Development of Test Procedure for the Evaluation of Building Energy Simulation Tools

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Abstract

Developing a test procedure for the evaluation of building energy simulation tool used for the energy use analysis of HVAC systems and buildings in Japan, SHASE, Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, published the procedure as a guideline in 2016: Guideline of Test Procedure for the Evaluation of Building Energy Simulation Tool. This test procedure focuses on the evaluation of the energy use resulting from thermal load and HVAC system simulation of commercial buildings excluding residential buildings. To enable the identification of causal relationship between causes and results with the object of evaluating simulation tool's ability, the test procedure is divided into two parts, that is, thermal load simulation test and HVAC system simulation test, and also ASHRAE, American Society of Heating, Refrigerating and Air-conditioning Engineers, adopted same method in standard 140. The guideline focuses on evaluating the total energy consumption of HVAC system, so has feature that include not only equipment but also whole system as evaluating targets. This paper describes the outline of the test procedure and reports the test results by some participants and the lessons learned. SHASE intends that every building energy simulation tool should be tested by the guideline to show the reliability obtaining the user's confidence and the test procedure would be utilized for the education of tool users as well.

Introduction

Energy simulation is one of efficient tools when the energy performance of different HVAC systems is compared and evaluated. Although tool users wish to know the accuracy of the tools, few standardized procedures exist to evaluate simulation results of energy simulation tools. ASHRAE published the procedure as Standard 140, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs (ASHRAE 2011). However, as this procedure does not include a test procedure of HVAC systems commonly used in Japan, SHASE established a committee to develop the procedure. One of the backgrounds of this activity is that accurate estimation of building energy use became an important issue due to the substantial revision of energy conservation law in 2015. We need test procedures which can evaluate the total energy consumption of HVAC systems by simulation tools.

Developing a test procedure for the evaluation of building energy simulation tool, SHASE established a committee in 2013 and published the procedure as a guideline in 2016 (SHASE 2016). This paper describes the outline of the test procedure and reports the test results by some users and the lessons learned.

Outline of Test Procedure

The objective of this test procedure is to determine the reliability of energy simulation tools for HVAC systems including thermal load simulation, and for their use in the education and training of users in the use of these tools. The scope of this test procedure is limited to air conditioning systems and associated ventilation systems. Also, systems for residential buildings is outside the scope of this test procedure.

From the point of view of simulation tool evaluation, the scope of this procedure is broadly divided into thermal load simulation and HVAC system simulation, and evaluation of each constituent element and the overall system is carried out, with the objective of simplifying the identification of the cause and effect relationship between the causes and the results. Fig. 1 shows the test case configuration. Note the guideline does not include the control logic analysis now. We are examining the test

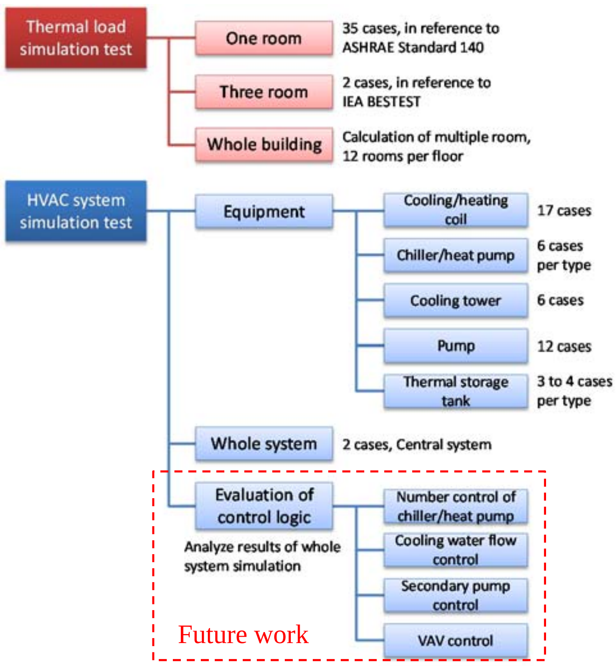


Figure 1: Test case configuration

procedure of control logic now, and will revise the guideline in the future.

The following is a description of the conditions and the trial results for each test case. Table 1 shows an overview of the tools used in the simulation trials. Note that the simulation trials using NewHASP, LCEM and BEST were not conducted by these program authors but by just users, and the results were not verified by the program authors.

Thermal Load Simulation Test

Three types of test are carried out: one room test, multiple room test, and whole building test.

In the one room test, the non-steady state thermal load (sensible heat only) of an imaginary building model with only one room is calculated for various cases in which the configuration of the model is changed, such as with or without the sun shade, the position of windows, the thermal capacity, the interior temperature setting, with or without the ventilation, etc.

In the three room test, the steady-state thermal load (sensible heat only) of an imaginary building model with three rooms is calculated for cases where internal walls are with or without.

In the whole building test, the non-steady state heat load (sensible and latent heat) of a medium scale office building (total floor a rea 10,000 m^2) is calculated for the building as a whole.

In each test the results of the different tools are compared, and the differences in the results between each case are evaluated. We generally use different tools for determining capacity or predicting energy consumption in Japan. We don't focus on evaluating the peak load because the guideline focuses on latter. The simulation results of peak load are shown for reference. Note that most of the one room test and the multiple room test were extracted from the ASHRAE Standard 140 and BESTEST (R. Judkoff and J. Neymark 1995).

One room test

In addition to the thermal load simulation test cases prescribed in ASHRAE Standard 140, an additional 4 cases were newly prescribed, so a total of 35 cases are analyzed. The simple right-angled parallelepiped building model shown in Fig. 2 was taken as the case, and annual simulations were carried out for several cases changing the calculation conditions little by little, to verify the validity of the simulation tools.

The four additional cases of Case 900-J series were based on the Standard 140 Case 900, but adding conditions from common Japanese architectural and air conditioning specifications that are not included in the Standard 140 test cases. Case 900-J 1 is a case in which the external wall thermal insulation was changed from external thermal insulation to internal thermal insulation, and 2 cases are prescribed: the external wall specification prescribed in Standard 140 (900-J1-1), and the common Japanese external wall specification (900-J1-2). Case 900-J2 is a case in which air conditioning time is changed from all hours to 12 hours a day, and Case 900-J3 is a case in which blinds are provided on the window.

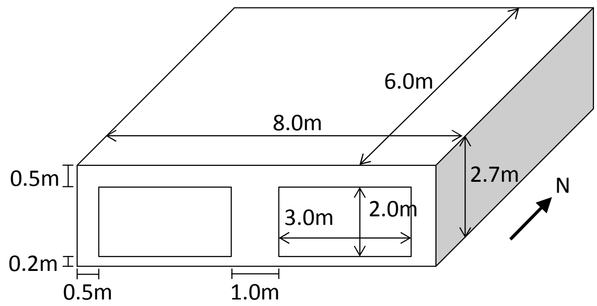


Figure 2: Isometric drawing

Table 1: List of Simulation tools using for trial of developed test procedure

Name	Abbreviation	Version	Authoring Organization	Reference
NewHASP/ACLD, ACSS	NewHASP	Ver.20121213	Japan Building Mechanical and Electrical Engineers Association	JAMBEE (1986)
LCEM	LCEM	Ver.3.10	Public Buildings Association of Japan	Ito M, et al. (2007)
The BEST Program	BEST	Professional Edition BEST1307	Institute for Building Environment and Energy Conservation	Hasegawa I, et al. (2017)
ACSES/Cx	ACSES/Cx		Yoshida Laboratory of Kyoto University	Yoshida H, et al. (2013)
"No name"	Kyushu-U		Sumiyoshi Laboratory of Kyushu University	Sumiyoshi D, et al. (2009)
HVAC Simulation Program for Office Spaces	OFFICE	EcoWin Ver.3.0.2	Kajima Technical Research Institute	Togari S, et al. (1993)
Energy Network Simulation Tool	ENe-ST		Kajima Technical Research Institute	Mihara K, et al. (2015)

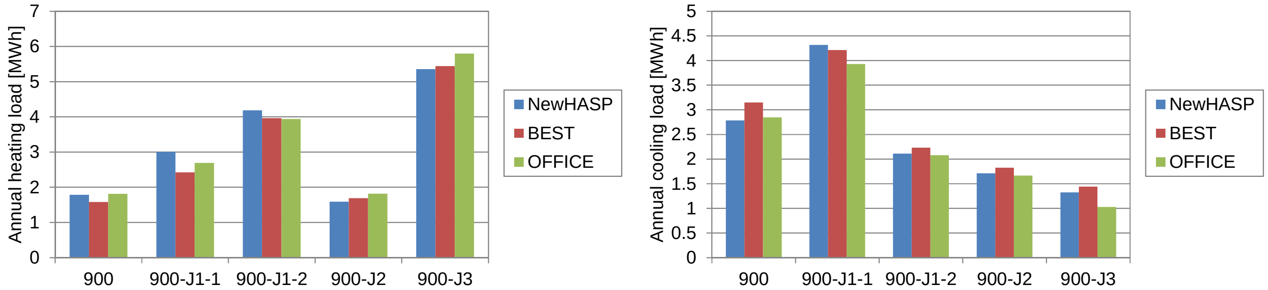


Figure 3: Annual load of Case 900-J series (left: heating, right: cooling)

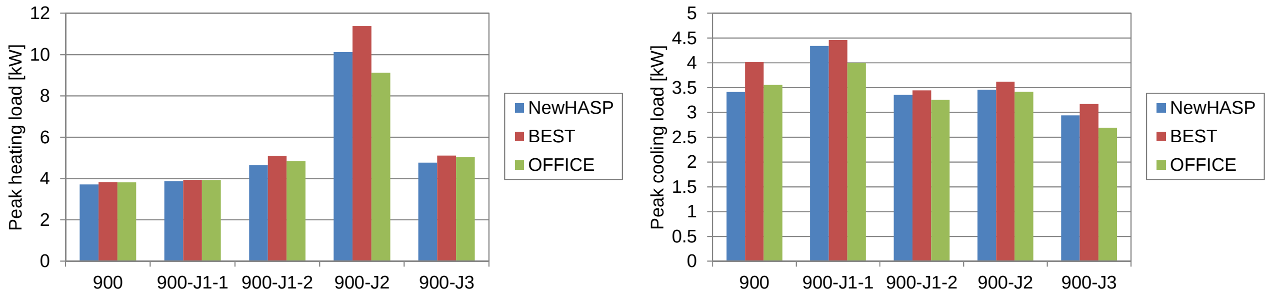


Figure 4: Peak load of Case 900-J series (left: heating, right: cooling)

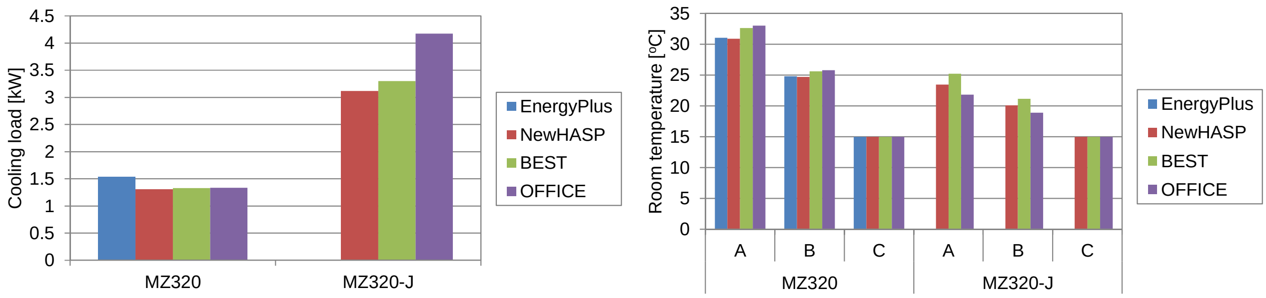


Figure 6: Peak load (left) and room temperature (right) of Case MZN and MZA

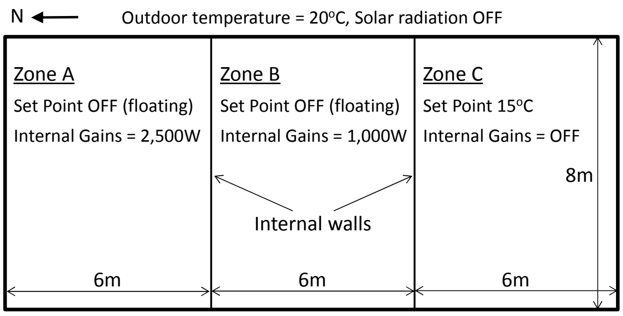


Figure 5: Plan of three rooms

Figs. 3 and 4 show examples of the calculation results. Comparing Case 900 and 900-J1-1 it can be seen that the latter has a greater annual heat load, and it is considered that this is due to the effect of the thermal capacity of the external walls. As a result of the intermittent air conditioning of Case 90 0-J2 the annual heat load is reduced, but the peak load (in particular for heating) is increased. In Case 900-J3 the amount of sunlight transmitted is reduced by the blinds, so the heating load is increased, and conversely the air conditioning load is reduced.

Three room test

Two cases were prescribed with and without internal walls for the three room model shown in Fig. 5. Internal heat generation was applied to Zone A and B, and Zone C was air conditioned with a setting temperature of 15°C. Case MZN with internal walls is Case MZ320 in the IEA BESTEST Multi-Zo ne Non-Airflow In-Depth Diagnostic Cases. Case MZA with no internal walls has the walls between the three rooms removed to enable movement of air between the zones. For both cases a steady state calculation was carried out.

Fig. 6 shows examples of the calculation results. In Case MZA with no walls, the cooling load was larger, and it can be seen that the room temperature in zones A and B was reduced. In Case MZA, the OFFICE cooling load was slightly increased, but it is considered that this was because the method of calculation of the amount of movement of air between zones was different from that of the other tools.

Whole building test

The annual load was calculated for a whole office building with 7 stories above ground and a total floor area of 10,000m^2 located in Tokyo, Japan. Fig. 7 shows a plan view of the standard floor and floor configuration. The air-conditioning conditions, the heat generation conditions, the wall specification, etc., are prescribed in detail for each room, to ensure that there would be no uncertainty among the users when preparing the simulation model.

Figs. 8 and 9 show the annual load and the maximum load for each zone on the standard floors (2nd floor to 6th floor) as an example of calculation results. These results were recalculated with revised input condition and not the same as results shown in the guideline. It can be seen that the load varies depending on the differences in room use or orientation, and differences in the interior/perimeter.

HVAC System Simulation Test

It is considered that the factors that affect the energy consumption of HVAC systems can be divided into 3 types: the performance of each equipment, the combination of equipment, in other words the system configuration, and the control behaviour.

First, each equipment model is evaluated to check whether the specification can be appropriately modelled or not. Secondly, the performance, such as heat

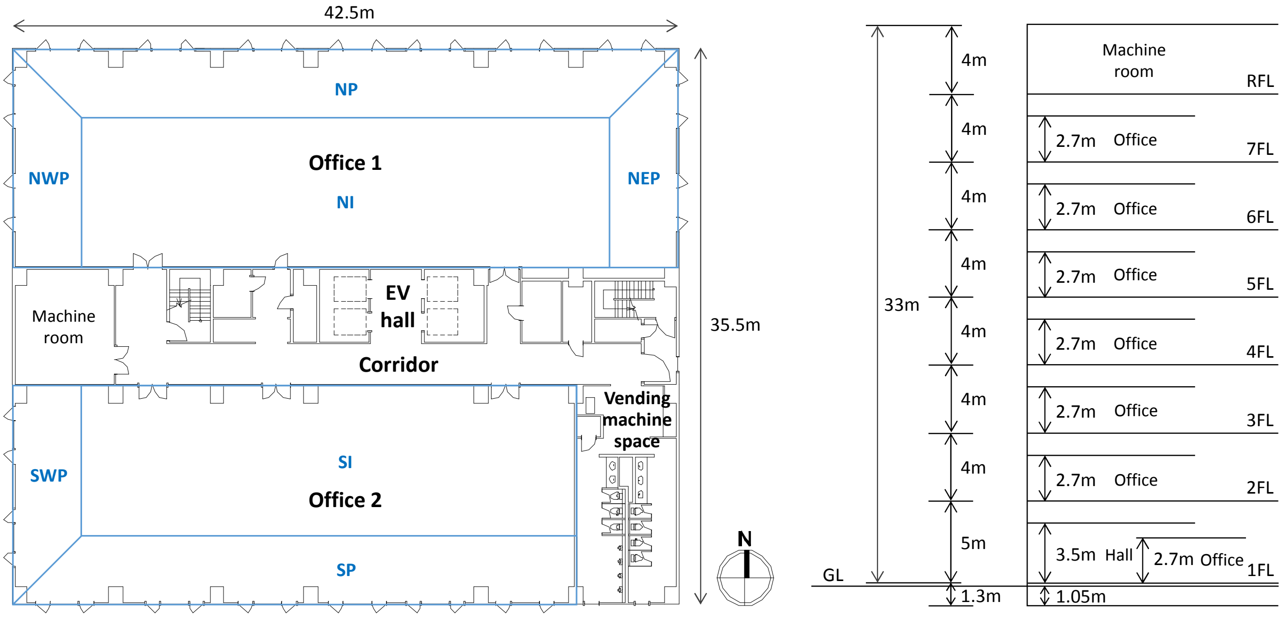


Figure 7: Standard floor plan (left) and floor configuration (right) of office building

Figure 8: Annual load per floor area

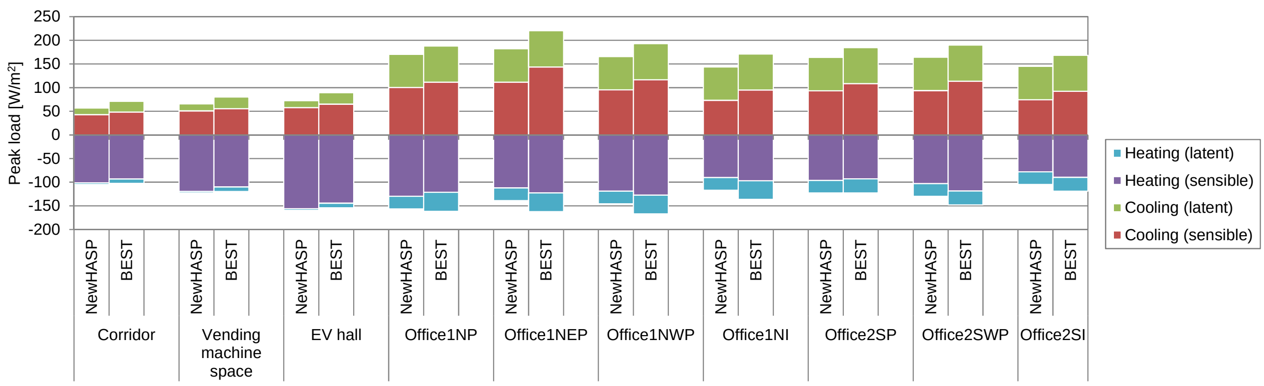


Figure 9: Peak load per floor area

production, energy consumption and efficiency, of whole system which is composed of equipment models is evaluated. Last, automatic control logics are evaluated. The simulation tool with inadequate control logics can not output adequate results even though equipment is appropriately modelled. So, it is important to check not only the energy consumption, efficiency and so on but also automatic control logics.

Therefore three types of tests are carried out: equipment tests, whole system tests, and evaluation of the automatic control logic. Note the guideline does not include the control logic analysis now.

Equipment test

In the equipment tests, the accuracy of each of the equipment models is evaluated. In the guidelines, test procedures are provided for air source heat pump/chillers

Table 2: Specification of air source heat pump/chiller

	Cooling	Heating
Capacity [kW]	150	150
Power consumption [kW]	49.8	50
Flow rate [L/min]	430	430
Outlet temperature [°C]	7	45
Head loss [kPa]	46	46

Table 3: Test Cases of air source heat pump/chiller

Case No.		Load factor [%]	Load [kW]	Outlet temperature [°C]	Flow rate [%]	Outdoor temperature [°C]
Cooling	RC110	100	150	7	100	35
	RC120	75	112.5	7	100	30
	RC130	50	75	7	100	25
	RC210	75	112.5	7	75	30
	RC310	90	135	5	100	35
	RC320	109	163	9	100	35
Heating	RH110	85	127.1	45	100	0
	RH120	64	95.3	45	100	5
	RH130	42	63.6	45	100	10
	RH210	64	95.3	45	75	5
	RH310	62	93.2	47	100	0
	RH320	88	132.7	43	100	0

Table 4: Specification of cooling coil

	Cooling	Heating
Flow type	Counter flow	
Material	Tube: Cu, Fin: Al	
Capacity [kW]	44.2	36.6
Water flow rate [L/min]	127	105
Air flow rate [m^3/h]	7,476	7,476
Front area [m^2]	0.748	0.748
Row	6	4
Circuit	Half flow	
Inlet water temperature [°C]	7	50
Outlet water temperature [°C]	12	45
Inlet air temperature [°CDB]	27.5	17.5
Inlet air temperature [°CWB]	20.4	11
Outlet air temperature [°CDB]	15.1	32.1
Outlet air temperature [°CWB]	14.6	16.6
Water flow velocity [m/s]	0.98	0.81
Air flow velocity [m/s]	2.78	2.78
Heat transfer coefficient [W/m^2K]	845	849

Table 5: Test cases of cooling coil

Case No.		Inlet air temperature [°CDB]	Inlet air humidity [g/kg]	Inlet water temperature [°C]	Air flow rate [%]	Outlet air temperature [°CDB]
Cooling	CC110	27.46	12.06	7	100	14.3
	CC120	27.46	10.2	7	100	13.5
	CC130	27.46	12.06	7	75	13.5
	CC140	27.46	12.06	7	50	12.5
	CC150	27.46	12.06	7	25	11.1
	CC230	27.46	12.06	7	100	14.8
	CC240	27.46	12.06	7	100	15.8
	CC250	27.46	12.06	7	100	17.6
	CC310	33.3	17.6	7	20	13
Heating	CH110	17.46	5.54	50	100	36.1
	CH120	17.46	5.54	50	75	37.7
	CH130	17.46	5.54	50	50	39.8
	CH140	17.46	5.54	50	25	42.8
	CH220	17.46	5.54	50	100	35.3
	CH230	17.46	5.54	50	100	33.7
	CH240	17.46	5.54	50	100	30.4
	CH310	0.6	1.4	50	21	40.2

and gas absorption type water chillers and heaters as heat sources, chilled and hot water coils and cooling towers as heat transfer equipment, pumps as transport equipment, and thermal energy storage tanks as other equipment, but the equipment is scheduled to be increased in the future. Apart from thermal energy storage tanks, results are

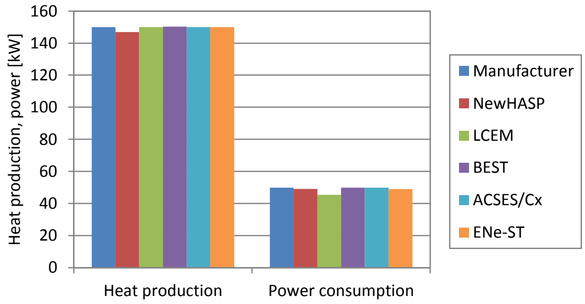


Figure 10: Simulation result of Case RC110

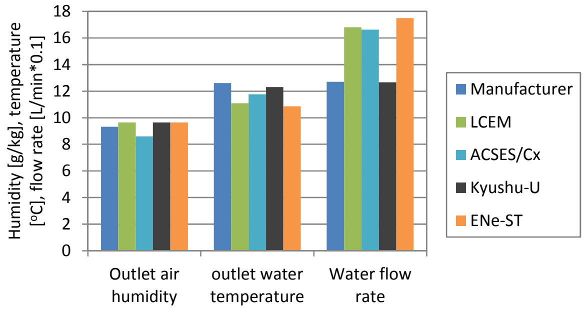


Figure 11: Simulation result of Case CC110

output based on equipment specifications supplied by manufacturers, and the accuracy of the simulation tools is evaluated by comparing the results with the characteristics supplied by the manufacturers. In the case of thermal energy storage tanks there is virtually no equipment specifications or property values from the manufacturers, so evaluation is carried out for tests in which there is a balance between charge and discharge operation, and results are compared for the various tools.

In the following figures which show simulation results, the reason why the tools had various results is that the tools may have different model algorithms. Additionally, some tools can’t be input specified characteristics to. In that case, users selected a model having similar characteristic.

a. Heat source equipment

In the tests of heat source equipment, two types are prescribed: air source heat pump/chillers and absorption chillers, but here the test conditions for air source heat pump/chillers are described. The specification of the relevant equipment is shown in Table 2. In addition specification curves are provided by users as ancillary material. Table 3 show s the test cases. For both heating and cooling, the energy consumption, etc., was calculated when the load factor, the chilled/heating water outlet temperatures, the chilled/heating water flow rates were varied. Fig. 10 shows an example of the calculation results.

b. Hot water coil

The specification of the relevant equipment (hot water coil only) is shown in Table 4, and the test cases are shown in Table 5. For both heating and cooling, the chilled/heating water flow rates, the chilled/heating water outlet temperatures, and the outlet air humidity are calculated when the inlet air conditions, outlet air temperature setting value, and flow rates are varied. Here,

Table 6: Specification of cooling tower

Type	Open, Cross flow
Capaciy [kW]	939.4
Inlet water temperature [^{o}C]	37
Outlet water temperature [^{o}C]	32
Outdoor temperature [^{o}CWB]	27
Water flow rate [L/min]	2,693
Air flow rate [m^3/min]	1,783
Fan motor output [kW]	7.5
Motor efficiency [-]	0.92

Table 7: Test cases of cooling tower

Case No.	Outdoor temperature [^{o}CWB]	Inlet water temperature [^{o}C]	Air flow rate [%]	Water flow rate [%]
CT110	27	37	100	100
CT120	23	33	100	75
CT130	19	29	100	50
CT140	15	25	100	25
CT230	19	29	75	50
CT240	15	25	50	25

Table 8: Specification of pump

Type	Centrifugal pump
Motor output [kW]	11
Water flow rate [L/min]	1,077
Total head [m]	25
Shaft power [kW]	6.55
Input power [kW]	7.49
Motor efficiency [-]	0.92
Inverter efficiency [-]	0.95

Table 9: Test cases of pump

Case No.	Flow rate [%]	Total head [kPa]
P110	100	245.1
P120	75	269.6
P130	50	284.3
P140	25	299
P210	75	138.2
P220	56.3	152
P230	37.5	159.8
P240	18.8	168.6
P310	50	61.8
P320	37.5	67.6
P330	25	71.6
P340	12.5	74.5

Table 10: Specification of water thermal storage tank

Volume per tank	$90m^3$, W5,000mm * L9,000mm * H2,000mm
Number of tanks	10
Effective volume ratio [-]	1.0
Base temperature [^{o}C]	12
Structure	Concrete: upper face 150mm, other face 1,000mm, heat conductivity 1.4W/mK Insulation: polystyrene foam 50mm, heat conductivity 0.037W/mK

the outlet air temperature (setting value) is adopted as an input because in many of the energy simulation tools, the method adopted is back calculation of the chilled/heating water flow rate in accordance with the setting temperature. Fig. 11 shows an example of the calculation results.

c. Cooling towers

The specification of the relevant equipment is shown in Table 6, and the test cases are shown in Table 7. The cooling water outlet temperature and the fan electric power, etc., are calculated when the external air wet bulb temperature, the cooling water inlet temperature, the water flow rate, and air flow rate are varied. Fig. 12 shows an example of the calculation results.

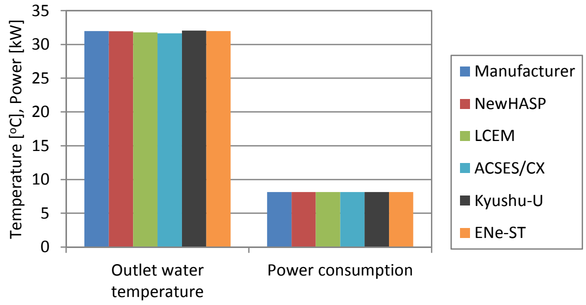


Figure 12: Simulation result of Case CT110

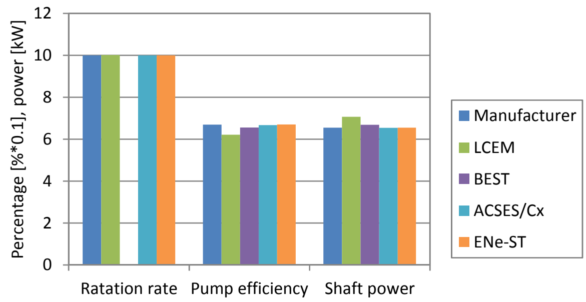


Figure 13: Simulation result of Case P110

d. Pumps

The specification of the relevant equipment is shown in Table 8. In addition specification curves are provided by users as ancillary material. Table 9 shows the test cases. For both heating and cooling, the energy consumption, etc., is calculated when the flow rate and pump he ad are varied. Fig. 13 shows an example of the calculation results.

e. Thermal energy storage tanks

In the simulation of thermal energy storage tanks, the outlet temperature and the accuracy of the energy balance associated with the heat storage and dissipation are important. Therefore in this test, evaluation is carried out to determine whether these can be accurately calculated under extremely simple conditions. There are many types of thermal energy storage tank, but in this guideline tests are carried out for the following 3 types.

- thermal energy storage tank of multi-connected complete mixing type

- thermal energy storage tank of thermal stratification type

- thermal energy storage tank of static ice type

In the following, the test conditions are described taking thermal energy storage tank of multi-connected complete mixing type as an example.

The specification of the thermal energy storage tank is shown in Table 10. The operational temperature and flow rate conditions during thermal energy storage and heat dissipation are as shown in Table 11. Table 12 shows the test cases. The energy balance, the inlet and outlet temperatures, the temperature distribution within the tank, and the heat loss are calculated when the accumulation and heat dissipation period and thermal insulation properties are varied. Fig. 14 shows an example of the calculation results.

Whole system test

In order to simplify the test, the secondary side HVAC system is limited to a HVAC system installed in office room 1 and office room 2 on the standard floors (2nd to 7th floors) of the whole building model, and the heat source system is provided by six standard floors.

The heat source system diagram is shown in Fig. 15, and the HVAC system diagram is shown in Fig. 16. Also, the specification of each equipment is shown in Tables 13 and Table 14. The air-conditioning periods are taken to be 6/1 to 9/30 for cooling, and 12/1 to 3/31 for heating. In the intervening periods it is envisaged that the HVA C system

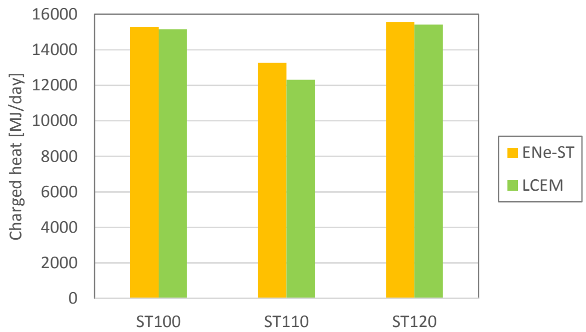


Figure 14: Daily charged heat of Case ST100 – ST120

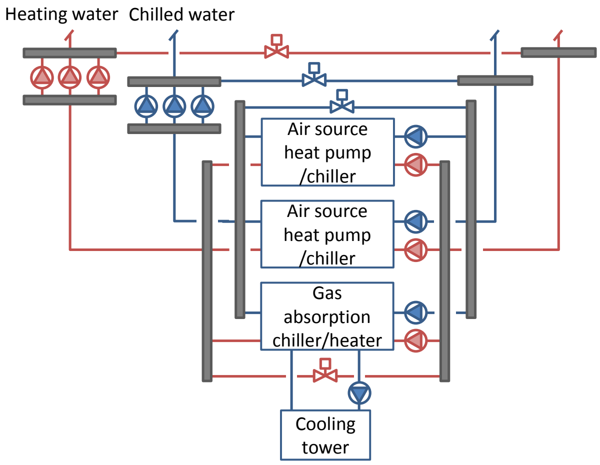


Figure 15: System diagram of heat source system

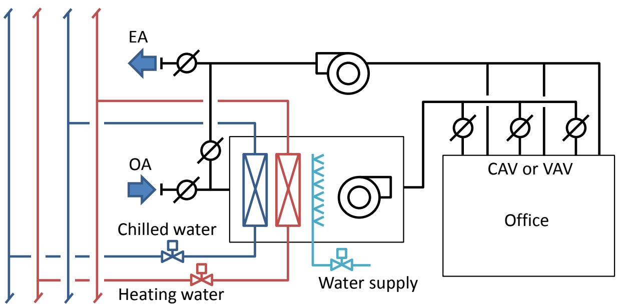


Figure 16: System diagram of air-conditioning system

Table 11: Operation condition of charge/discharge

Operation mode	Inlet temperature of lower temperature tank [°C]	Inlet flow rate to lower temperature tank [L/min]	Inlet temperature of higher temperature tank [°C]	Inlet flow rate to higher temperature tank [L/min]
Charge	7	1,500	-	0
Discharge	-	0	12	1,500
Charge/Discharge	7	1,500	12	1,500

Table 12: Test cases of water thermal storage tank

Case No.	Description
ST100: completely insulated	1) The heat conductivity of insulation is set to 0W/mK to insulate tanks completely. 2) Following daily operation is repeated 30 times. Charge mode is operated from 0:00 to 10:00, discharge mode is operated from 12:00 to 22:00, and the system stops rest of the day.
ST110: completely insulated & Charge/Discharge operation	1) The heat conductivity of insulation is set to 0W/mK to insulate tanks completely. 2) Following daily operation is repeated 30 times. Charge mode is operated from 0:00 to 8:00, charge/discharge mode is operated from 8:00 to 16:00, and discharge mode is operated from 16:00 to 24:00.
ST120: with heat loss	1) The heat conductivity of insulation is set to 0.037W/mK. 2) Following daily operation is repeated 30 times. Charge mode is operated from 0:00 to 10:00, discharge mode is operated from 12:00 to 22:00, and the system stops rest of the day.

Table 13: Specification of the heat source system

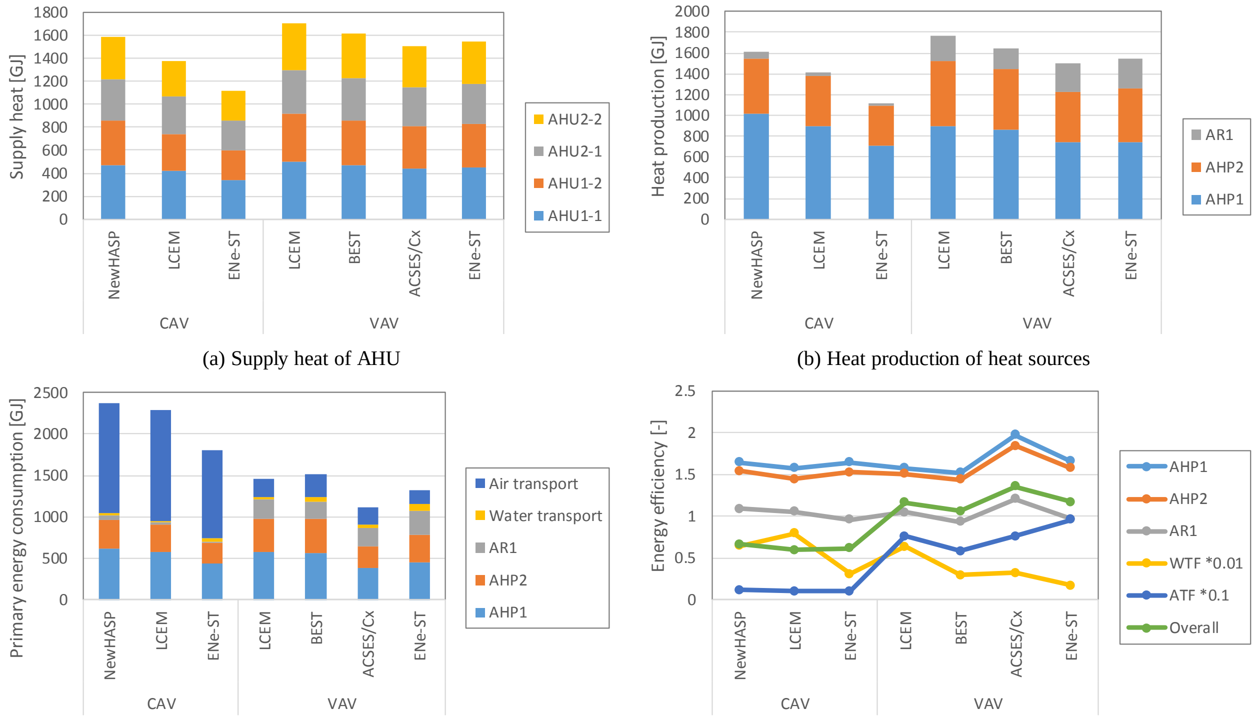
Name		Specification	Number
Absorption chiller/heater system (AR)	Gas absorption chiller/heater	Capacity 527kW, Gas consumption 32.4m^3/h	1
	Cooling tower	Capacity 939kW, Fan motor output 7.5kW	1
	Primary pump	Flow rate 1,512L/min, Total head 15m, Motor output 7.5kW	2
	Cooling water pump	Flow rate 2,693L/min, Total head 25m, Motor output 18.5kW	1
Air source heat pump /chiller system (AHP)	Air source heat pump/chiller	Capacity 300kW, Power consumption 99.6kW	2
	Primary pump	Flow rate 860L/min, Total head 15m, Motor output 3.7kW	4
Secondary pump		Flow rate 1,077L/min, Total head 25m, Motor output 11.0kW	6

Table 14: Specification of the air-handling units

Name	Composition	Specification
AHU1-1 (for perimeter of office room 1)	Supply air fan	Flow rate 7,476m^3/h, Shaft power 3.44kW
	Return air fan	Flow rate 6,946m^3/h, Shaft power 1.31kW
	Cooling coil	Capacity 44.2kW, 6 rows, Half flow
	Heating coil	Capacity 36.6kW, 4 rows, Half flow
	Humidifier	Evaporative humidifier, Capacity 15.5kg/h
AHU1-2 (for interior of office room 1)	Supply air fan	Flow rate 6,212m^3/h, Shaft power 3.11kW
	Return air fan	Flow rate 5,700m^3/h, Shaft power 1.30kW
	Cooling coil	Capacity 38.8kW, 6 rows, Half flow
	Heating coil	Capacity 32.4kW, 4 rows, Half flow
	Humidifier	Evaporative humidifier, Capacity 15.4kg/h
AHU2-1 (for perimeter of office room 2)	Supply air fan	Flow rate 5,106m^3/h, Shaft power 2.53kW
	Return air fan	Flow rate 4,712m^3/h, Shaft power 1.04kW
	Cooling coil	Capacity 30.7kW, 6 rows, Half flow
	Heating coil	Capacity 32.3kW, 4 rows, Half flow
	Humidifier	Evaporative humidifier, Capacity 11.2kg/h
AHU2-2 (for interior of office room 2)	Supply air fan	Flow rate 5,730m^3/h, Shaft power 3.01kW
	Return air fan	Flow rate 5,242m^3/h, Shaft power 1.29kW
	Cooling coil	Capacity 36.1kW, 6 rows, Half flow
	Heating coil	Capacity 30.0kW, 4 rows, Half flow
	Humidifier	Evaporative humidifier, Capacity 14.6kg/h

is stopped, and the ventilation is also not operating. The temperature and humidity conditions set within the rooms are 26°C and 50% during cooling, and 22°C and 40% or higher during heating. However, during summer the humidity is not directly controlled, and in winter it is controlled with a humidifier.

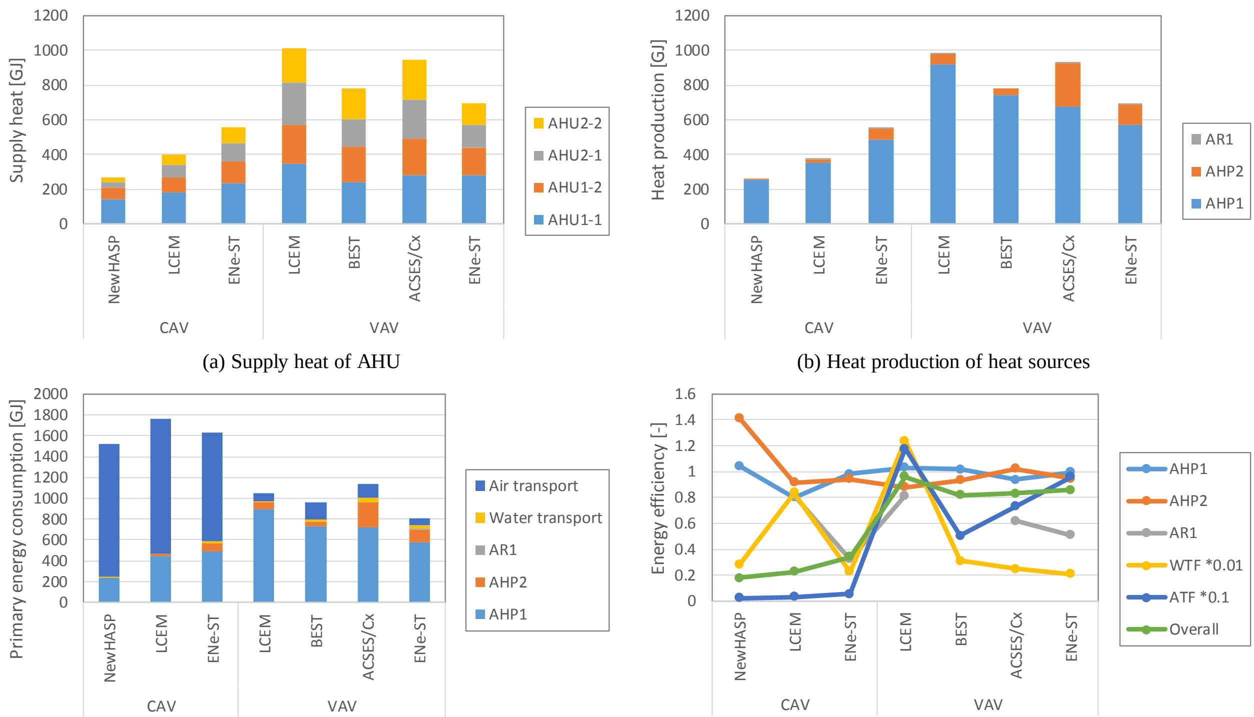
Figs. 17 and 18 show an example of the calculation results for cooling operation and heating operation. In particular during heating, there was a large difference in the constant air volume (CAV) and variable air volume (VAV) heat processing quantity, and it is considered that this was because with VAV the load in each zone was appropriately processed. Also, it was confirmed that there



(a) Supply heat of AHU (b) Heat production of heat sources

(c) Primary energy consumption (d) Energy efficiency based on primary energy

Figure 17: Simulation results of cooling operation



(a) Supply heat of AHU (b) Heat production of heat sources

(c) Primary energy consumption (d) Energy efficiency based on primary energy

Figure 18: Simulation results of heating operation

was a large difference in electrical power between CAV and VAV.

At present enhancement of the test cases is being investigated, in order to increase the variation in systems that are subject to testing. For example, higher efficiency heat sources, moderation of chilled/heating water temperature, variable water volume control pumps, addition of energy recovery ventilators, and CO_2 concentration control of supply fresh air, etc., are being investigated. In addition, in order to simplify the analysis of the calculation results, calculation of the quantity of heat separating the sensible heat/latent heat, and display of the operational status on representative days is being considered.

Conclusion

The procedure of the SHASE Guideline of Test Procedure for the Evaluation of Building Energy Simulation Tool is described in detail together with the test results. The guideline focuses on evaluating the total energy consumption of HVAC system. However, the HVAC system types and components provided in the guideline are very limited compared to commonly used HVAC systems. Therefore increasing the variation of the system types and components with their test result examples is our necessary future work. We will consider the test procedure of tools which collaborate with BIM in the future work too.We expect that every building energy simulation tool will be tested by the procedure to show the reliability resulting in getting the user’s confidence and the test procedure will be utilized for the education of tool users as well.

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