ESL-IC-14-09-26a

Diagnosis of Effectiveness of HVAC System and Energy Performance of Osaka-Gas Building through Retro-Commissioning

Part 1

Outline of HVAC Systems and Diagnosis of Energy Efficiency of Air Systems.

Toshiomi Hatanaka Osaka Gas Co.,Ltd. Osaka, Japan
Ko-ichiro Aoki Manager Osaka Gas Co.,Ltd. Osaka, Japan
Norio Matsuda Building Service Commissioning Association Nagoya, Japan
Motoi Yamaha Professor Chubu University Kasugai, Japan
Hideki Tanaka Designated professor Nagoya University Nagoya, Japan
Nobuo Nakahara Nakahara Laboratory, Environmental Syst.-Tech Nagoya, Japan

Outline of Building

- Modern-historical office building in Osaka
- Floor Area

- South part:18,422 m^2 (built in 1933)
- North part:28,475 m^2 (built in 1966)
- Total floor area:46,987 m^2

- Number of floors

8F+B2F

Outline of Heat generating plant

- Experienced several times of Retrofits
- (N) Varied from original "Centrifugal Chillers + Boillers" (N) to;
  ⇒ Co-generation
  + Absorption Chillers (*Gene-Link*)
- (S) Original Centrifugal Chillers w/WTES
  ⇒ Absorption Chillers
- South and North plants are connected to share each other.

Outline of HVAC SYSTEM

- Experienced several times of Retrofits
- (N) Varied from original "Dual-duct system(Int.) +induction-units (Peri.) to;

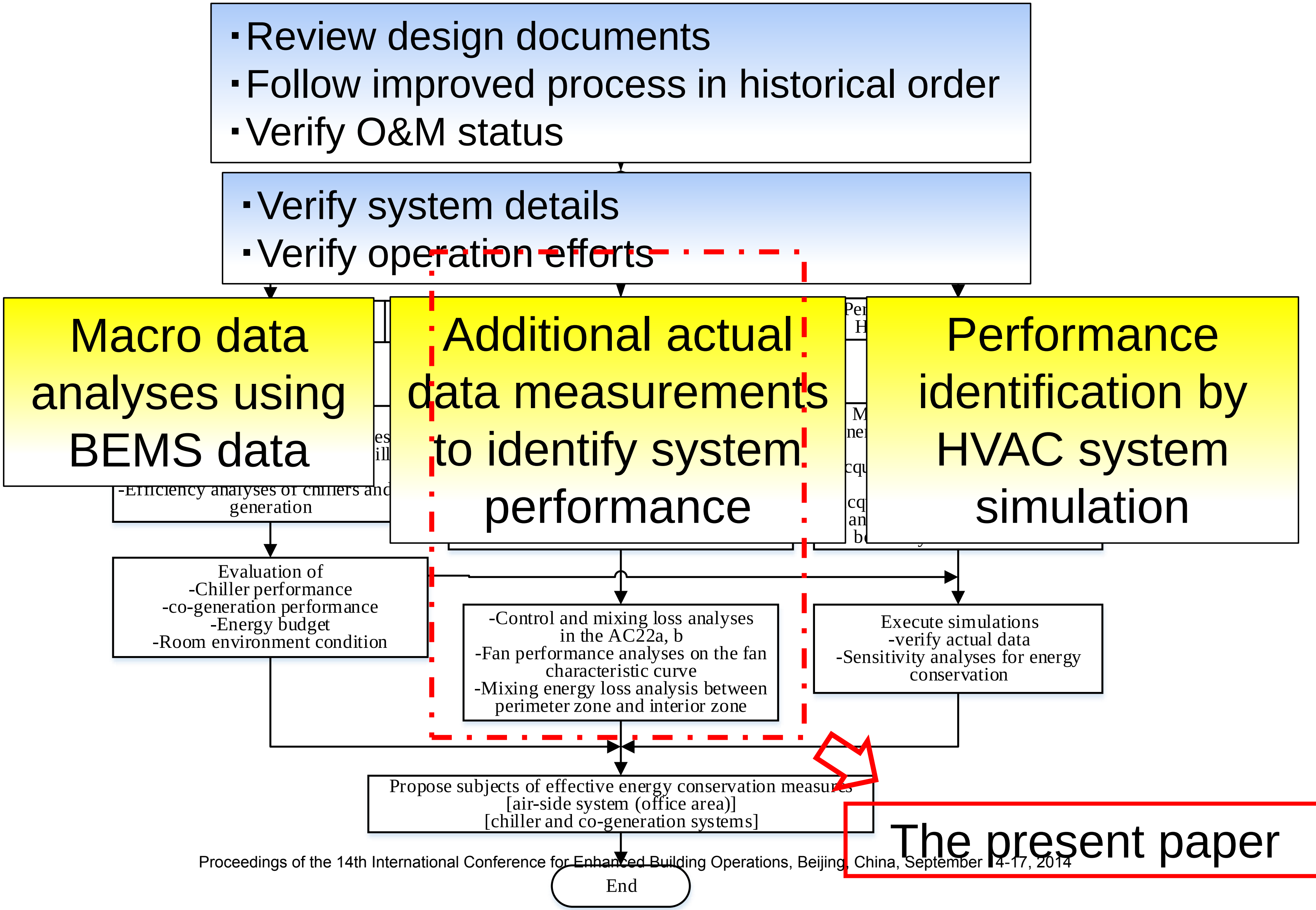
⇒No-mixing dual duct VAV(Int.)
+4P FCU w/ Primary Air (Peri.)

Target of This paper

- (S) Varied from original Single duct on-off VAV (Int.)+induction-units(Peri.) to;

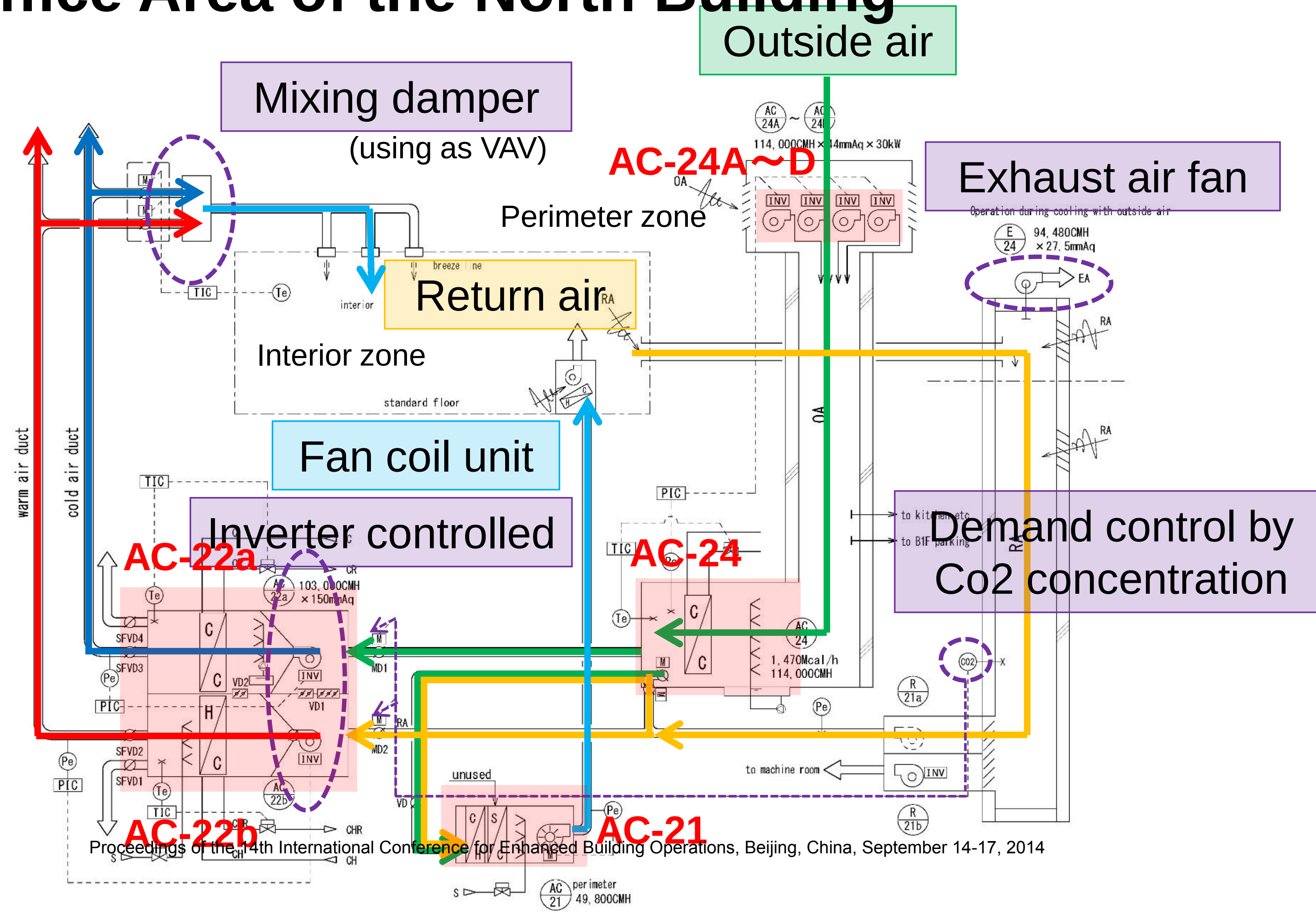
⇒Single duct on-off VAV(Int.)
+4P FCU w/ Primary Air (Peri.)

Performance verification process

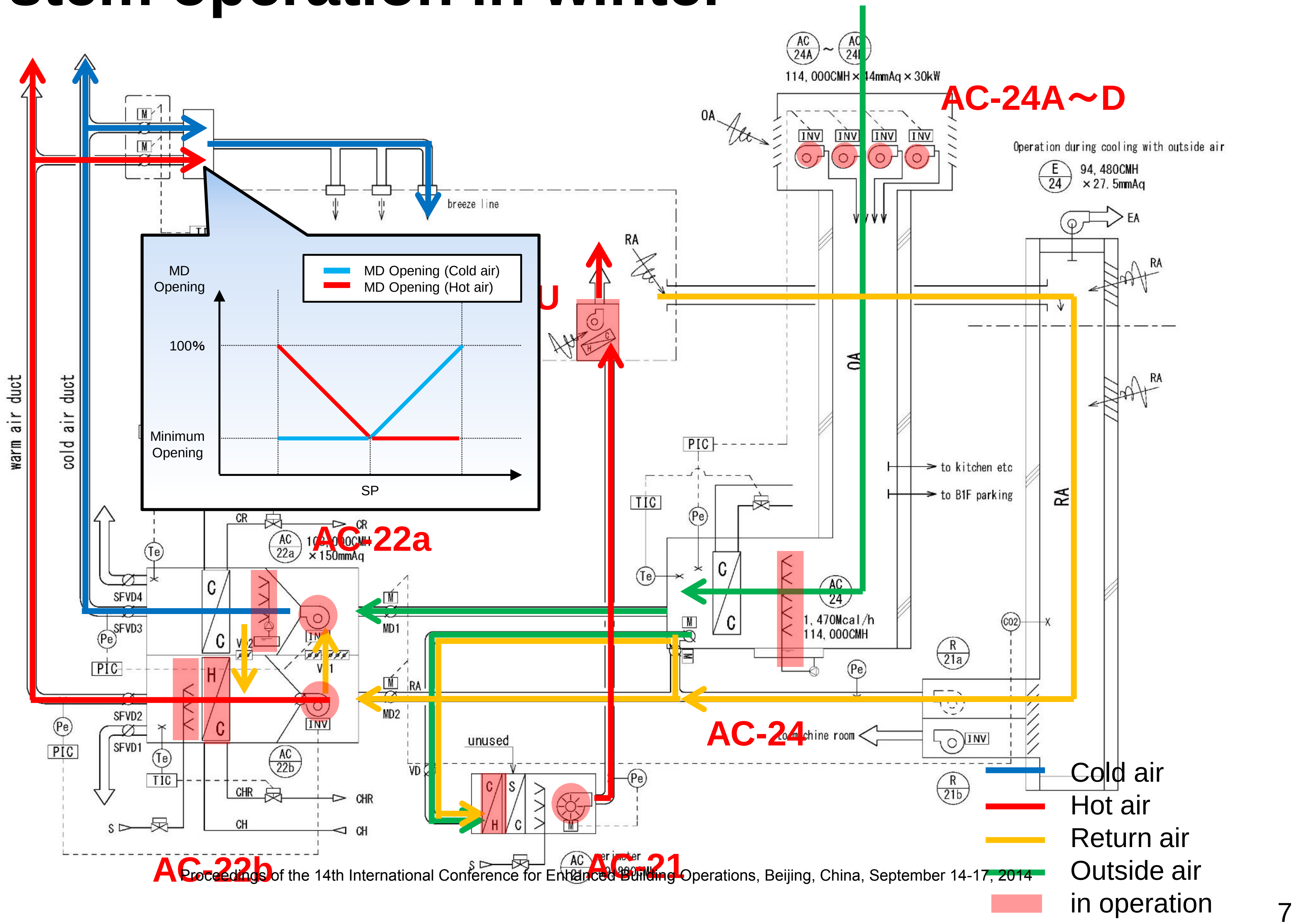


Identifying System Operation

Detail of Air-Conditioning System and Controls for the Office Area of the North Building



System operation in winter



Evaluation of Energy Loss by Mixing in AC-22 by Actual Measurements and Process Analysis

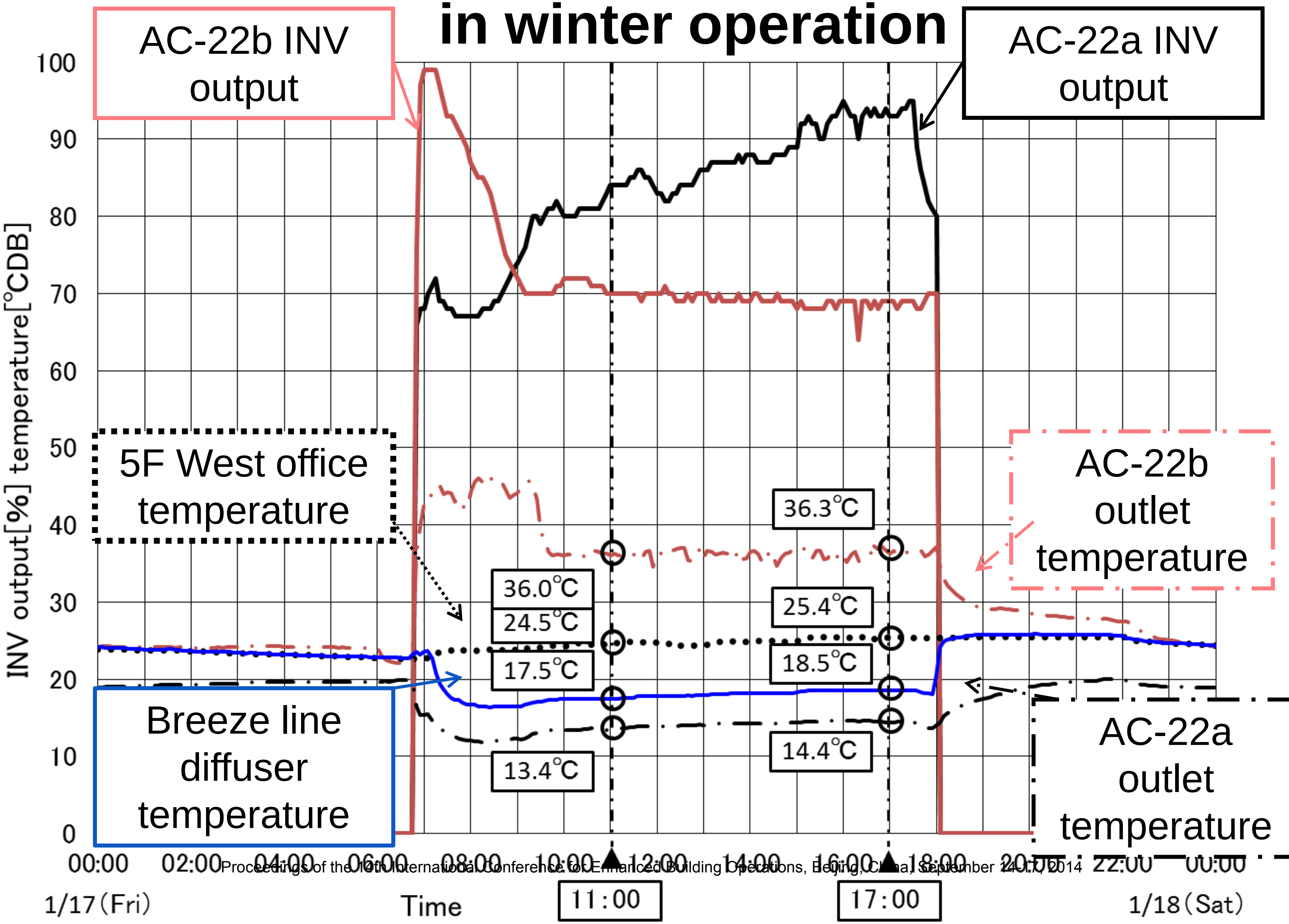
Measured data in summer and winter in 2013

	At 11:00 August 27, 2013 (in summer)		At 11:00 January 17, 2014 (in winter)	
	AC-22a	AC-22b	AC-22a	AC-22b
INV Output	97% (58.2Hz)		84% (50.4Hz)	70% (40.8Hz)
Air volume at the outlet duct	87,848m³/h	OFF	56,968m³/h	42,635m³/h
Power consumption	70.0kW		46.8kW	20.6kW
Outlet static pressure	854Pa		798Pa	802Pa
5F MD cold air damper position	9%open		100%open	0%
Outlet temperature	12.4℃		13.4℃	36℃

Proceedings of the 14th International Conference for Enhanced Building Operations, Beijing, China, September 14-17, 2014

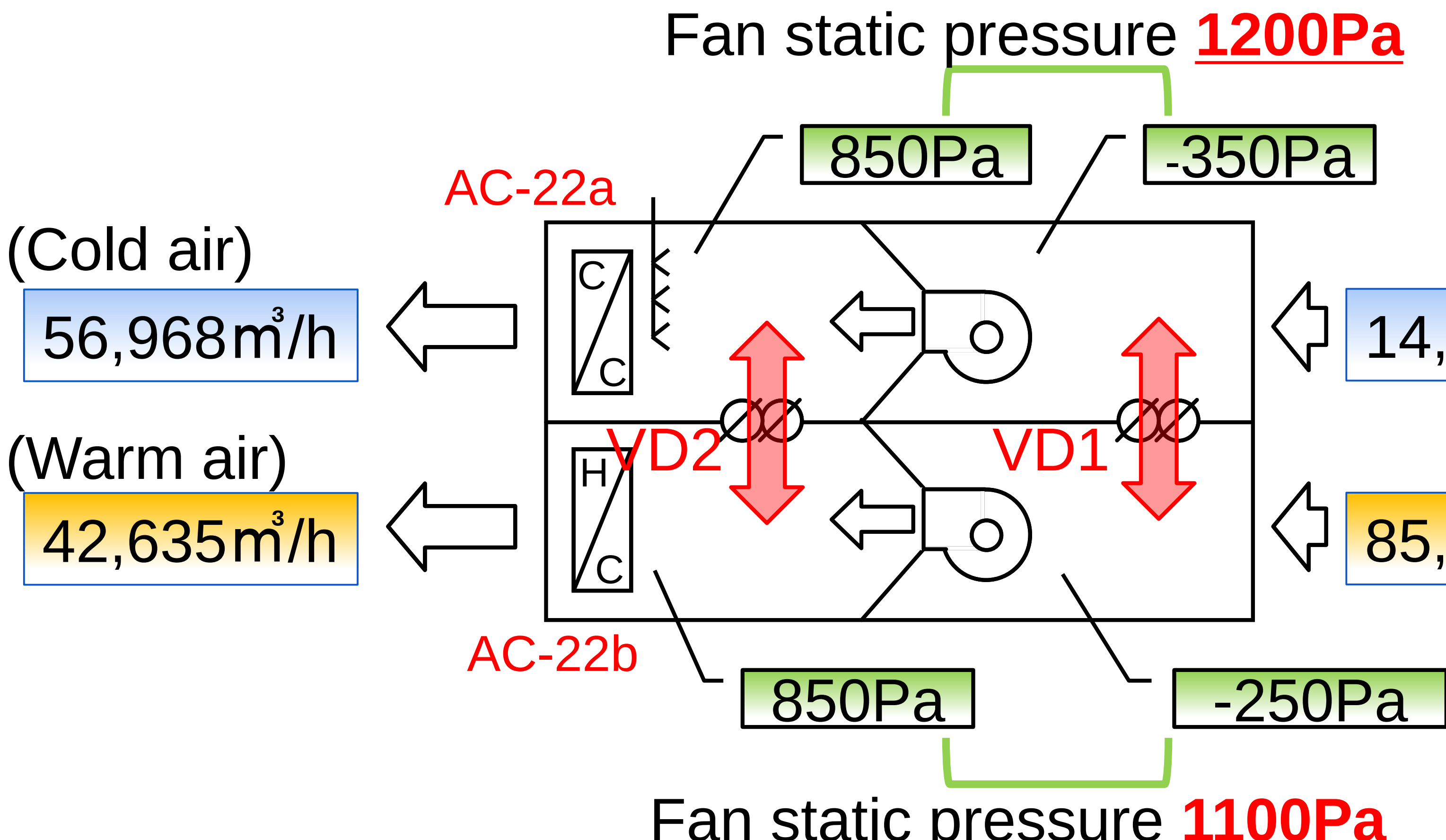
ESL-IC-14-09-26a

Example of Actual Process Variables around AC-22 in winter operation



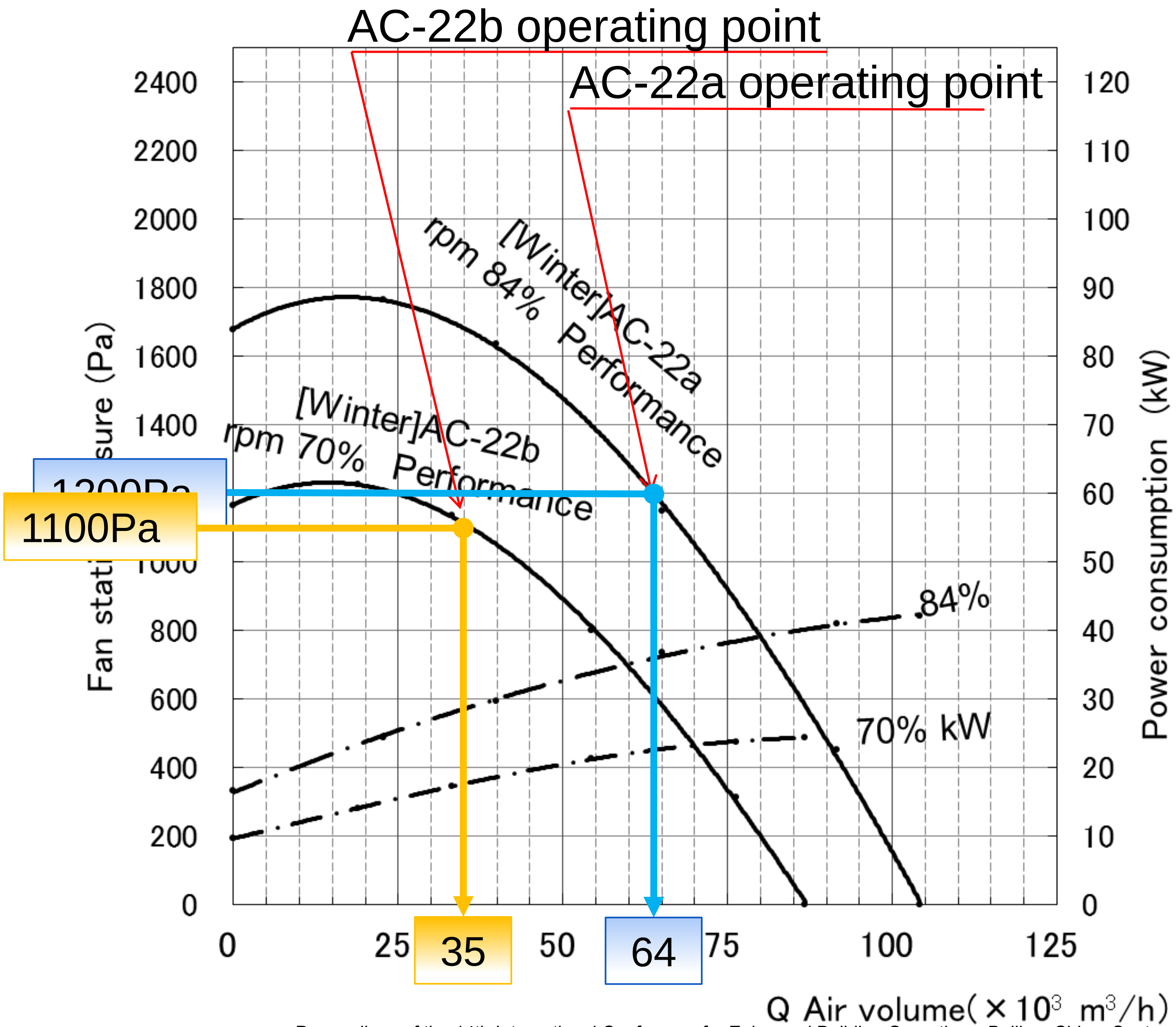
Mixing inside AC-22 due to bypass dampers

The air volumes through the by-pass dampers VD1 and VD2 in AC-22 are estimated by calculating the air volumes of fans alone.



Proceedings of the 14th International Conference for Enhanced Building Operations, Beijing, China, September 14-17, 2014

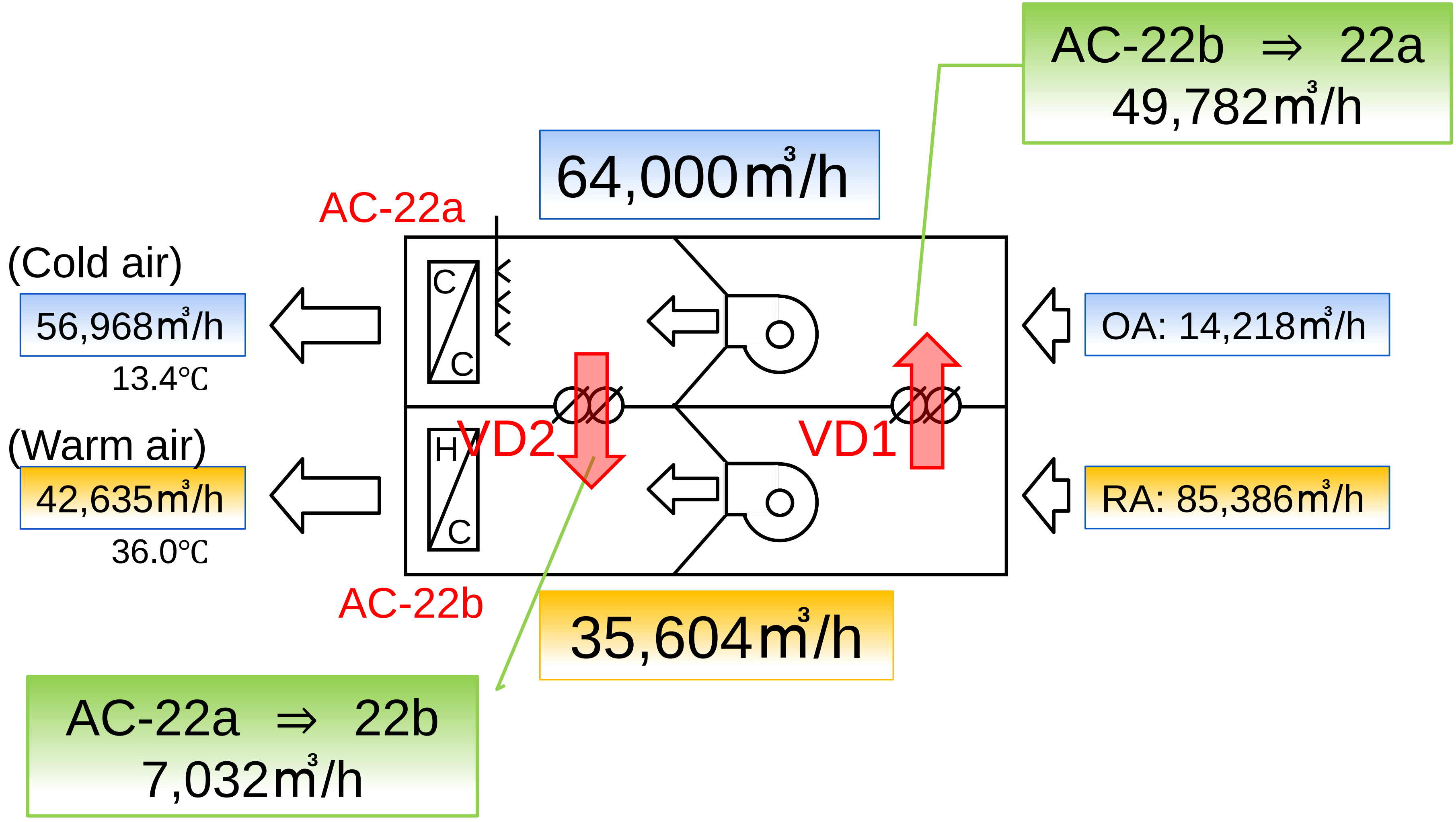
Air volumes at 11:00 on January 17,2014



Operating point

[AC-22a]
64,000m³/h
×1,200Pa

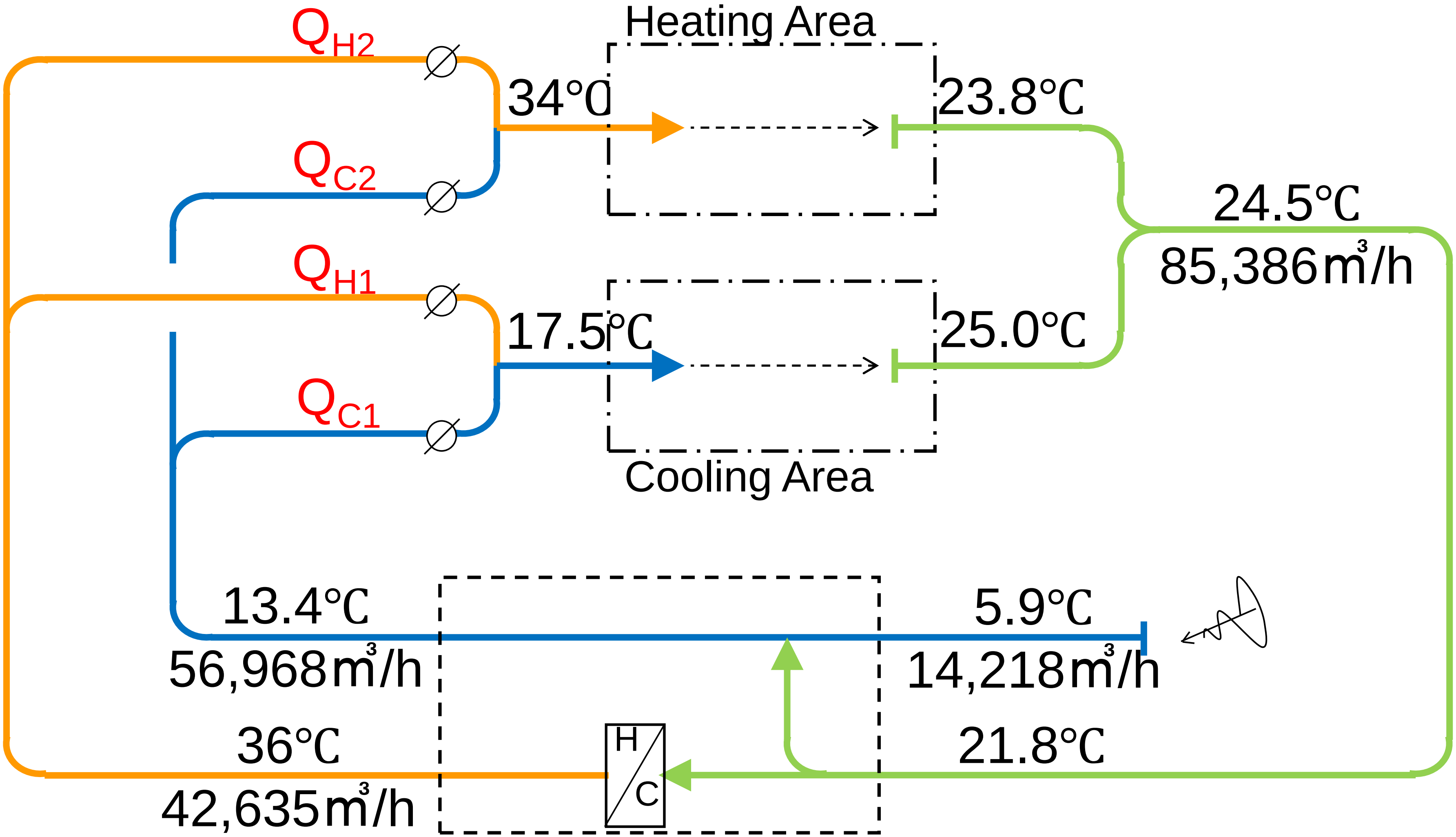
[AC-22b]
35,000m³/h
×1,100Pa



Air volumes at 11:00 on January 17,2014

Evaluation of the energy loss by mixing in winter

Air volume balance obtained by actual measurements.



Measured data around AC-22 system, 11:00 on January 17, 2014

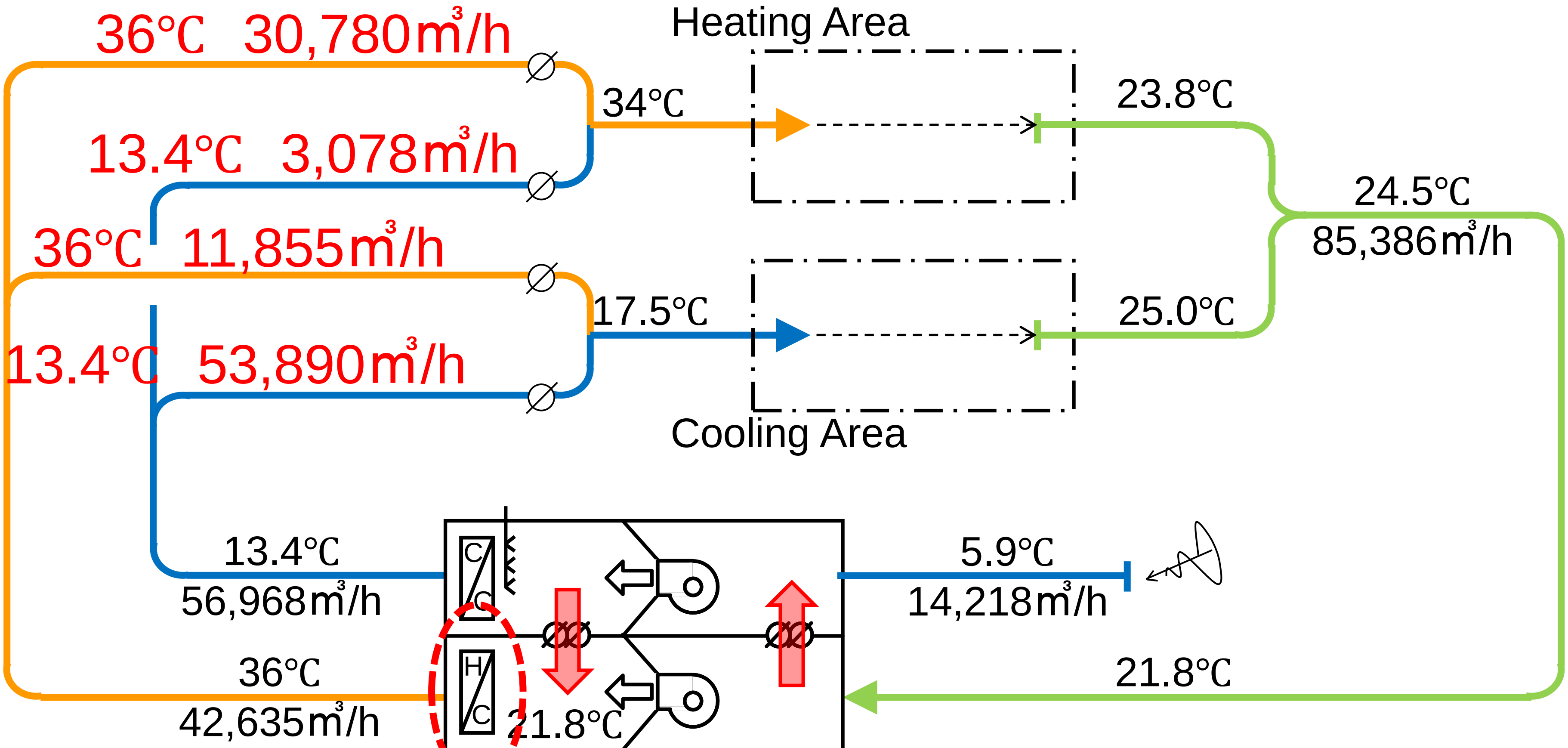
Proceedings of the 14th International Conference for Enhanced Building Operations, Beijing, China, September 14-17, 2014

Finding mixing air volume from heat balance

$$(13.4 \times Q_{C1} + 36 \times Q_{H1}) \div (Q_{C1} + Q_{H1}) = 17.5$$
$$(13.4 \times Q_{C2} + 36 \times Q_{H2}) \div (Q_{C2} + Q_{H2}) = 34$$
$$Q_{C1} + Q_{C2} = 56{,}968$$
$$Q_{H1} + QH_2 = 42{,}635$$

→

Q_{C1}=53,890 m³/h
Q_{C2}=3,078 m³/h
Q_{H1}=11,855 m³/h
Q_{H2}=30,780 m³/h



Air volume balance of cold air and warm air at 11:00 on January 17

Heating coil output

$$(36℃ - 21.8℃) \times 42,635\ m^3/h \times 1.2\ kg/m^3 \times 1.006\ kJ/kg \div 3,600\ s/h = \mathbf{203.0\ kW}$$

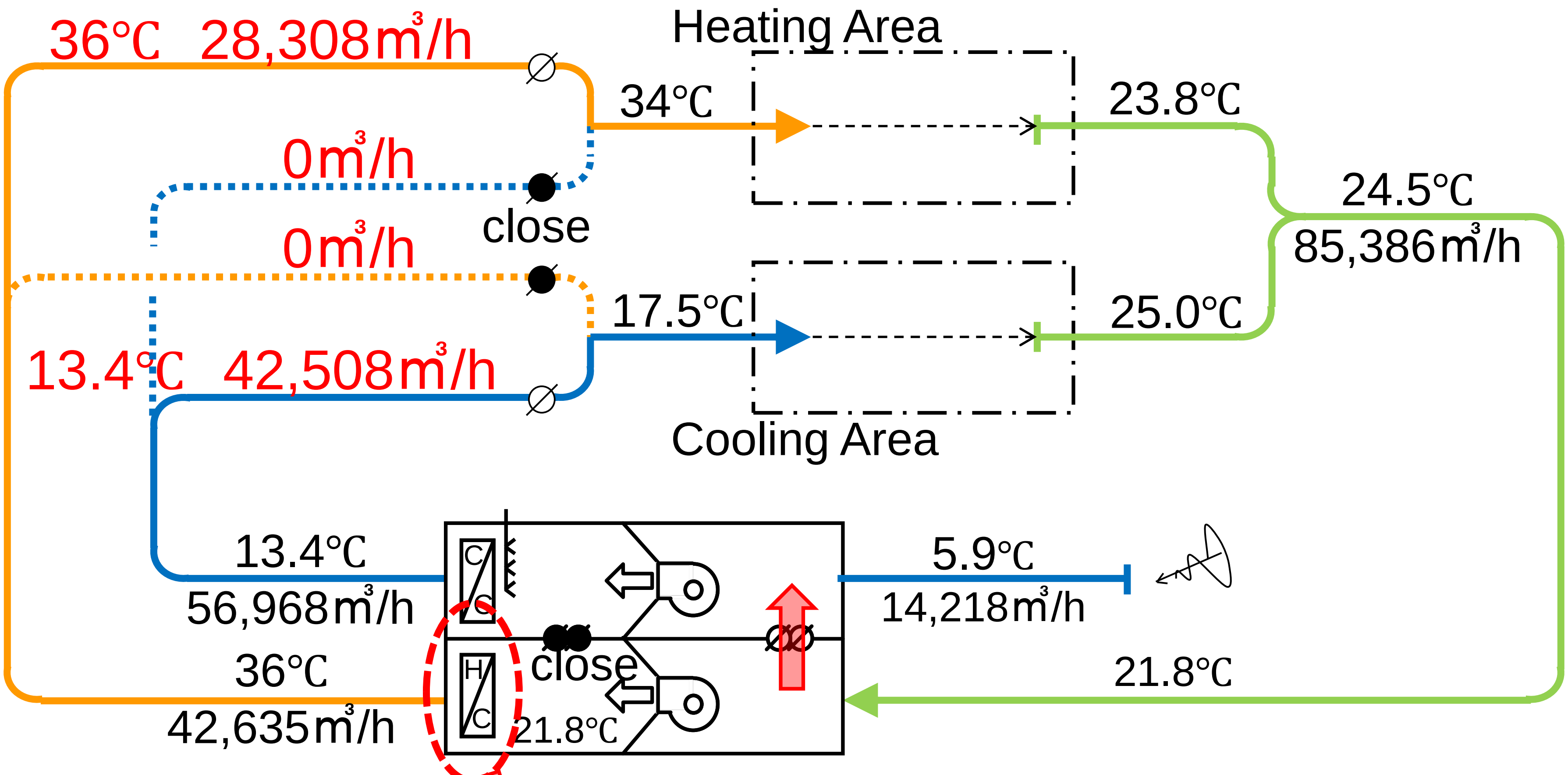
Estimation of air and heat balance at no mixing assumption

The air volume necessary to cooling area without any mixing

65,745 × (25 − 17.5)/(25 − 13.4) = 42,508 m^3/h
Excess air volume:
56,968 − 42,508 = 14,460 m^3/h.

The air volume necessary to heating area without any mixing

33,858 × (34 − 23.8)/(36 − 23.8) = 28,308 m^3/h
Excess air volume:
42,635 − 28,308 = 14,327 m^3/h.



Air volume balance of cold air and warm air in case of no mixing

Heating coil output at no mixing assumption

$$(36℃ - 21.8℃) \times 28{,}308\ \text{m}^3/\text{h} \times 1.2\ \text{kg/m}^3 \times 1.006\ \text{kJ/kg} \div 3{,}600\ \text{s/h} = \mathbf{134.8\ kW}$$

Thermal energy loss by mixing

- **Thermal energy loss by mixing**

= Difference of the heating coil output

=203kW–134.8kW=**68.2kW**

Fan power energy loss by mixing

Fan power energy loss is as follows

(The fan efficiency × motor efficiency : 0.5)

- AC-22a fan:14,460 m^3/h/3600×1,200 Pa/0.5=9.6 kW
- AC-22b fan:14,327 m^3/h/3600×1,100 Pa/0.5=8.8 kW
- The total : **18.4kW**

Primary energy loss by mixing

Assuming the comprehensive system COP based on primary energy is 0.7;

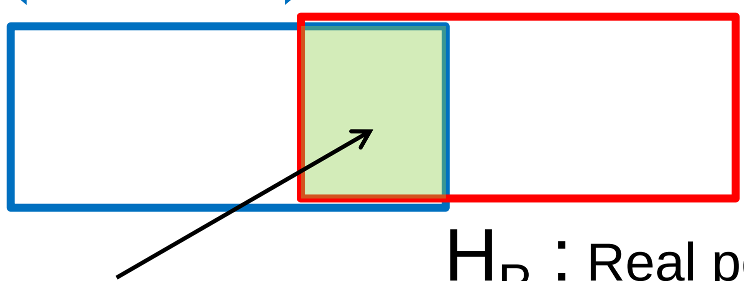
- Primary thermal energy loss :
  68.2kW/0.7=97.4kW×3.6MJ/kW=350.7MJ/h
- Primary energy loss of fan power consumption :
  18.4kW×9.97MJ/kW=183.4MJ/h
- The total : **534.1MJ/h**

Energy Mixing Loss Between Interior and Perimeter Zones at Simultaneous Heating and Cooling

Definition of the mixing energy loss

Q_I : Actually supplied cold energy

H_I : Real interior cooling load



H_P : Real perimeter heating load

Mixing energy loss

Q_P : Actually supplied warm energy

The mixing loss ratio (MLR)

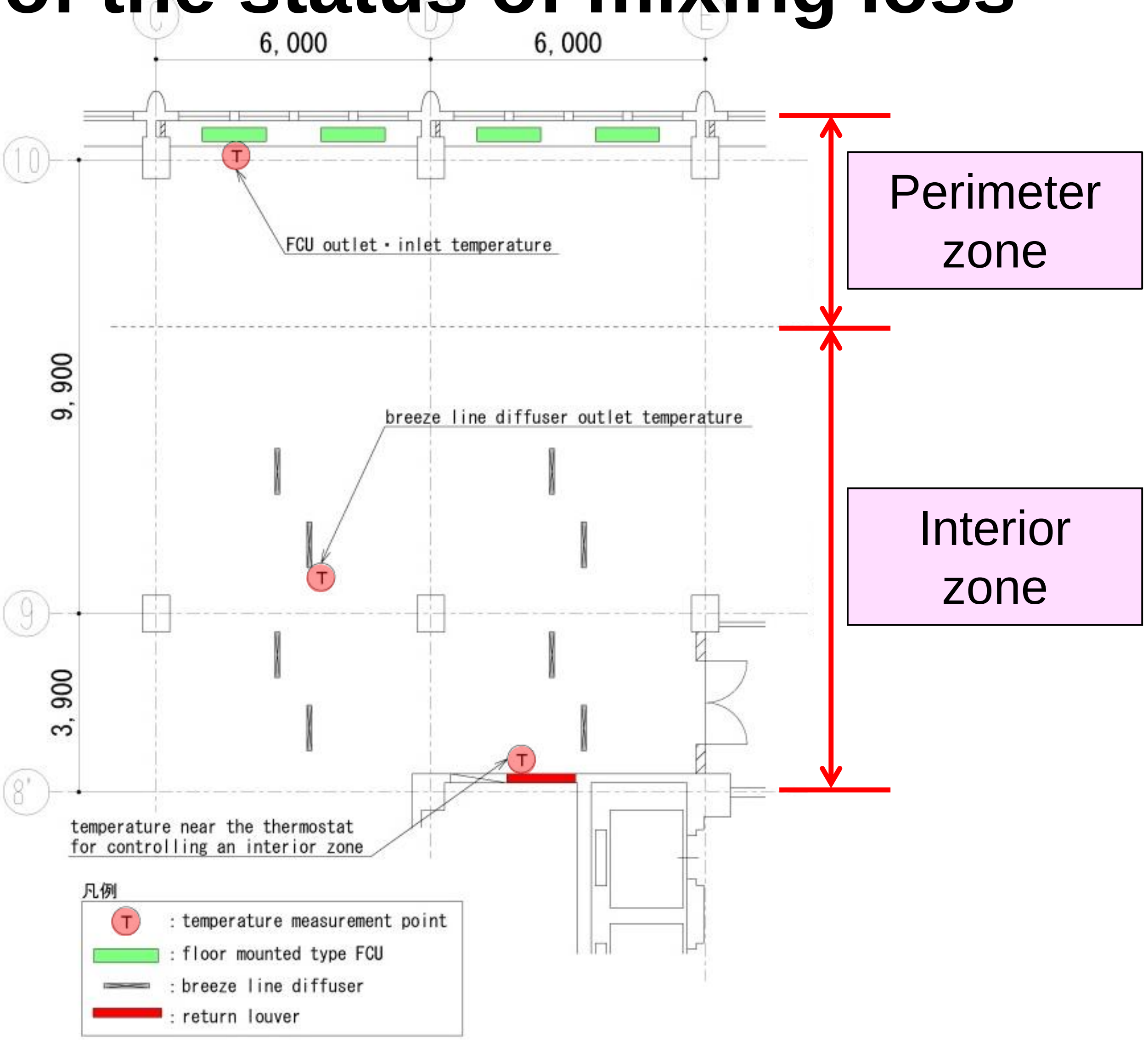
$$MLR = \{ (|Q_P| - |H_P|) + (Q_I - H_I) \} / (|H_P| + H_I)$$

H: Real heat load (subscript I: interior cooling load (+), P: perimeter heating load (-))

Q: Actual heat supply/removal (subscript I: interior cold heat (+), P: perimeter warm heat (-))

Proceedings of the 14th International Conference for Enhanced Building Operations, Beijing, China, September 14-17, 2014

Estimation of the status of mixing loss

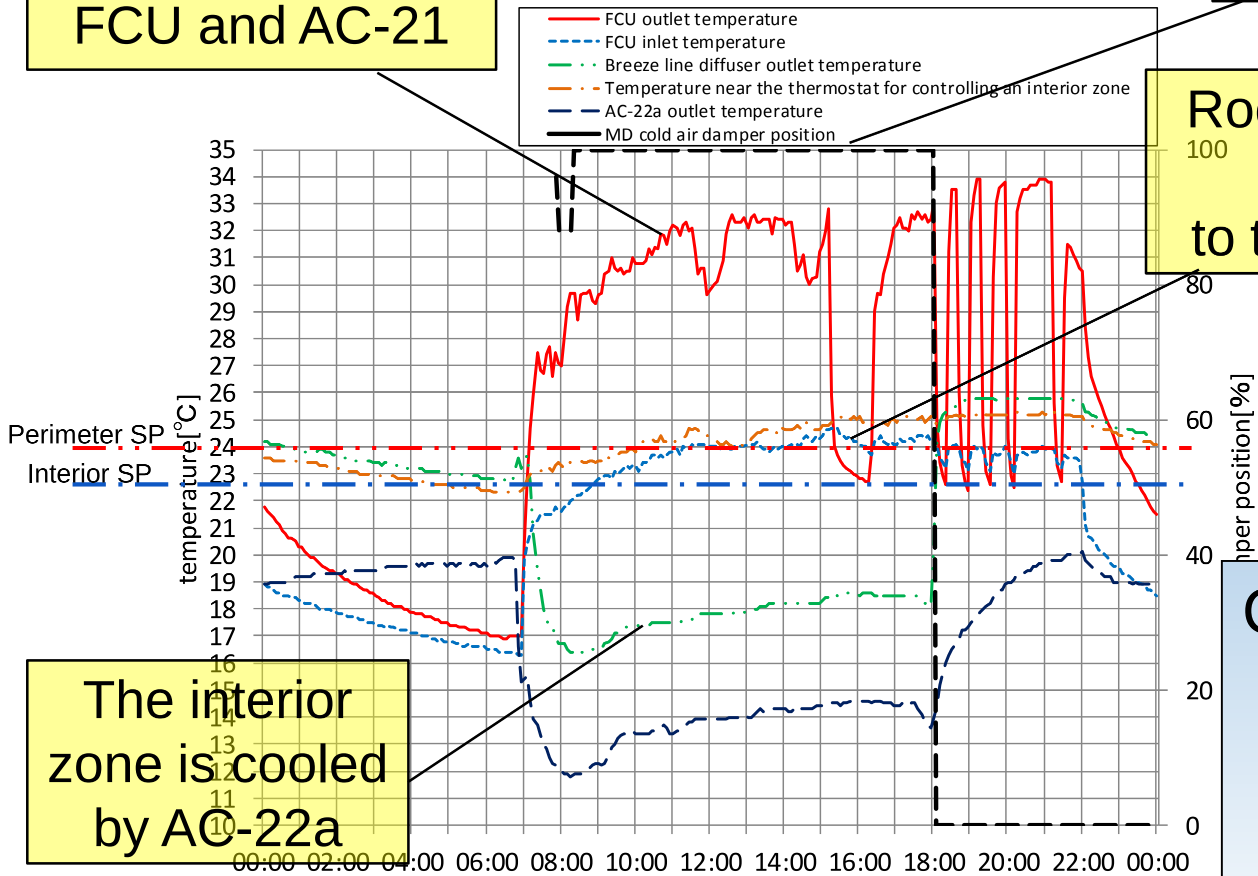


Temperature measurement points in the west office area on 5F

The perimeter zone is heated by FCU and AC-21

The MD cold air is open 100%except during the start up

Room temperature is about 23～25℃ to the interior SP of 22.5℃.



The interior zone is cooled by AC-22a

Cooler room air of the interior and warmer room air of the perimeter mixes at the boundary area, resulting mixing energy loss.

Temperature measurement on Friday, January 17, 2014 in the west office area on 5F

Temperature control in the interior and perimeter zones

Preset temperature in each zone

	Set value	Remarks
Preset temperature in the interior zone	22.5ºC	Check the set value of MD (mixing dampers) from the central monitor.
Preset temperature in the perimeter zone	24ºC	Visual check of the set value of the northwestern FCU, the temperature of which were measured.

Estimation table of the mixing loss ratio (MLR)

Significant factors effecting MLR (Nakahara et.al)

Significant Factors		Description of Selected level	(Average=-2) Factorial effect
A	P : Depth	4.5 m	15
C	P : Outlet direction	0º	4
F	I : Outlet air volume (air change rate)	MD opening: 100%. Air change rate: 5/h.	-8
G	I-P : Preset temperatures difference	-1.5ºC (I: 22.5ºC, P: 24ºC)	44
B × D	**Length of hanging wall × P: Outlet Ar number**	Hanging wall: None, Ar. number: middle	-18
B × H	**Length of hanging wall × I: thermostat position**	Hanging wall: None I thermostat position: Wall	-22
C × D	**P: Outlet direction × P: Outlet Ar. number**	P Outlet direction: 0ºC P Outlet Ar number: middle	8
		Sum of factorial effect	23 (%)

⇨ MLR ≒ -2+23%= **21%**

Proceedings of the 14th International Conference for Enhanced Building Operations, Beijing, China, September 14-17, 2014

Improvement Measures for Energy-efficiency for AC-22 (Interior zone dual-duct VAV)

- Preventing mixing thermal energy loss
  - Improve control strategy to prevent mixture at the dual duct mixing dampers,
  - Close the bypass-damper VD2 in AC-22,

    ⇒Reduction of the thermal energies of **68.2kW**

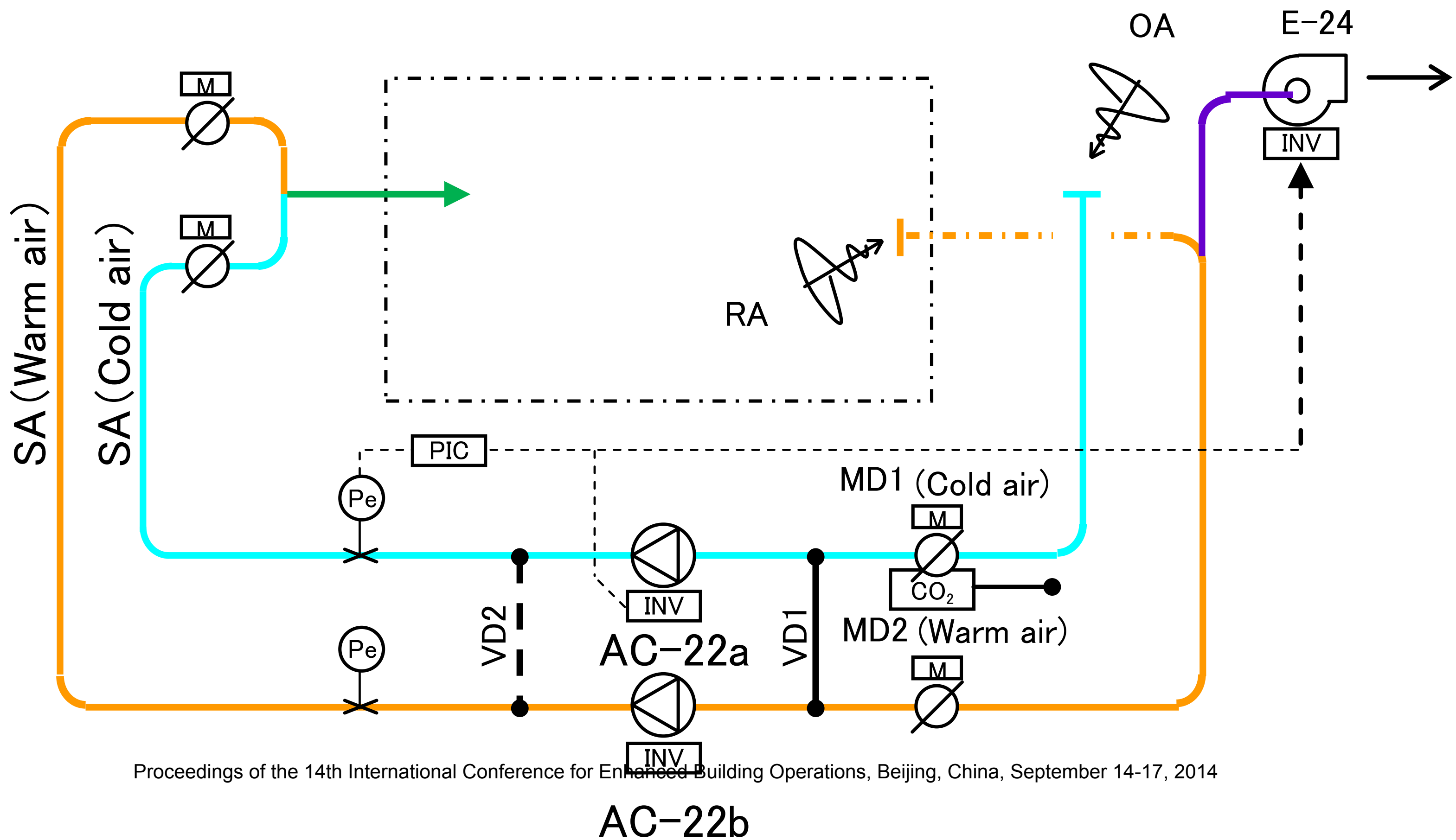
- Reducing excessive fan power consumption due to mixing
  - Inside AC-22 VD2 bypass damper shall be completely closed.

    ⇒Reduction of fan power consumption of **18.4kW**

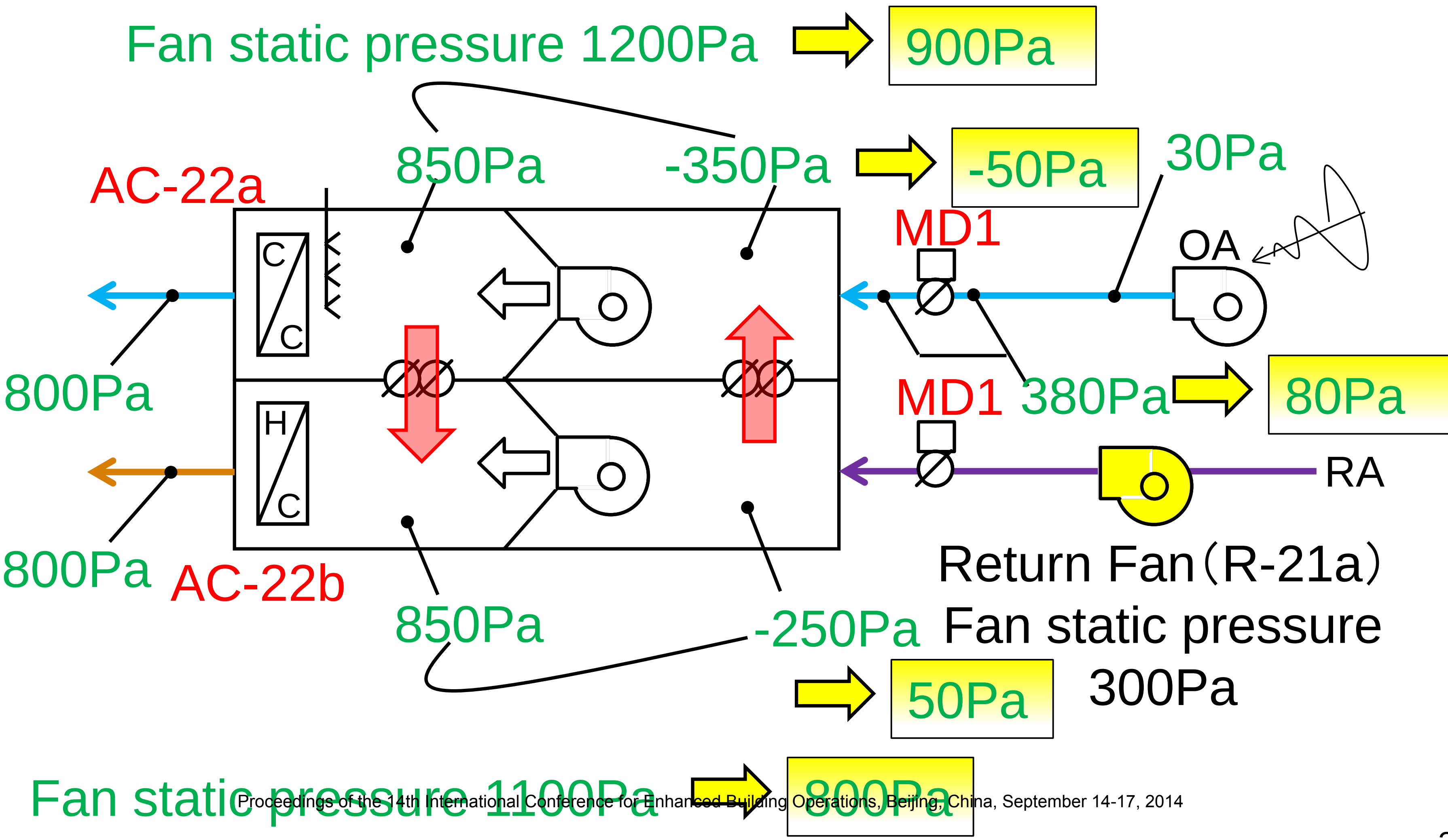
Proceedings of the 14th International Conference for Enhanced Building Operations, Beijing, China, September 14-17, 2014

➢ Effective utilization of outside air (cold air) in the intermediate season as economizer

The control algorithm is available elsewhere as outside air cooling.



➢ Re-installing the return fan and reducing the outlet static pressure settings for AC-22a,b.



ESL-IC-14-09-26a

The effect of energy saving by re-installing the return fan R-21a is calculated as follows.

Before (present condition)

- AC-22a fan:64,000m^3/h/3600 × 1,200Pa/0.5=42.7 kW
- AC-22b fan:35,603m^3/h/3600 × 1,100Pa/0.5=21.8 kW

⇒The total : 64.5kW

After (future condition)

- AC-22a fan:64,000m^3/h/3600 × 900Pa/0.5=32.0 kW
- AC-22b fan:35,603m^3/h/3600 × 800Pa/0.5=15.8 kW
- R-21a fan : 85,385m^3/h/3600 × 300Pa/0.5=14.2 kW

⇒The total : 62.0kW

Reduction of the fan power consumption becomes 2.5kW.

Proceedings of the 14th International Conference for Enhanced Building Operations, Beijing, China, September 14-17, 2014

Improvement measures to minimize the mixing energy loss between the interior and perimeter zones.

- Reducing the excessive air conditioning capacity in the perimeter zone.
  - Minimizing the primary air volume in the AC-21 system.
  - Reducing the maximum capacity of FCU and AC-21.
- Lowering the preset temperature in the perimeter zone, and raising the preset temperature in the interior zone in order to obtain mixing energy gain.

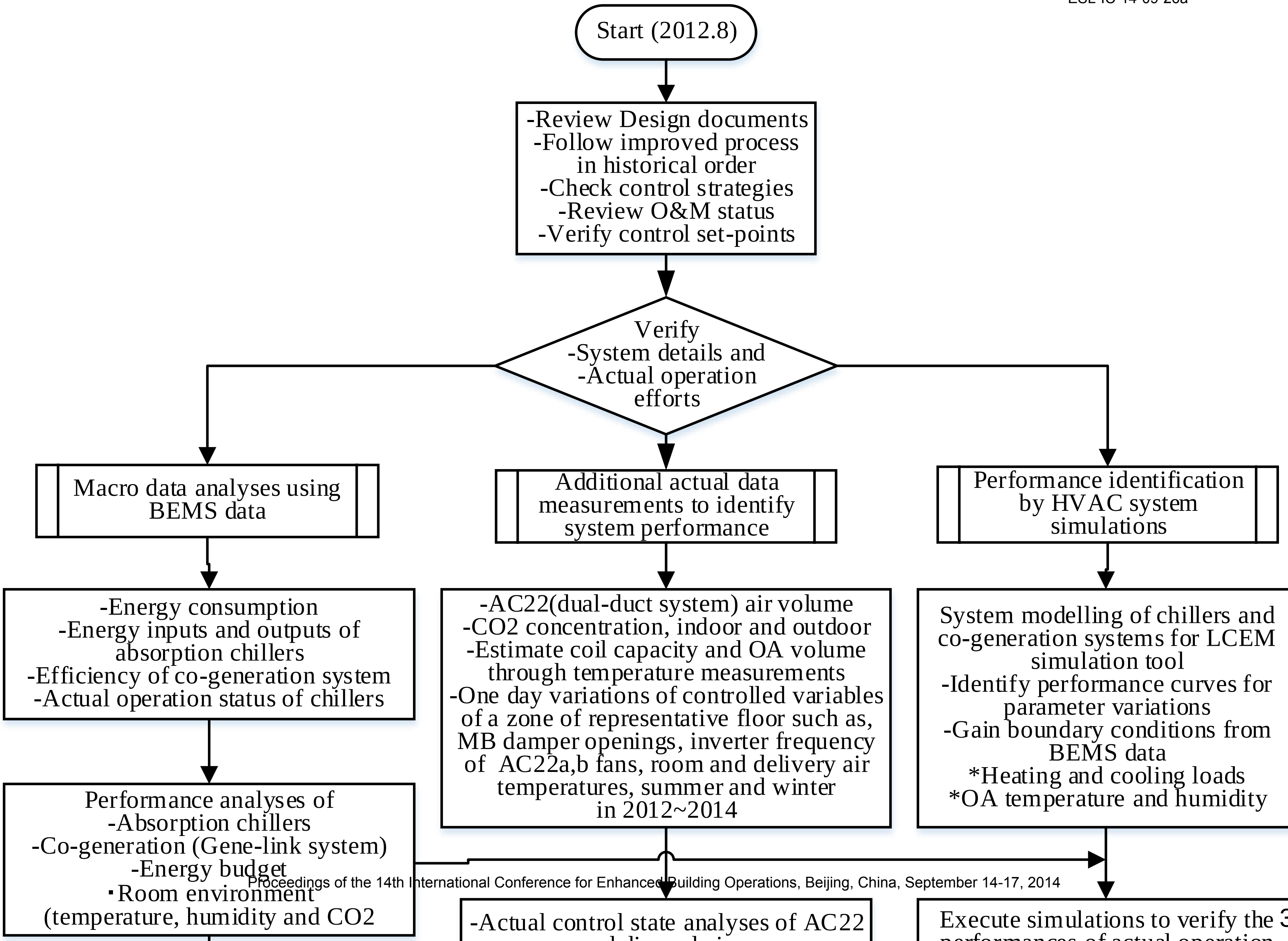
- Change the mixing damper control schedule to eliminate minimum opening preset to exclude stable mixing of warm and cold air.

- Reducing the outlet volume of cold air in the interior zone in the vicinity of the perimeter zone, and preventing direct mixing loss with the perimeter zone.

- Lowering the cold air ventilation temperature from the current level to reduce the air change rate.

Discussion

- Next Figure shows the performance verification process flow in this study.
- It also shows the long-term improvement strategy for the air system and the basic concept of grading-up the energy plant now under consideration. Some energy-saving measures require extensive modification. Continuous renovation plans will be formulated in collaboration with the operation staff as the continuous commissioning process, that is, the combination of on-going commissioning by O&M +FM and re-commissioning by the third party.


Start (2012.8)
-Review Design documents
-Follow improved process in historical order
-Check control strategies
-Review O&M status
-Verify control set-points
Verify
-System details and
-Actual operation efforts
Macro data analyses using BEMS data
Additional actual data measurements to identify system performance
Performance identification by HVAC system simulations
-Energy consumption
-Energy inputs and outputs of absorption chillers
-Efficiency of co-generation system
-Actual operation status of chillers
-AC22(dual-duct system) air volume
-CO2 concentration, indoor and outdoor
-Estimate coil capacity and OA volume through temperature measurements
-One day variations of controlled variables of a zone of representative floor such as, MB damper openings, inverter frequency of AC22a,b fans, room and delivery air temperatures, summer and winter in 2012~2014
System modelling of chillers and co-generation systems for LCEM simulation tool
-Identify performance curves for parameter variations
-Gain boundary conditions from BEMS data
*Heating and cooling loads
*OA temperature and humidity
Performance analyses of
-Absorption chillers
-Co-generation (Gene-link system)
-Energy budget
・Room environment
(temperature, humidity and CO2
-Actual control state analyses of AC22
Execute simulations to verify the

Thank you for your kind attention