

Simulation Method of HVAC Systems Using Self-Adjusting Templates for the Building Energy Simulation Tool

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ABSTRACT

This paper describes simulation methods of HVAC systems using self-adjusting templates, which are implemented in the Building Energy Simulation Tool (hereafter "the tool"). To achieve extensibility and maintainability, the modular structure has been introduced. Each device is modeled as a module class that has common functions. These functions are formatted. One of the new features of the tool is the "template" structure, which enables us to drastically reduce input data. A template is a partial system implemented, which is to be prepared in advance with several parts connected with each other. For example, an AHU template is provided including several modules such as supply air fans, return air fans, heating and cooling coils, humidifiers, and control systems so that the connecting media, such as air, water, and signals can work as air conditioners. There are several types of the templates, and each template shell (common interface with external connection nodes) is defined by type. A template can easily be replaced with another if they are of the same type. Template functions can reduce errors in the connection between modules during the system building. As "AHU/FCU" template shell types, various templates such as "VAV (2 coils, HEX)" template, "VAV (1 coil, HEX)" template, "CAV (1 coil, HEX)" template, "FCU (1 coil or 2 coils)" template and so on are implemented. It is possible for users to replace a template with another because these templates have the same interface. Therefore, without considering each module such as "a coil" and "a fan", we can replace an air-conditioning unit of "AHU" equipment with "FCU", keeping the external connection. In addition, the template systems such as "Zone", "Heat Source", "Heat Source Group", "Pump", "Ventilation", "Elevator", "Hot Water", "Plumbing", "Thermal Storage", and "Cogeneration" are provided. We define a group of these templates as "The whole building".

INTRODUCTION

As countermeasures against global warming, we are now required to perform an annual energy simulation of energy saving. In the tool, various templates are prepared so that we can start the simulation easily. When we use a self-adjusting template, the equipment is controlled in the given conditions. At the same time, a program makes a calculation adjusting an equipment capacity. Therefore, we can start the simulation without setting the equipment capacity.

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Overview of the calculation method and the element module

Like existing simulation tools such as TRNSYS and EnergyPlus, the tool is designed so that we can express each equipment model using modules which have the standardized format, and we will create the entire system connecting these modules with each other. We assume that the tool can accept various system configurations (i.e., various connection patterns of the modules) and allow users to add modules, helping to improve maintainability. The tool is built by means of Java language, and each module is expressed as a class. In addition, we implement common interfaces, which are quite abstract. Therefore, the details of each module can be hidden from the outside.

Table 1 shows common interface methods of element module. During the calculations, the main routine (calculation engine) calls a method of each module in order. SetProfile method sets a fixed value such as equipment specifications of each module. Initialize method sets up a connection relationship between other modules. SetProfile method and initialize method are called only once at the start of a calculation. Output method, the main calculation part of the simulation, calculates output values based on values of input nodes and the internal state of the module, and the results are set in the output node. Internal state of the module is equivalent to the state variable in the dynamic model. However, the state variable includes such information as private variables for each object, instead of providing any specific variable for the state variable. Update method calculates the internal state of the next step referring to input values and the current internal state. It is necessary to describe the contents of the method only in the case of a dynamic module. Output and update methods are called once per each calculation time step.

Table 1. Methods element module implements

Methods	Processing content
setProfile	To set a fixed value, such as equipment specifications.
initialize	To set up a connection relationship with other modules.
outputs	In each calculation time step to calculate the output from the input and internal state.
update	At the end of each calculation time step, to update the internal state of the module.

Medium class

As media for connecting the modules, air (supply and return air, outside air), water (hot and chilled water, cooling water, plumbing), electricity, gas, control signals (on/off operation mode, cooling and heating mode, the control amount, the observed value) and so on are available. In the tool, we created classes of these media to set up a mechanism for certainly transmitting multiple state values of the media. Table 2 shows examples of the medium classes. For example, in the BestAir class, dry-bulb temperature [°C], absolute humidity [g/g (DA)] and the mass air flowrate [g/s] have been defined as "Field variable" to manage the state of the air by object. In addition, we have provided a method which corresponds to the psychrometric chart function (getTempWB, etc.), which enables us to easily get the state values such as the wet-bulb temperature, specific enthalpy, relative humidity, and dew-point temperature.

Table 2. Examples of Medium Class

Medium Class Name	Field variable	Examples of methods	Connection node name
BestAir	Dry-bulb temperature[°C]	getTempDB	airIn / airOut
	Absolute humidity[g/g(DA)]	getTempWB	airInOA / airOutEA
	Mass flow rate[g/s]	getEnthalpy	airInRA / airOutSA
BestWater	Temperature[°C]	getTemp	watIn / watOut
	Mass flow rate[g/s]	getFlowRate	watInCD / watOutCD
BestElectricity	Active Power[W]	getActivePower	eleIn / eleOut
	Reactive Power[Var]	getReactivePower	
BestGas	Gas consumption[W]	getWatt	gasIn / gasOut

Outline of solving method

There are 2 solving methods for module-based simulation programs. One is the method for solving nonlinear equations expressing an entire HVAC system based on Newton's method, etc. The other is the method to simply calculate modules successively. The tool applies the latter method and shortens calculation time intervals to calculate the dynamic variations over time (hereinafter called the explicit method). In other words, the tool does not aim to solve the equations based on convergent calculations.

Feedback control

In the tool, the input and output of each device module is in principle to be set to match the physical input and output. For example, as for an air-conditioner coil, the physical input (conditions of inlet air dry-bulb temperature, absolute humidity, and flowrate, conditions of inlet water temperature, and flowrate) shall be regarded as input values of the module, and the physical output (conditions of outlet air dry-bulb temperature, absolute humidity, and flowrate, conditions of outlet water temperature, and flowrate) shall be regarded as output values of the module. The same idea is applied to the room module. Instead of outputting the load required to keep the set temperature and humidity, we input the actual supply air temperature, humidity, and flowrate in order to output the room temperature and humidity as a result of the calculation.

For example, when we try to control a coil flowrate of air-conditioning system of constant air volume, like the real system, we need to perform the feedback control of two-way valve of the coil in order to get the room temperature close to the set value. The tool is supposed to be used as an energy simulation tool rather than an operation simulator. However, since the input and output of the module should match the physical input and output, we are unable to avoid introducing the feedback control.

In the system simulation of the tool, convergent calculations in the calculation time step are not performed. Successively transferring the output data between modules of the equipment, we proceed to the next time step. It is called the explicit method. In this method, we do not intend to evaluate the controllability of the air-conditioning system which has dynamic characteristics. Even if the main purpose is to evaluate the period energy, in order to control room temperature, supply air temperature and the like, the feedback control needs to be included as a real system. Therefore, PID control module is used for the tool.

Template

Here, "module" means a single component formed by a fixed format with input and output nodes, which corresponds to one single device in principle. In the tool, while we build a system connecting several element modules, the number of the components is enormous in the air-conditioning system. In order to reduce time and efforts to arrange and connect these modules, we provide templates in advance.

A template is an aggregate of modules, which have already been connected with each other and packaged. For example, an air-conditioner template includes the modules such as a coil, a fan, and a humidifier and also has the input and output ports for external connections like the modules.

Table 3 shows the main template list. These templates are currently implemented.

Some examples of the templates and the template shells are shown in Figure 1 and Figure 2. Figure 1 shows an "AHU/FCU template shell" for an air-handling unit and a FCU. Figure 2 shows an "HS template shell" for a heat source facility.

"VAV (2 coils and HEX)" template is shown in Figure 1. In this case, as the element modules such as a coil, a humidifier, and a fan are arranged and connected beforehand, users only have to adapt the module specifications inside a template (such as the air flow rate and the coil capacity) and the external connections.

Table.3 Example of Template

Template Shell	Implemented Template
Zone	Single-zone, CAV and Zone(5, 10, 20), VAV and Zone(5, 10, 20)
Zone and Air-Conditioner	Single-zone and air-conditioning, AHU and Zone(1, 5, 10, 20), Outdoor unit of Airconditioner and Indoor units with Zone (1, 5, 10, 20, 40, 60)
BM-outdoor unit	Multiple type air conditioner outdoor unit
BM-indoor unit	Multiple type air conditioner indoor unit
AHU/FCU	combination of various parts : AHU(SA-Fan, RA-Fan, 1-coil, 2-coil, T-HEX, Humidifier), CAV, VAV, Dual-Duct FCU(1-coil, 2-coil)
Heat Source and Pump (HS)	Centrifugal liquid chiller, heatpump chiller, absorption refrigerating machine Boiler, Heat exchanger
Heat Source Group(HSG) (Self-adjusting)	Thermal storage system, Gas engine cogeneration system VAV and Zone, AHU/FCU(VAV), HS
Entire building equipment	combination of various template (with Ventilation, Elevator, Hot Water)

As the "AHU/FCU template", "VAV (There are two coils and HEX) template" is shown in Figure 1. In addition to this template, we have prepared various templates such as "VAV (1 coil, without HEX) template", "CAV (1 coil, without HEX) template", and "FCU template", all of which have common connection nodes as shown in Figure 1 for the external connections (interfaces). Users will be able to replace a template with another keeping the external connections if these templates have the same interface. That is, without taking into account the internal structure of the element modules such as a coil module or a fan module, we can replace the "AHU" with "FCU".

The same idea is applied to the "HS template" (Figure 2). Since the condenser water system is also included in "HS template", we can replace the heat source equipment already connected with another heat source regardless of whether the system is air-cooled or water-cooled type.

"HS group template" consists of several heat sources, primary pumps, a header, the operating number control module and the like. Its interface is similar to that of the "HS template". If these templates are completed, construction of the entire system (modular placements and connections) would be relatively simple. In addition, since it is possible to add or delete element modules within each template, the flexibility and extensibility of the system construction are maintained.

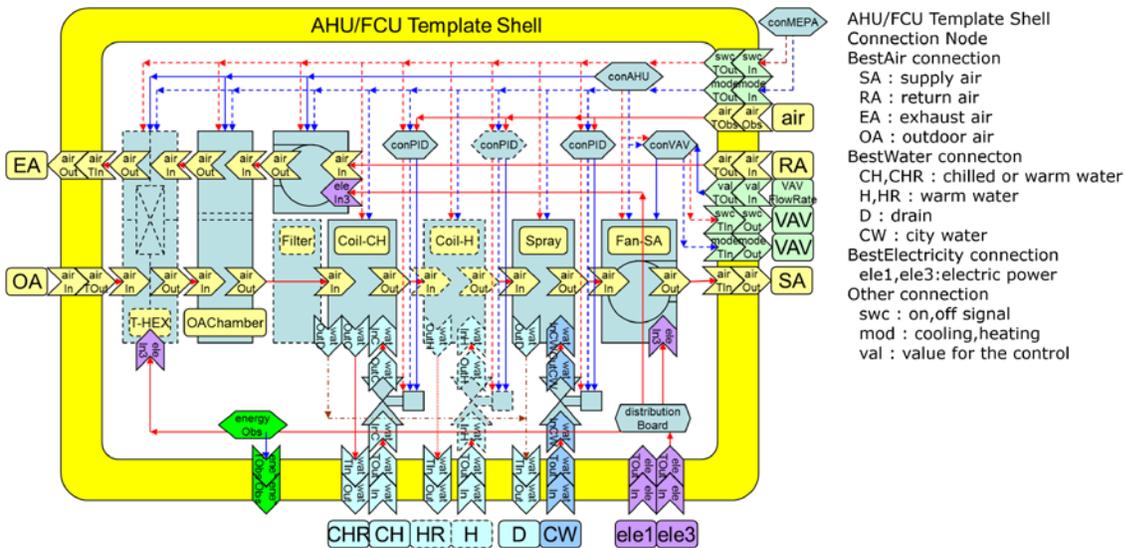


Figure 1 An example of AHU/FCU template and template shell

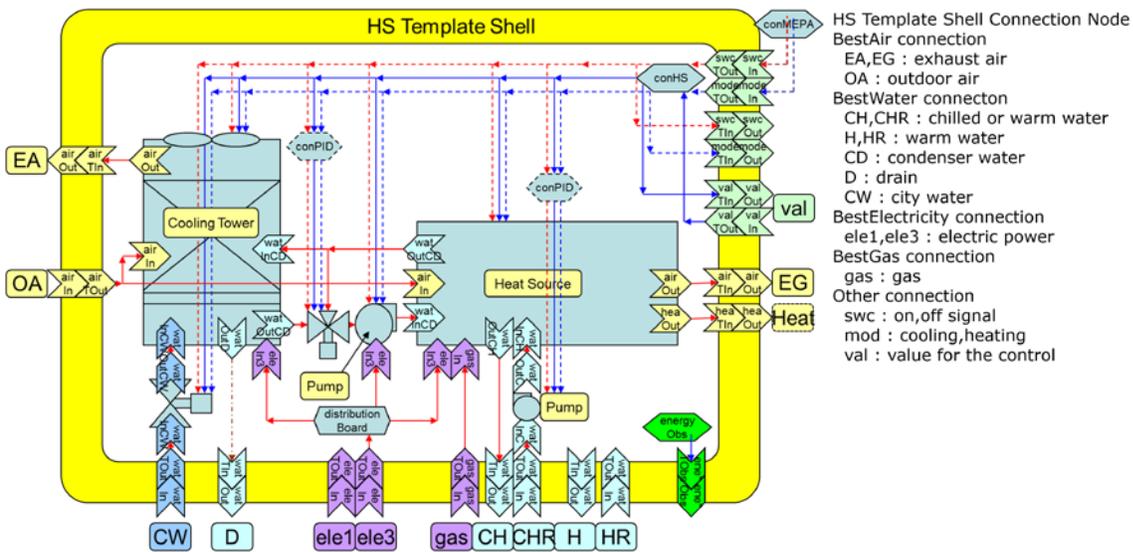


Figure 2 An example of HS template and template shell

"Zone and Air-Conditioner template" is a macro template that includes air conditioner outdoor unit template, indoor unit template, and zone template as shown in Figure 3.

It has the nested structure. Originally, each template needed to be connected with ducts, pipes, and control lines to build the system. On the other hand, today thanks to the template, in which all the connections have been completed, we can easily make changes. Moreover, we can intend to reduce not only mistakes in the connections but also work time to input the data. As the connections inside "Zone and Air-Conditioner template" have been completed, users only have to focus on the external connections without considering internal connection status, while users still need to input specifications of each equipment.

In addition, air conditioner outdoor unit template and indoor unit template are "Self-adjusting template". Therefore, you can start a calculation without determining the equipment capacity in advance.

By replacing configuration templates inside the zone and air-conditioner template, we can easily build other different systems.

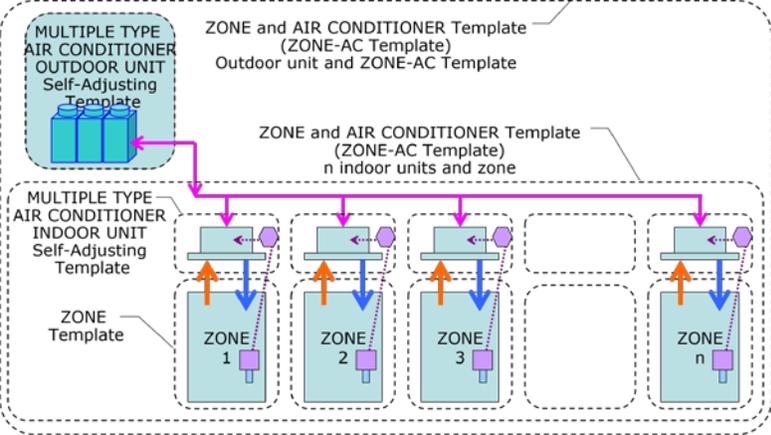


Figure 3 Examples of nested template (zone and air-conditioner template)

Figure 4 shows a model example of an air-conditioning system by means of the template (4-pipe, dual-duct, VAV). In this example, all templates are self-adjusting template. VAV units in each zone template adjust its maximum air flow rate, and the AHU dual-duct template works for the adjustment for the maximum air flow rate of supply air fan depending on the air flow rate of return air. The coil specifications in the AHU dual-duct template is adjusted depending on the air flow rate and temperature of return air. At the same time, the water side of the coil is also adjusted. The cooling capacity of primary cold heat source equipment is adjusted depending on the water flow rate and temperature of return water. The maximum water flow rate of the secondary pump is also adjusted at the same time.

As for heat sources, two types of the self-adjusting templates are available. One is the self-adjusting primary cooling equipment template, and the other is the primary heating equipment template. Both templates are connected to the AHU dual-duct self-adjusting template using 4 pipes. Since the entire facility template of the dual-duct system is available, we do not need to make any complicated connection between the templates, using ducts, pipes, and control signals. If we replace the template of the heat source and the air-conditioner with self-adjusting template, we can easily make a calculation.

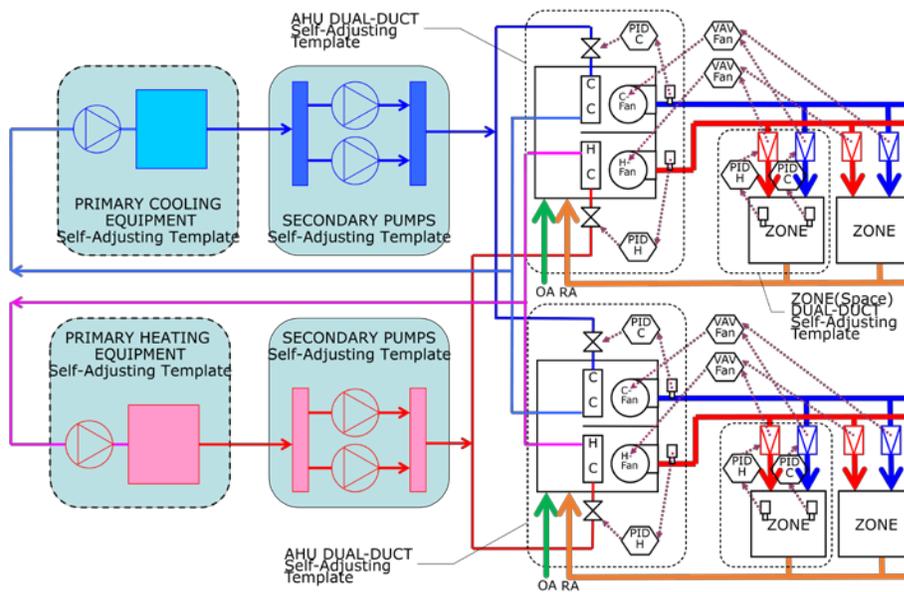


Figure 4 An example of model of the air-conditioning system by the template (4-pipe, dual-duct, VAV)

IMPROVEMENTS AND CAPACITY ADJUSTMENT TRIAL CALCULATION EXAMPLE OF SELF-ADJUSTING TEMPLATE

Self-Adjusting method by the moving average value

In the improved version, we calculate a moving average value of the capacity to be applied to a requested amount of heat and the required air volume in accordance with the preset number of the calculation steps. After that, we adjust the capacity according to this moving average value. This is the new method. The number of adjustment calculation steps for calculating a moving average value can be changed. For example, considering a moving average value per hour, we can adjust the capacity carrying out 12 calculation steps every 5 minutes. If we carry out 6 calculation steps every 5 minutes, it means that we adjust the capacity considering the moving average value per 30 minutes.

The initial value of the capacity, which is to be adjusted, should be left small. Then we adjust the value utilizing a manipulated variable of the control module, which we call “the method for increasing the feedback”. For example, when we adjust the supply air flowrate to a zone, we build an air-conditioning system adopting the VAV system. In addition, a maximum value of the manipulated variable of the PID control module, which controls the air flowrate of the VAV unit, should be more than 100% such as 101%. Then we can increase the VAV unit maximum air flowrate at a constant rate when the capacity is insufficient for the load.

A value of a manipulated variable sent from the PID control module is usually between 0% and 100%. If the value of the manipulated variable is 0%, it is a minimum air flowrate of an operating capacity (in this case, it means the required outside air flowrate to the zone). If the value of the manipulated variable is 100%, the VAV unit is to operate and the operating capacity is regarded as a maximum air flowrate. We set a value more than 100% (this time it is 101%) for a maximum value of a manipulated variables. Therefore, the VAV unit module, which has received the manipulated variable exceeding 100%, detects that the current maximum flowrate is not good enough. Then the VAV unit module changes its maximum flowrate to increase the flowrate in accordance with the manipulated variable.

The adjusted air volume in each VAV unit is collected by VAV fan control modules. At the same time, a required air flowrate of a self-adjusting AHU template is also adjusted. Hot and cold water flow coming from the self-adjusting AHU template is collected by the self-adjusting heat source template so that its maximum capacity can be changed if necessary. As described above, the capacity of the equipment ranging from the VAV unit to an AHU or a heat source is to be adjusted accordingly.

Calculation examples using the self-adjustment template

Conditions of the trial calculation. The conditions applied to the trial calculation example of self-adjusting template of the air-conditioning equipment which has the dual-duct system as follows: the air-conditioning model is shown in Figure 4. There are two types of the models. One is in the north 4 zone, and the other is in the south 4 zone. We apply 4-pipe annual heating and cooling system. In addition, the target room temperature is 22°C-26°C (71.6°F-78.8°F), and the AHU has the dual-duct VAV system with 2 coils and 2 supply air fans. Regarding the target temperature of supply air, cold air is 14°C (57.2°F), while warm air is 32°C (89.6°F). A minimum air flow rate is 33.3g/s (58.8cfm). The number of the adjusting steps is 12, and we have made calculations for two years at 5-minute intervals.

Calculation Results. As an example of trial calculations of a self-adjusting air-conditioner template which has the dual-duct system, we indicate the adjustment state of the cold supply air flowrate in Figure 5(b). Even in the winter, a cooling load is generated even in the interior zone. In the meantime, since it was in the process of adjusting an air flow until May of the first year, the cold supply air flowrate was insufficient. Therefore, the room temperature was higher than 26°C (78.8°F), which was preset. However, in the second year, as the cold supply air flowrate was adjusted, the room temperature was cooled and kept at 26°C (78.8°F).(Figure 5(a)) A heating load was light, and a slight increase in the minimum air volume of the initial value has been adjusted. We show the required number of the calculation steps regarding a cold heat source and a heat source in Figure 5(c). We also add the moving average value of the required capacity of 12 calculation steps. We performed the trial calculations at 5-minutes intervals, which means that the average capacity of 12 calculation steps represents the average capacity per hour.

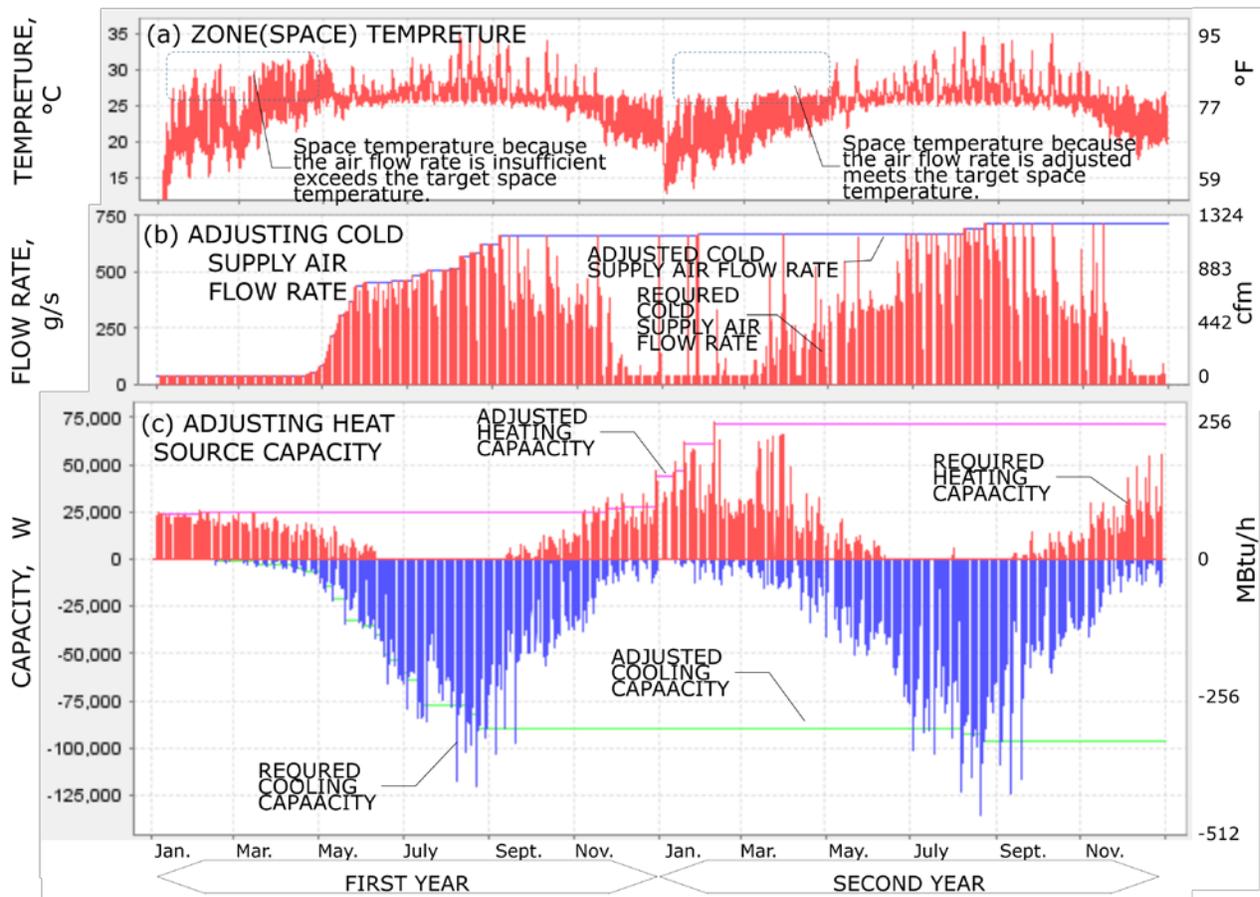


Figure 5 Adjustment example of the supply air and the heat source capacity using self-adjusting template
 (a) Zone (Space) temperature (b) Adjusting cold supply air flow rate (c) Adjusting heat source capacity.

CONCLUSION

This report describes simulation methods of HVAC Systems using Self-Adjusting Templates for the Building Energy Simulation Tool. Self-Adjusting template would enable us to get accustomed to the simulations. In the example of the last calculation, you can easily change the controller object from room temperature to the PMV. It will be useful for the design of a radiant cooling system. We would like to make a presentation on them if we have an opportunity.

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