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Model Based Commissioning Tool for Air-Conditioning Distribution Systems

Harunori Yoshida (Prof. & President of BSCA, Japan)

Takashi Noda (Ms. Student)

Oakayama University of Science

1. Issues

2. Simulation Model of Distribution System

3. Example of VWV System

4. Example of VAV System

5. Conclusions



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- Energy consumption of air and water distribution in air-conditioning systems reaches up to **12%** of the total energy consumption in office buildings.

Water Service & Transportation
15%

Heat Source Machines
31%

Air-conditioning
43%

Lighting & Office Appliances
42%

Air and Water Distribution
12%

Energy consumption in office buildings

Proceedings of the 14th International Conference for Enhanced Building Operations, Beijing, China, September 14-17, 2014
quoted from the home-page of Energy Conservation Center Japan

- **Variable water volume (VWV) and Variable Air Volume (VAV) systems are often used as an energy conservation measure for distribution systems.**
- **However intended energy conservation is not necessarily attained in many building systems because for example;**
 - **The mechanical systems are not properly adjusted on-site.**
 - **The parameters of automatic control systems are not tuned well.**
 - **Generally the capacity of designed systems is too large to process real loads.**
 - **Etc.**

- However on-site work such as carrying out the adjustment of valve opening and the tuning of control parameters **requires much labor cost or time** due to trial-and-error process.
- In addition such work is **not often permitted** by the building owners being afraid of adverse effects caused by the work while building use.
- **Use of a simulation** tool will be useful to obtain the optimal operation settings through the investigation of the system behavior with desk study and consequently **to estimate the amount of energy conservation and to shorten the work time.**
- The simulation tool should be so accurate that it can simulate the behavior with the real system's sophistication.

Developing simulation models of the air and water distribution system



Testing the model accuracy by applying it to real system data



Analyzing the system performance by the simulation model to check whether the performance is as intended



Investigating if better or optimal control parameters or thresholds could be found

1. Issues

**2. Simulation Model of
Distribution System**

3. Example of VWV System

4. Example of VAV System

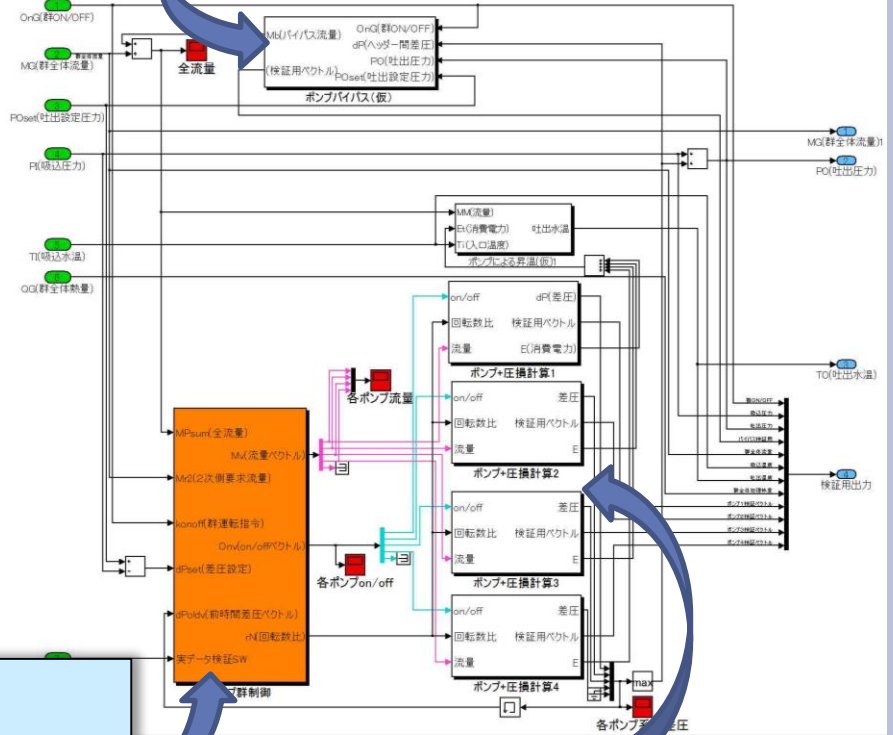
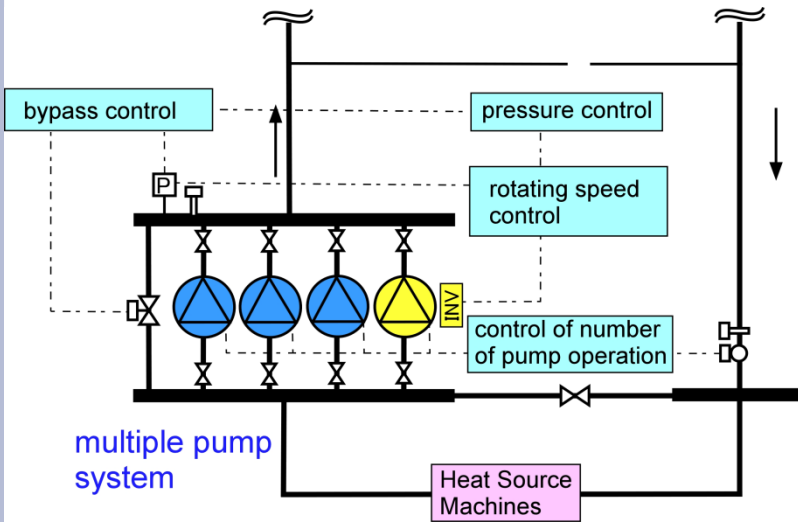
5. Conclusions

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- Modeled by MATLAB/Simlink

model

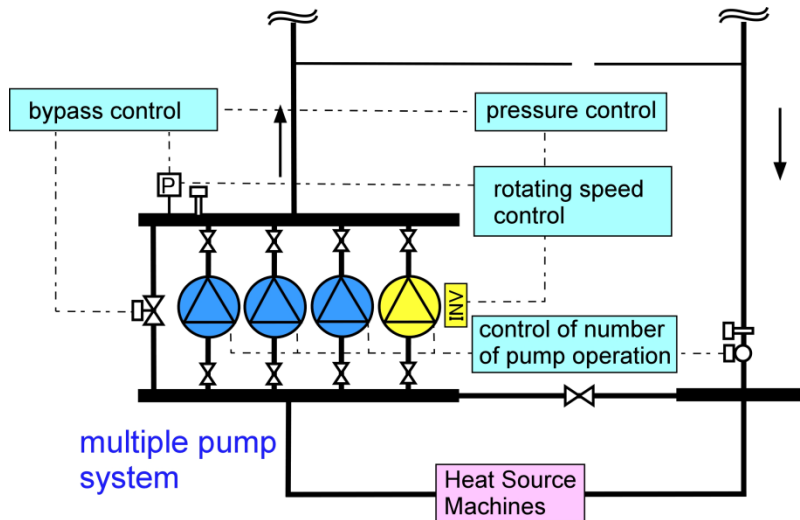
Bypass control



Pump Control

- number of pump operation
- rotating speed
- outlet pressure

Pumps and Valves



- Input and Output for the multiple pump system
- **Input:**
 - flow rate demand
 - Inlet pressure
- **Output:**
 - flow rate
 - outlet pressure

- Not only modeling pump performance but also **modeling valve characteristics** is necessary because valve opening is very often adjusted intentionally in real buildings, which affects model accuracy very much.

- Pump performance is modeled by a polynomial function which parameters are found from the given pump performance curve.

$$r = \frac{N}{N_R}$$

N : rotating speed

N_R : rated rotating speed

Pump model

$$C_h = a_1 C_f^4 + a_2 C_f^3 + a_3 C_f^2 + a_4 C_f^1 + a_5$$

$$\eta = b_1 C_f^4 + b_2 C_f^3 + b_3 C_f^2 + b_4 C_f^1 + b_5$$

$$C_f = \frac{m}{\rho N D^3}$$

C_h : dimensionless Pressure

C_f : dimensionless flow rate

η : pump efficiency

ρ : fluid density

D : rotation speed

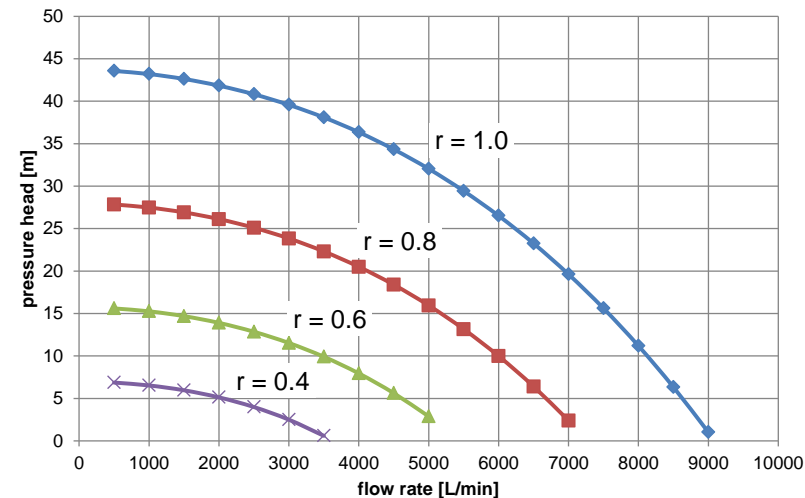
N : pressure

Δp : input power

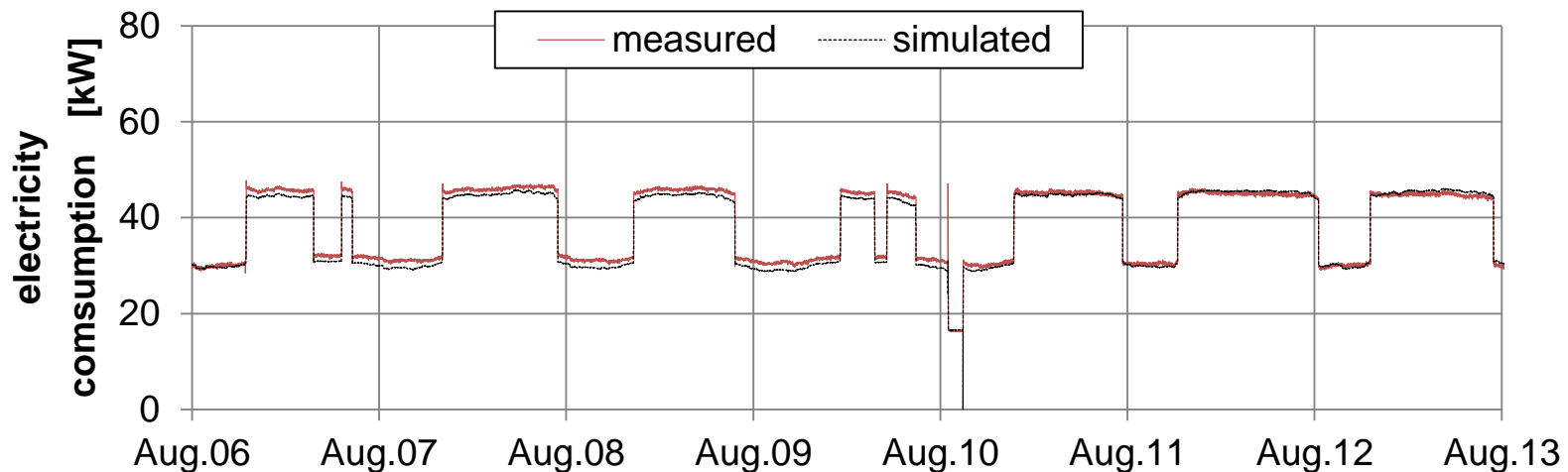
$a_{1-5} \cdot b_{1-5}$: model parameters

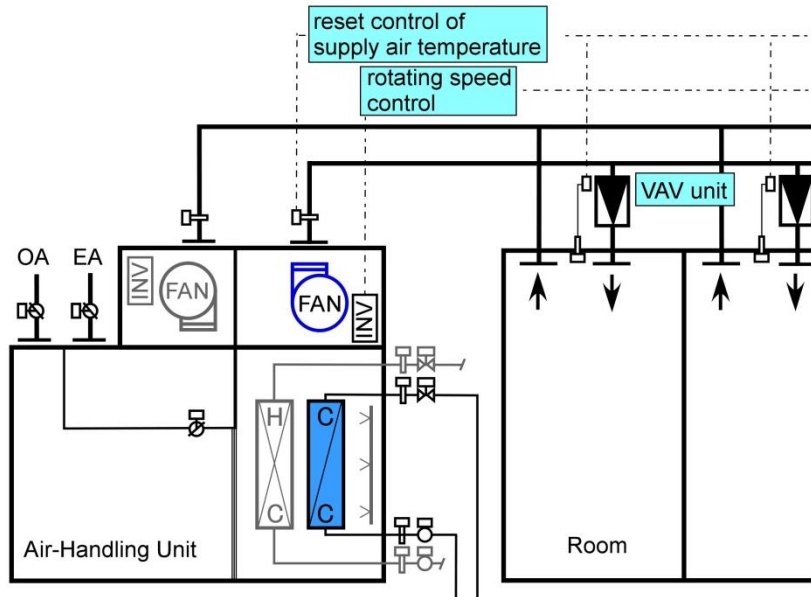
$$C_h = \frac{1000 \Delta p}{\rho N^2 D^2}$$

$$E = \frac{m \Delta p}{\eta \rho}$$

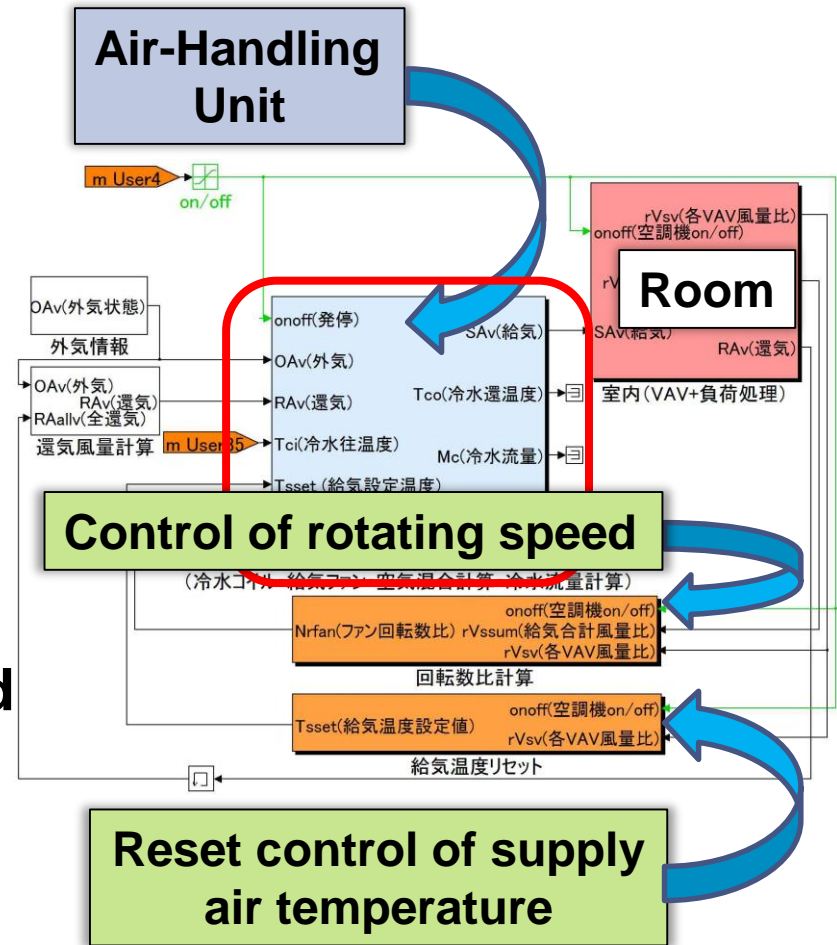


- The accuracy of a simulation model is tested using the measurement data taken from the BEMS of real buildings.
- As shown in the below figure the model accuracy is enough high to investigate the system.





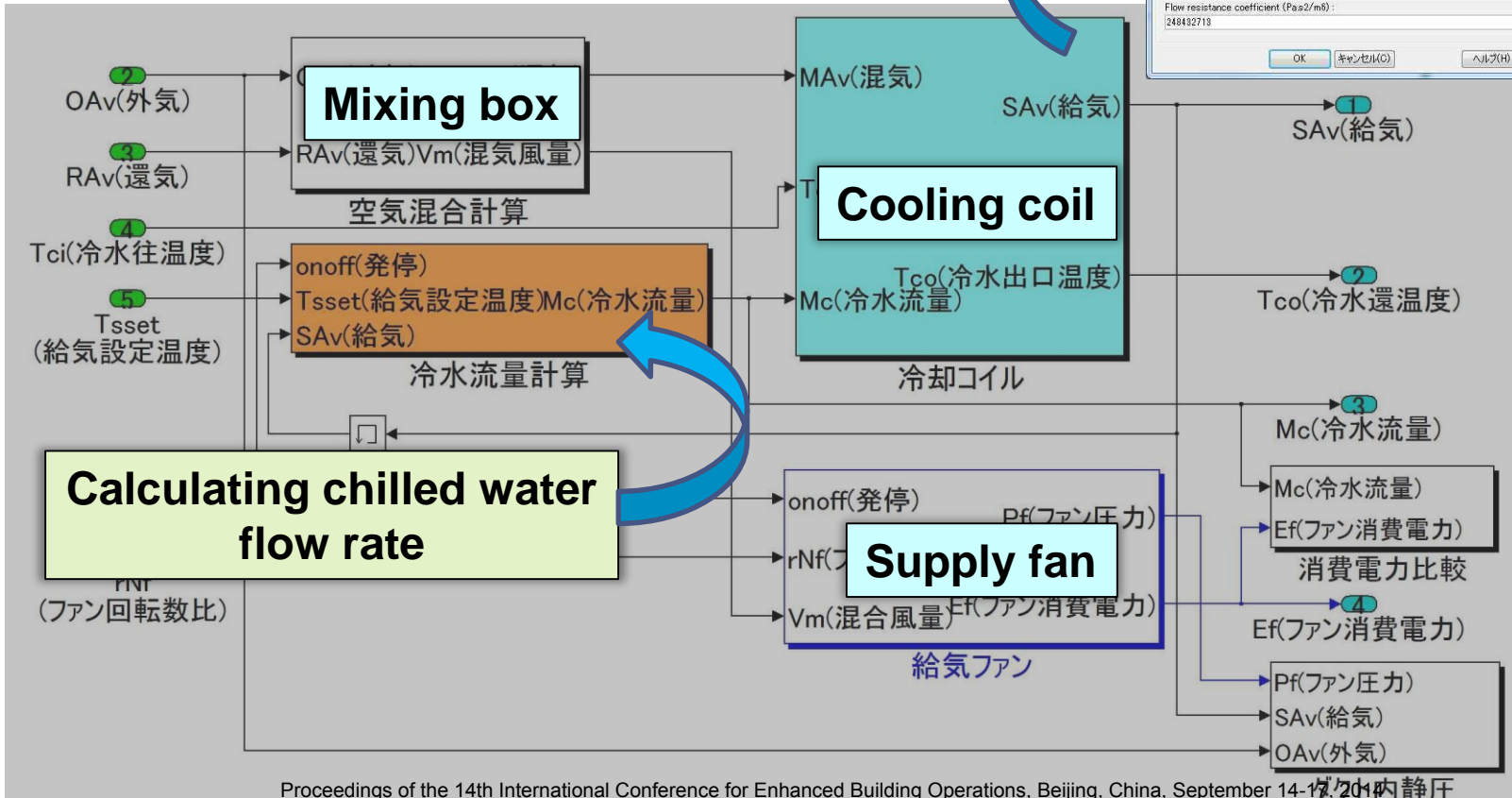
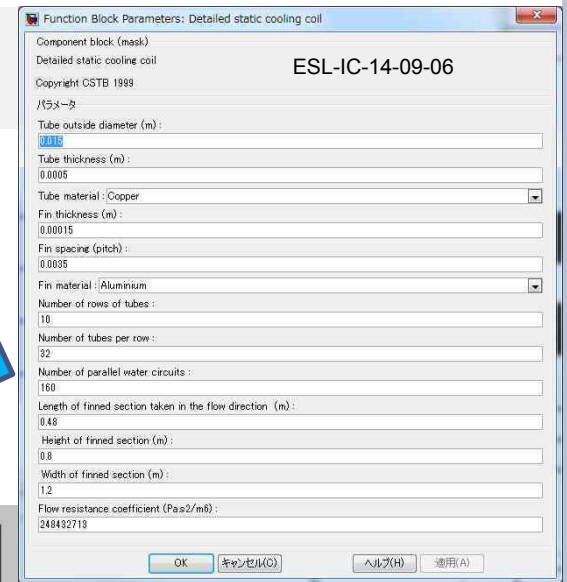
- Fan rotating speed is controlled based on the **amount of the supply air volume**.
- Supply air temperature is **reset** from time to time according to the **degree of VAV unit opening**.



VAV SYSTEM

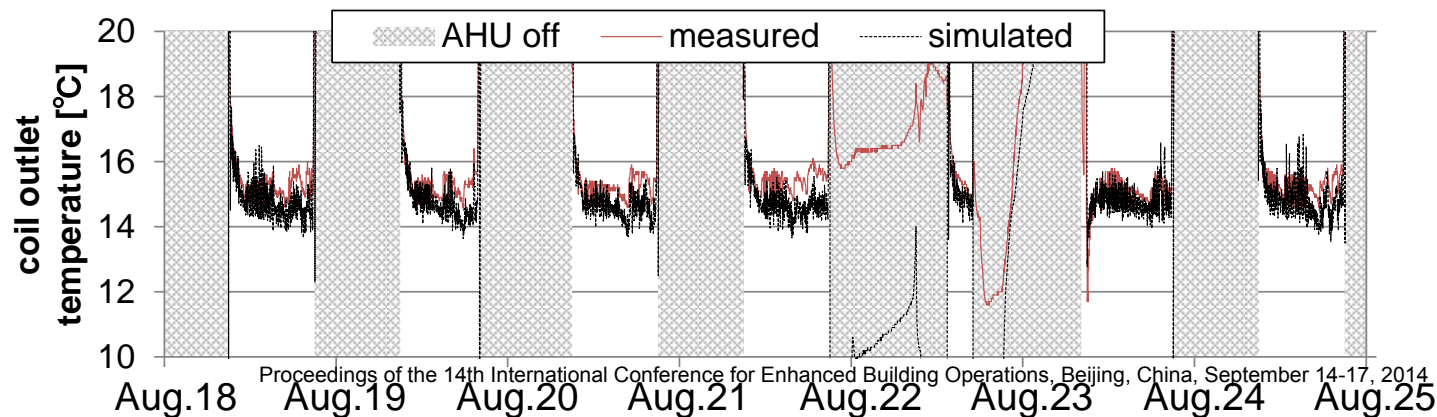
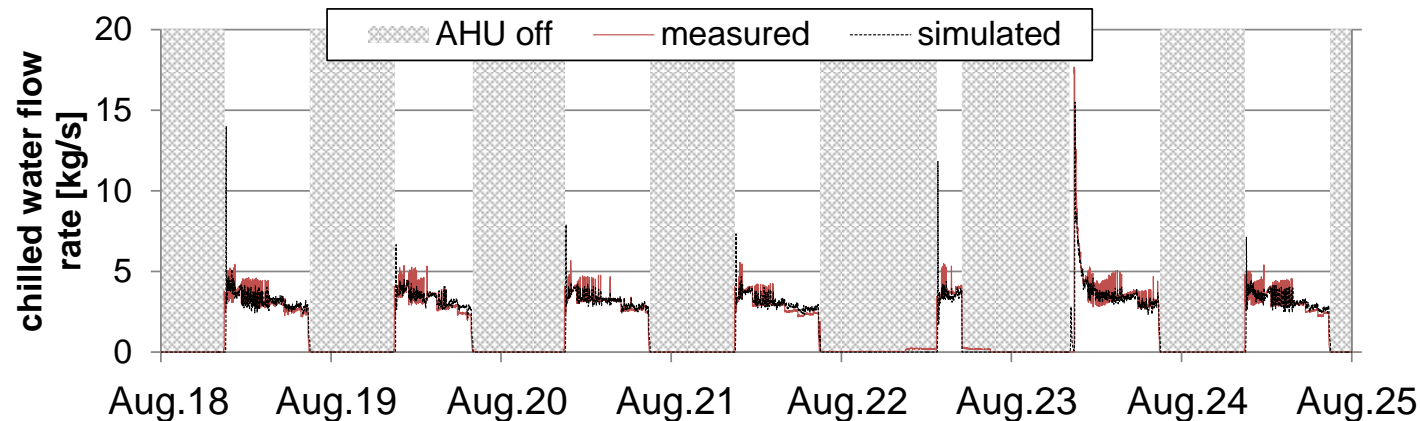
Air-Handling Unit (Expanded)

Detailed cooling coil model is used.

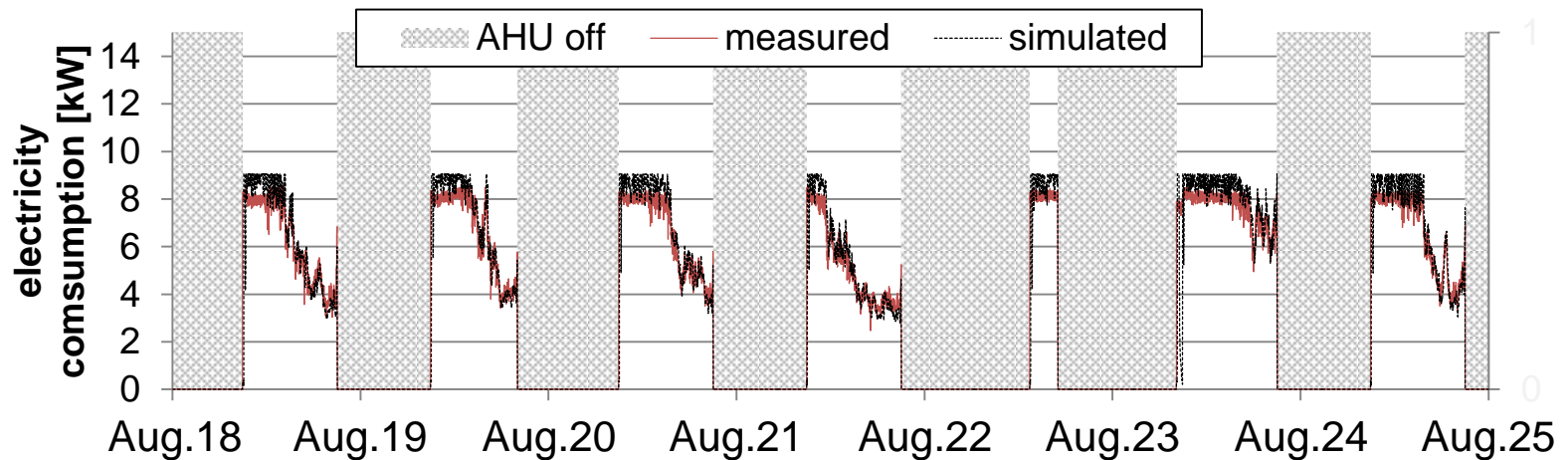


Validation of coil performance

- Both the flow rate and outlet temperature of the chilled water show good agreement between the measurement and the simulated.



- Accuracy of fan power consumption is good as well; just +3% larger than the measured.



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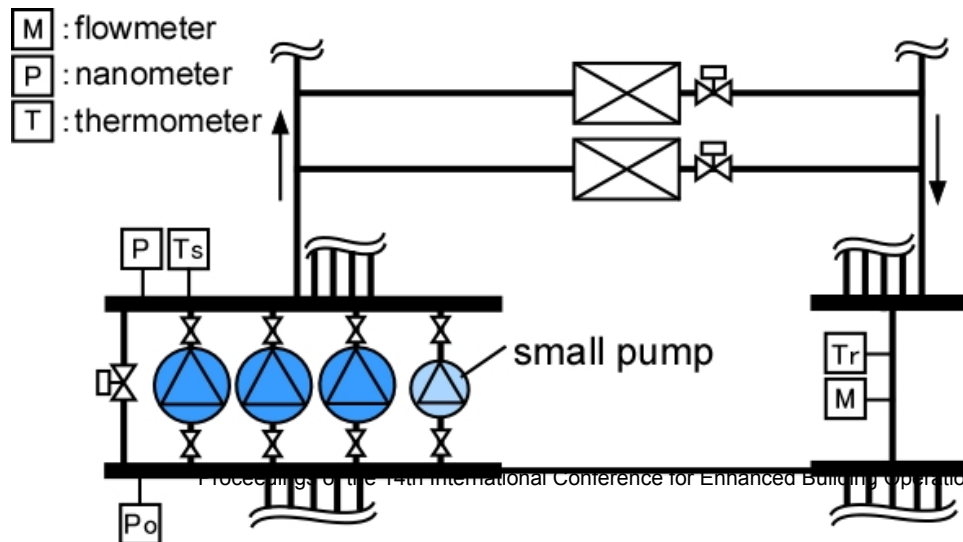
4. Example of VAV System

5. Conclusions

EXAMPLE No.1 of VWV SYSTEM

ESL-IC-14-09-06

- In this system four pumps with constant rotating speed are equipped.
- One pump is designed as a half capacity of the others in order to increase the number of operation steps to adapt wide flow rate change.
- The openings of the valves associated to the pumps varies from 50% to 100%. The valve openings are set on site sometimes without particular reasons.
- The number of pump operation is controlled manually by operating staffs.



Results

Study A

- The threshold to change the number of pumps, which is now used by the operation staffs, **is 1.5 times larger** than the specified value by the design engineers.
- It is predicted that **23% energy conservation** will be attained by adapting this value.

Study B

- Only **two pumps out of four are used** even in high load period.
- It is predicted that **34% energy conservation** will be achieved if pump capacity is decreased by applying **impeller-cut** by which the average number of pump operation is increased.

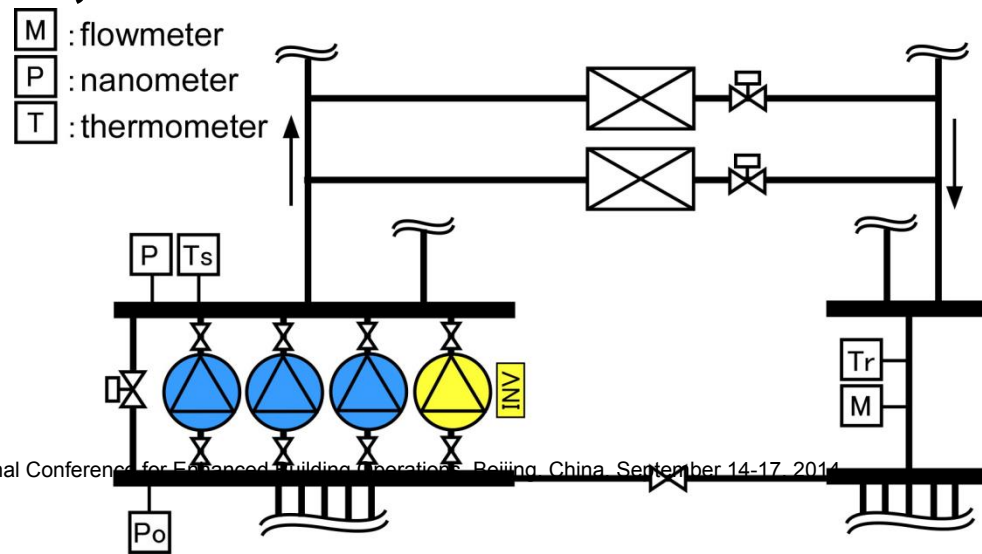
Study C

- It is predicted that **41% energy conservation** will be achieved if all pumps are equipped with a variable rotating speed controller by installing inverter.

EXAMPLE No.2 of VWV SYSTEM

ESL-IC-14-09-06

- In this system **only one pump** is a variable rotating speed pump out of four pumps; three are constant rotation.
- The shortcoming of this system is that the rotating speed **cannot be reduced less than the level** which is compelled by the pressure created by the other constant speed pumps.
- As a result the controllable range of the rotating speed becomes **very narrow**; sometimes almost constant.



Results

Study A

- Energy conservation of 7% will be attained if the present **threshold is increased by 20%**.

Study B

- Energy conservation of 7% will be attained if the present minimum rotating speed **is decreased down to 50% from the present value 60%**.

Study C

- Energy conservation of **41%** will be attained if all pumps are equipped with inverter controller.

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EXAMPLE No.1 OF VAV SYSTEM

ESL-IC-14-09-06

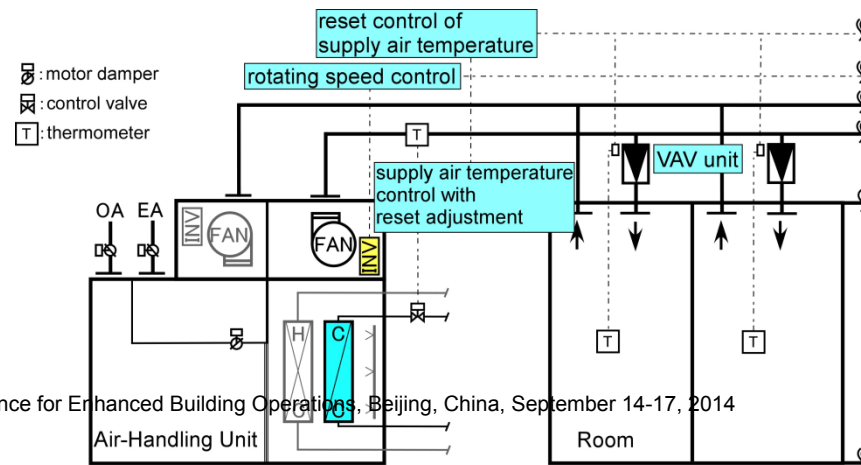
- In this system four VAV units are equipped and the each **minimum air-flow rate is set as 25%**.
- The **rotating speed N** of the supply fan is determined by the following equation:

$$N = N_R \left(0.5 \times \left(\frac{V}{V_R} \right) + 0.42 \right)$$

N_R : Rated rotating speed

V_R : Total air flow rate in design condition

V : Total air flow rate requirement by all VAV units



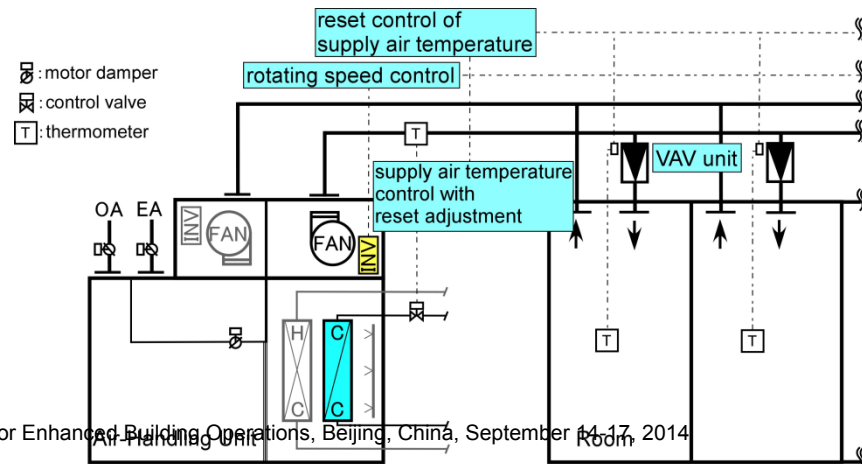
EXAMPLE No.1 of VAV SYSTEM

ESL-IC-14-09-06

- The supply air temperature is reset according to the ratio r_k of each air flow rate of the VAV units;
- If all the values of the ratio r_k of each VAV unit exceed **0.6 for 30 minutes**, the supply air temperature is decreased by **1.0 deg. C**.
- If at least one of the ratio of each VAV unit decreases **less than 0.25**, the supply air temperature is increased by **1.0 deg. C**.

Where,

r_k is the ratio of the supply air flow rate divided by the design flow rate.



EXAMPLE No.1 OF VAV SYSTEM

ESL-IC-14-09-06

Results

Study A

- In the real system very often the room temperature became lower than the set point. This is because the minimum ratio of the air flow rate is **set as 0.25** which is larger than the design set value of 0.2.
- If this fault is removed the room temperature will be improved but the fan energy consumption will be only reduced **by 3%**.

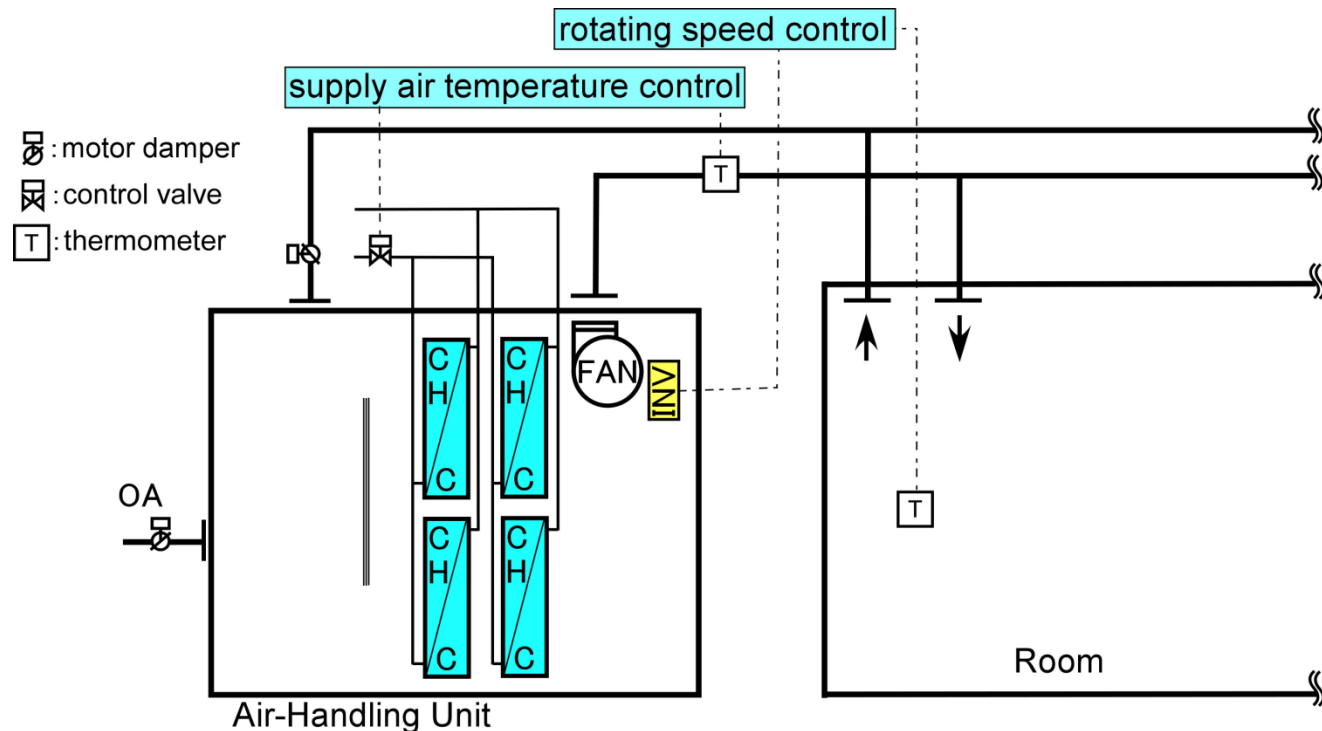
Study B

- It was found that the duct pressure is too large compare to the requirement.
- Simulation was carried out to check the effect of changing the parameters of the equation defining rotating speed which was shown before.
- Fan energy consumption will be **reduced by 19%** because of this adjustment.

EXAMPLE No.2 of VAV SYSTEM

ESL-IC-14-09-06

- In this system the room temperature is controlled by supply air volume change achieved by fan rotating speed control.
- The supply air temperature is set as constant; **15 deg. C.**

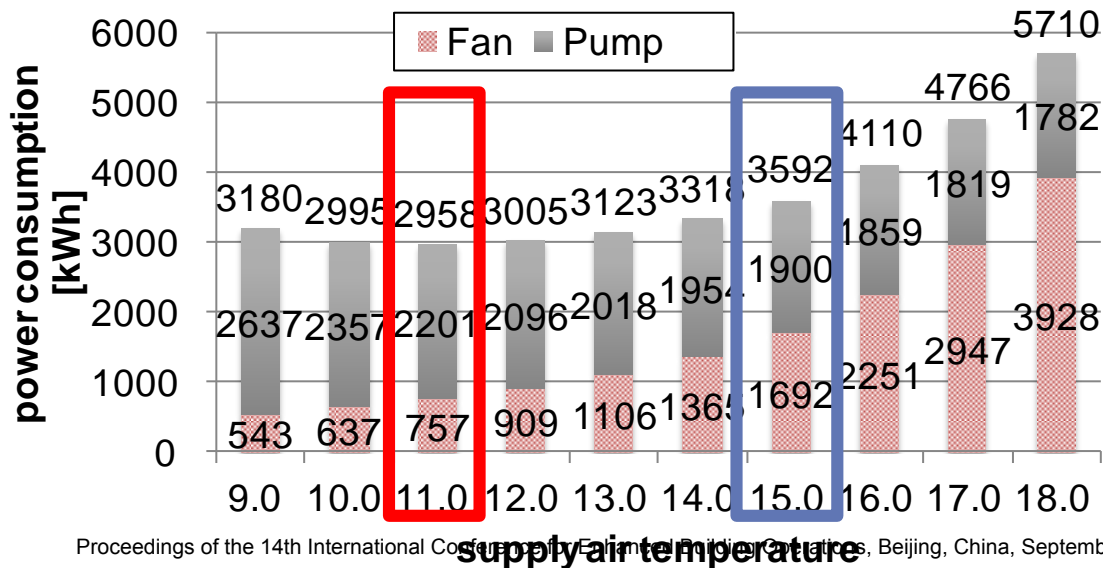


EXAMPLE No.2 of VAV SYSTEM

ESL-IC-14-09-06

Results

- If the supply air temperature set point is changed into 11 deg. C. from 15 deg. C., 18% energy consumption will be achieved.
- However the temperature difference of chilled water through the cooling coil will be decreased to 6.4 K from 8.8 K, which may increase energy use of the heat source plant.



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- **As energy consumption in HVAC distribution systems reaches 12% of total consumption, commissioning the system properly is very important.**
- **However it is not well achieved in real buildings due to the sophistication of the system.**
- **Specific points to be needed to pay attention are;**
 - **Valve openings, which are set to make pressure balance on-site, have much effect on VAV system energy performance.**
 - **Control parameters, especially threshold values, have much effect on energy performance.**
 - **But these are usually not tuned optimally after construction without paying attention.**

- **Simulation model is useful to investigate and estimate the effect of possible improvement before practice.**
- **In addition it can help to reduce the labor time needed in the trial-and-error practice work.**
- **In this report generalized simulation model for the investigation was developed.**
- **Several examples aiming energy conservation were shown.**

Thank you!



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