.) in each performance curves.

Table 1. Equipment characteristics model

Model Type	Outline	Equipment for Example
Empirical model	Empirical model is to calculate output data from input data by using the performance curves and performance table. Performance curves of equipment is expressed by multiplication by the influence functions that are approximated by polynomial equations.	central plant components, variable refrigerant flow equipment, fans and pumps (nominal performance), motor, variable-frequency-drive
Physics-based model	Physics-based model is to predicted the output condition physically by using the input condition.	fans and pumps (part load performance), cooling tower, cooling and heating coil, Humidifier

DATABASE STRUCTURE OF EQUIPMENT CHARACTERISTIC

Equipment characteristic database consists the combination of three data sets (nominal performance data, part load performance data, and dynamic performance data). Nominal performance data and part load performance data are steady-state performance. The outline of database of equipment characteristics is shown in Table 2. The database structure of equipment characteristics is shown in Figure 2.

In the BEST simulation, the input procedure of equipments is as follows: General information which can be obtained from manufacture's catalog, or specification from equipment lists in design drawings is given as nominal performance data. The module categorized by equipment type (e.g. compressor category: centrifugal, scroll, screw or efficiency category: high efficiency type and nominal efficiency type), is entered as part load performance data and dynamic performance data. However, dynamic performance database is under investigation, only deteriorating efficiency yielded under minimum part load ratio is embedded. Because users would be able to run the simulation just by choosing the equipment and inputting some general information, this database is useful for feasibility study simulation in schematic design.

Table 2. Outline of database of equipment characteristic

Database type	Outline	Characteristic
nominal performance database	Data of nominal capacity, efficiency, consumption, and etc. at rated condition (e.g. JIS: Japanese Industrial Standards)	some general information which can be attained by catalog equipment list in design drawing
part load performance database	Data of performance in the range of applicable condition and method to handle out of applicable condition	part load performance performance by leaving from the nominal condition deteriorating efficiency yielded under minimum part load ratio
dynamic performance database	Data of dynamic equipment characteristic	delay dynamics of the equipments with a large thermal loads

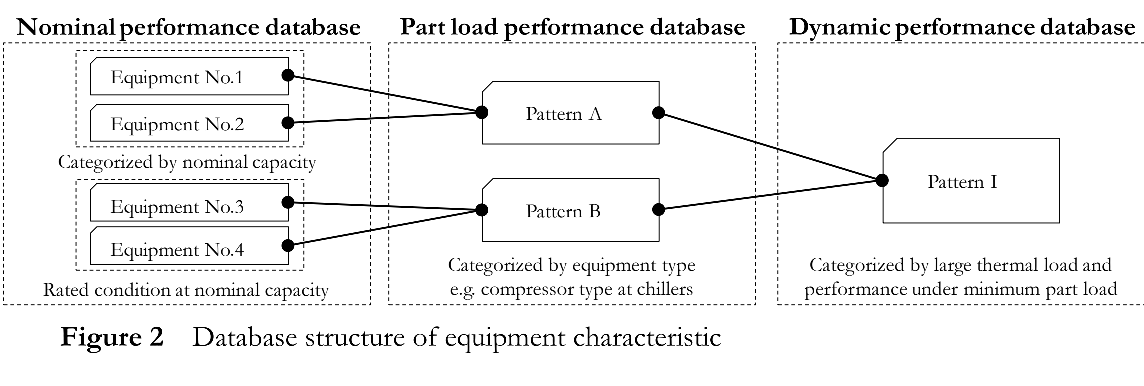


Figure 2 Database structure of equipment characteristic

Methods beyond applicable range of database

The performance curve and performance table data should be valid for the range of condition anticipated for the simulation. But in case where equipment is operated beyond the range in simulation and in reality, alternative methods beyond the range is determined for each equipment performance database.

For example, the database of water-to-water heat pumps has limited range of maximum and minimum temperature for outlet chilled water temperature and condensate water temperature. Figure 3 shows methods beyond applicable range of the database. Equipment characteristic beyond applicable range of database is, basically, characteristic on the boundary line. But compressor is off in case of: (1) under minimum temperature for freezing prevention, (2) set point temperature under /upper entering temperature limit for therms-off state.

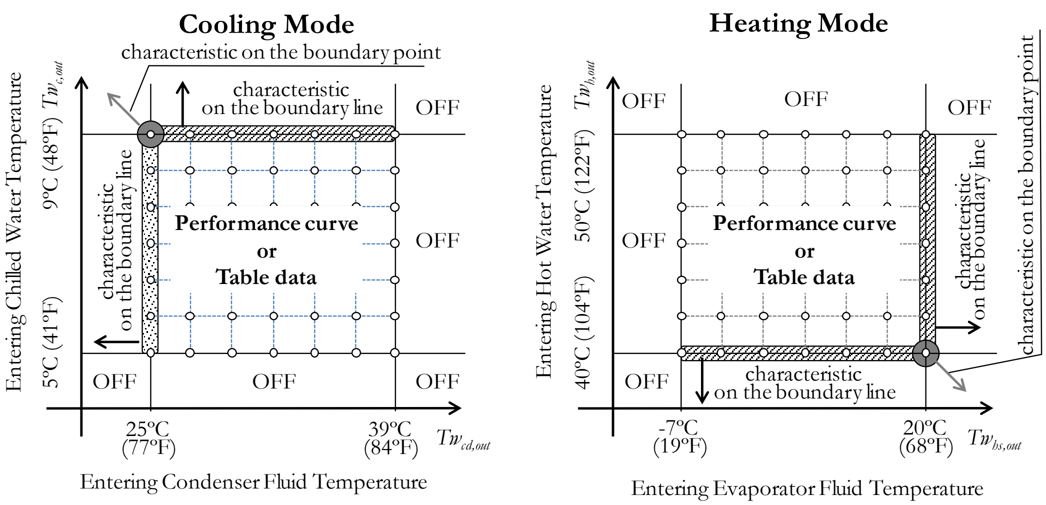


Figure 3 Methods beyond applicable range of database (water-to-water heat pumps)

The upper and the lower limit values of part load ratio are decided in database. If value of part load ratio is under the adaptive range of the approximation formula, users can select any of the following four alternative methods in each equipment data file. Methods for equipment characteristics under minimum part load ratio is shown in Figure 4. That is, (A) on/ off control by simulation time step; (B) replacement with the upper or the lower limit value; (C) use of a line that connects the origin and the lower limit value; or (D) center line between A and B. If value of part load ratio is over the adaptive range of the approximation formula, upper limit values of part load ratio is used.

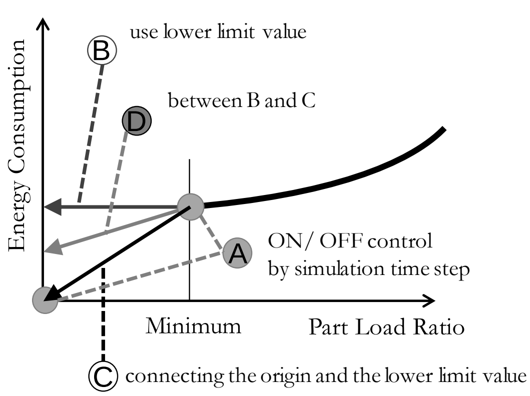


Figure 4 Methods for equipment characteristics under minimum part load ratio

Dynamic Performance

In the BEST program, the steady-state performance of equipments are expressed by using database as already described. The dynamic performance database would be sufficient if delay dynamics during start, stop and reboot operations are considered, and dynamic performance during continuous operation do not have to be considered. Dynamic performance must be considered for large thermal load equipments such as chillers, boilers and cooling towers, etc.. As for other equipments, only the steady-state performance is sufficient because the calculation time intervals are on five minutes basis. Dynamic performance is expressed by single time constant regressive approximation, so sequential order and time steps are investigated during start, stop and reboot operations.

Flow chart of calculating equipment

The example of a calculation for the equipment and the flow chart of the water-to-water heat pump are shown in figure 5. This flow chart illustrates the overall logic of the central plant components algorithms. The same procedures by this flow chart are repeated for each equipments to simulate output datas such as total capacity, power input, $Tw_{out,cd}$, and ,etc..

step-1: calculate required capacity $Q_{c,rq}$ with reference condition ($Tw_{c,in}$ and Mw_c) and set point ($Tw_{c,out,sep}$).

step-2: calculate maximum capacity $Q_{c,max}$ with reference condition ($Tw_{c,in}$, Mw_c, $Tw_{cd,in}$, and $Mw_{cd,}$) and set point($Tw_{c,out,sep}$).

step-3: calculate leaving water temperature Twout,c with $Q_{c,rq}$ and $Q_{c,max}$. When the required capacity ($Q_{c,rq}$) is higher than the maximum capacity($Q_{c,max}$), $Q_{c,rq}$ becomes $Q_{c,max}$. In that case, it goes back to step-1 to recalculate $Tw_{c,out}$.

step-4: calculate maximum electric power Pe_{max} with reference condition and $Tw_{c,out}$

step-5 calculate part load ratio PLR with $Q_{c,max}$ and $Q_{c,rq}$

step-6 calculate electric power Pe with PLR and Pe_{max} and calculate $Tw_{cd,out}$

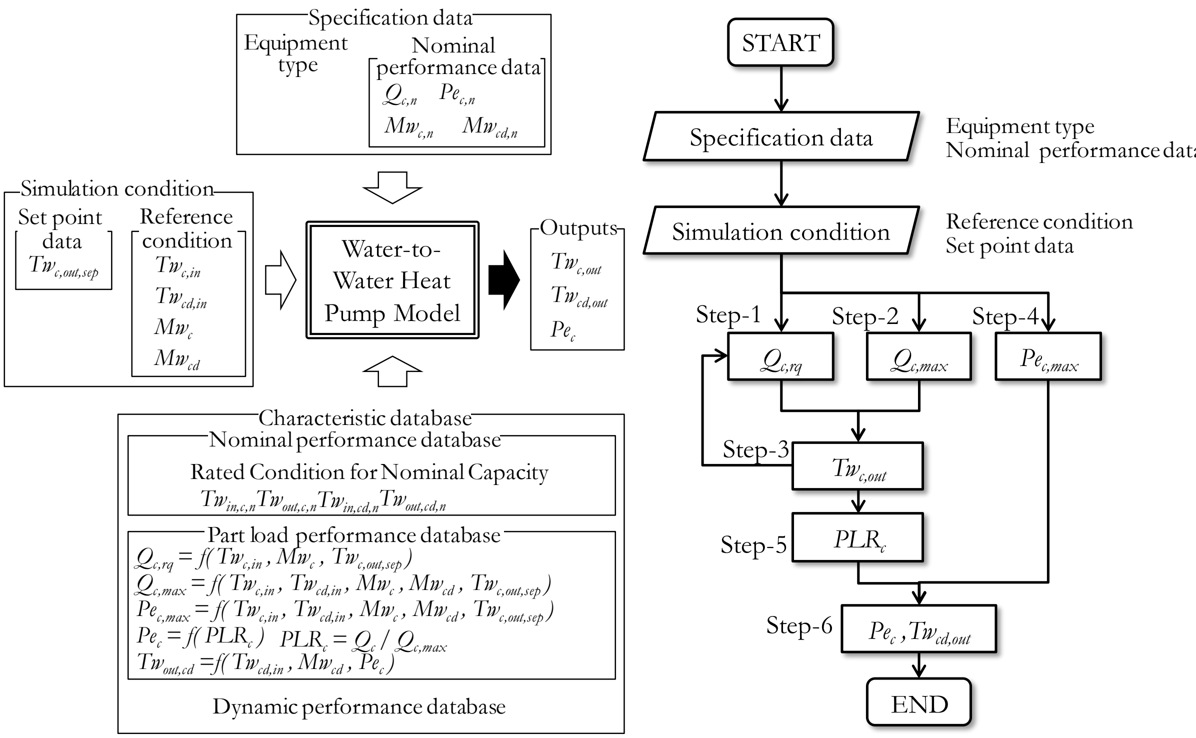


Figure 5 Flow chart of the central plant components

EXAMPLES OF EQUIPEMENT CHARACTARISTIC

Performance curve

Physics-based Model For example, the approximation formula for the heat transfer coefficient (K_f) of a coil in HVAC system, which can be predicted physically , can be written as follows;

$$Q_t = FA * K_f * WSF * N * MTD \tag{1}$$

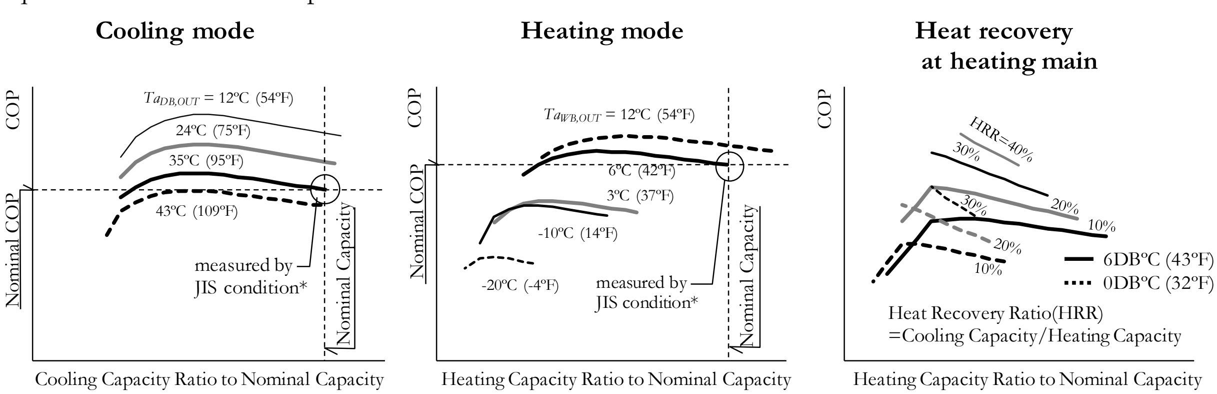
$$K_f = \frac{a}{(b*Va)^c + (d*Vw)^e} \tag{2}$$

$$WSF = f * SHF^2 + g * SHF + h \tag{3}$$

$$MTD = \frac{(Ta_{in} - Tw_{out}) - (Ta_{out} - Tw_{in})}{ln\left(\frac{Ta_{in} - Tw_{out}}{Ta_{out} - Tw_{in}}\right)} \tag{4}$$

This model calculates the coil performance using the coefficient of the wet surface, which is used in the design of the number of rows (*N*). By solving the simultaneous equations of equation (1) and the heat balance equations of air and water, the solution is obtained. Commonly, the approximation equations for the heat transfer coefficient (K_f) and the wet surface coefficient (*WSF*) are obtained from the AHU manufacturer. The relative humidity of the outlet air is assumed to be 95%. Hiromasa and etc. (2006) compared the accuracy of major simulation models by examination using the experimental data. This wet surface model had high accuracy over a wide range.

Empirical Model For example, the empirical model for variable refrigerant flow equipment with heat recovery is shown in Figure 6. Performance characteristics for each of four modes (cooling mode, heating mode, heat recovery mode at cooling main, and heat recovery at heating main) are approximated with empirical model. Outside air condition ($Ta_{DB,OUT}$) does not influence efficiency of heat recovery mode at cooling-main mode, but outside air condition influences efficiency of heat recovery at heating-main mode. This variable refrigerant flow equipment model is based on a polynomial equations in five ranges provided from the industry associations. Regardless of compressor type (electric motor and engine driven) or heat exchange type (air cooled or water cooled), a similar term of an algebraic equations can be used except for the coefficient.

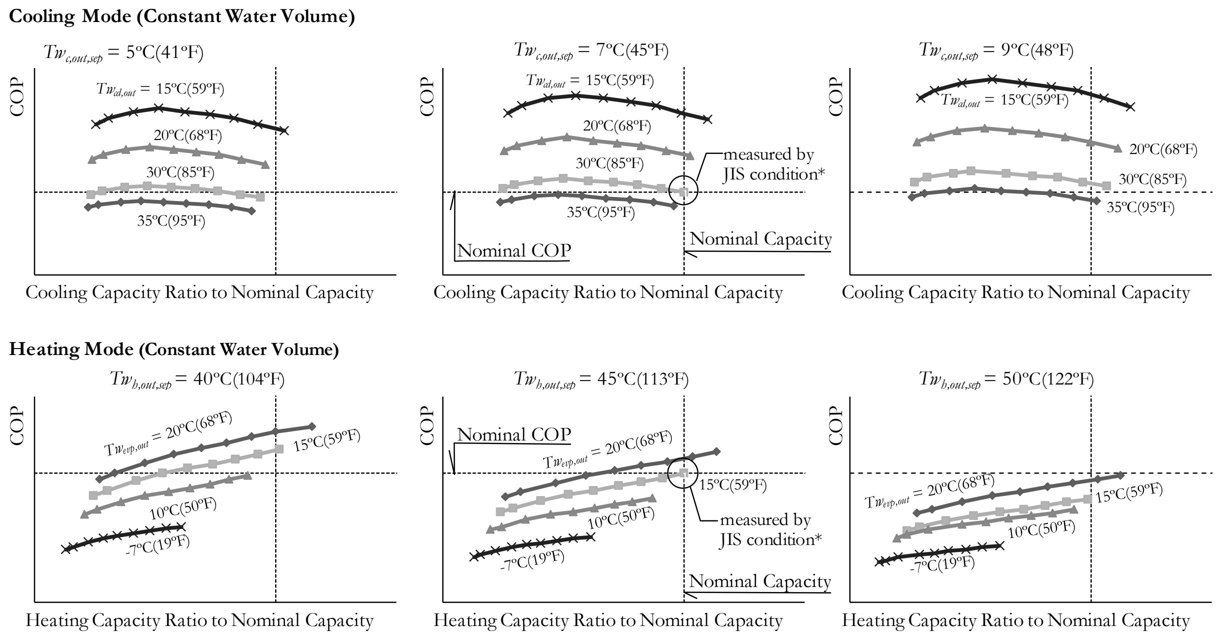


Note: JIS (Japanese Industrial Standards) B8616 Package air conditioners

Figure 6 Characteristic of variable refrigerant flow equipment with heat recovery

Performance table data

In the BEST program, not only the major equipments but also high efficient equipments are investigated. Example for performance table data of unit modular type of water-to-water heat pump(heat recovery type) with scroll compressor controlled by variable-frequency-drive is shown in Figure 7. The nominal input and output of equipment properties are estimated from the JIS condition. In this database, the difference of the condensate water and heat source water temperature ($Tw_{cd,out}$ and $Tw_{hs,out}$) depends on the chilled water and hot water temperature setting ($Tw_{c,out,sep}$ and $Tw_{h,out,sep}$) and effects the capacity and *COP* values. The data tables are evaluated using the straight line interpolation.



Note: JIS (Japanese Industrial Standards) B8613 Water chilling unit

Figure 7 Characteristic of Heat recovery unit modular water-to-water heat pump with scroll compressor controlled by variable-frequency-drive

CONCLUSION

This report describes the development of databases of the equipment characteristics for the BEST program, regarding the simulation method for HVAC systems. It is necessary to update the improved efficiencies of the equipment characteristics continuously. These equipment databases are maintained by adding new informations in neutral and fair way, not by specific manufactures. It is important that the simulation database is expanded and renewed in neutral and fair way. The English version of the BEST program is now under development but the worldwide weather datas are already available. And, the equipment characteristics of other countries can be added as new modules by installing these informations.

In the BEST program, equipment performance datas are basically created from data of the steady-state performance of the equipment. In addition, dynamic performance in equipment with a large thermal load and heat loss from pipes will be studied further.

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NOMENCLATURE

Ta = air temperature
Tw = water temperature
Q = capacity
PLR= part load ratio
Pe = electric power
Mw = water mass flow rate
K_c = heat transfer coefficient
V_a = front surface wind velocity
V_w = water velocity in the pipe
N = number of coil rows
FA = front area
WSF= wet surface factor
SHF= sensible heat factor
MTD= logarithm average difference in temperature
a, *b*, *c*, *d*, *e*, *f*, and *g*= coefficients.

Subscripts

c = chilled water
h = hot water
cd = condensate water
hs = heat source water
in = inlet
out = outlet
sep = set point
rq = requiered
max = maximum
DB = dry bulb
WB = wet bulb
OUT= outdoor

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