A Case Study of Continuous Commissioning of the VAV System in China

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Abstract: This paper introduces a continuous commissioning of the VAV system in a real building in China. On the base of nearly one year's testing data, the energy conservation level of the project is analyzed, and significance of further commissioning is emphasized. A systematic evaluation method for existing building's commissioning is developed. Moreover, this paper provides important experience and a feasible evaluation system for development of commissioning in China.

Key words: commissioning VAV RRPS TDCA ESR

1. BACKGROUND

Commissioning (Cx) is to improve the performance of building in compliance with owner's or occupants' requirement according to diagnosing, tuning and verifying building system, necessarily accompanied with fully development documentation[1].

Because of its importance in design, installation, system tuning and operation management, researchers, engineer, architecture and owners from all over the world have done a great deal of practice and research on Cx. In 1970s, USA and UK have begun practice in Cx. First CIBSE code on Cx was issued in 1989, while first ASHRAE Cx guideline was issued in 1989, the second version of which was issued in 1996. In Japan, the first formal application of initial Cx started in 2000, the results of which was published in 2001[2][3]. First Cx Research Center in Hongkong was established in 2002. In 2004, Japan's first Cx Process Guideline was issued. Meanwhile, a lot of research about Cx has been presented in the literature[4][5][6][7].

In China, Tsinghua University has finished on-site measurement and energy conservation analysis of more than 50 public buildings in Beijing, Shanghai and Shenzhen since 1996, and the total construction area is nearly 4 million meters. Other universities and research departments have also took many Cx applications. However, research about systematic Cx process and methods are insufficient, and few studies have provided comprehensive and detail data about Cx application.

This paper introduces a continuous commissioning application on Beijing Fortune Building, and proposes a systematic method of continuous Cx to study the control system's performance, indoor environment quality and energy consumption, especially applying a series of index to evaluate the operation performance of VAV system.

2. INTRODUCTION OF Cx CASE

Beijing Fortune Building is a slap-up office building, which was built in 1980s. The whole building is divided into two parts: main building and skirt building. The main building is 80m high with the construction area reaching 54490 m^2. There are 20 stories up ground and 2 stories underground. 3rd ~21st stories are mainly used as office room, designed with VAV system. Cx process is mainly divided into four periods (Fig.1): initial Cx began in 1998; retrofit started in 2003; Whole year's integrated Cx on the 12th floor's VAV system between Jan. 2005 and Jan. 2006; further Cx in the near future. This paper mainly focuses on the integrated Cx in 2005.

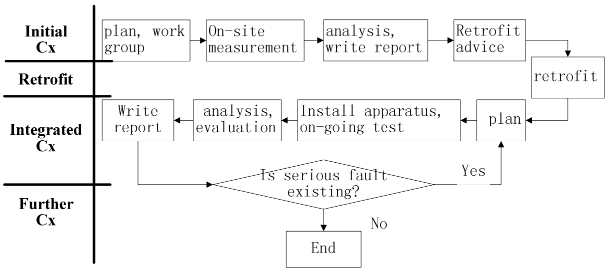


Fig.1 Cx process of this project

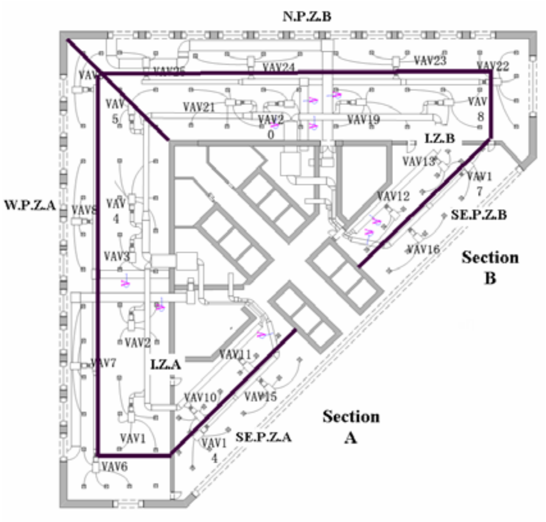


Fig.2 Plan drawing of HVAC system of 12th story after retrofitting

After retrofitting, the 12th floor is zoned to two large sections: section A and section B. Section A includes west perimeter zone (W.P.Z.A), interior zone (I.Z.A) and southeast perimeter zone (SE.P.Z.A), while section B includes north perimeter zone (N.P.Z.B), interior zone (I.Z.B) and southeast perimeter zone(SE.P.Z.B)(Fig.2). The plan of HVAC system after retrofitting is shown in Fig.2, and the parameters of AHU are exhibited in Tab.1.

Tab.1 Parameters of AHU

AHU	A14	B11	A12	B12	A13	B10
Zone	W.P.Z.A	N.P.Z.B	SE.P.Z.A	SE.P.Z.B	I.Z.A	I.Z.B
Rated Air Volume (m3/h)	7600		3700		12100	
Rated Power（kW)	4		2.2		7.5	

After retrofitting, both interior and perimeter zones are designed with VAV systems, and the control system includes four parts: terminal controller, integrated management unit, AHU controller and central monitor. Integrated management unit collects each terminal's measured temperature and SAV, and then calculates the fan speed and supply air temperature (SAT). Fan speed is calculated by the total required SAV and then verified by the opening of all the terminal valves.

3. Cx METHOD

This paper proposes an integrated method for continuous Cx, and the main framework is exhibited in Fig.3. The Cx method consists of four steps, and starts from calibration of main sensors. In this step, many calibration methods have been described in the literature[8] could be applied. After calibration, temperature difference between measured value by sensors and setpoint is applied to decide whether control system can satisfy occupant's requirement. If large deviation is obtained, OCM (Objective Control Method) should be applied to diagnose the performance of control system, which is introduced in detail by Zheng Han[9]. If deviation is small or step 2 is completed, evaluation of indoor environment quality will be conduced on. Finally, *RRPS* (ration of power to speed), *TDCA* (transport distribution coefficient of air) as well as *ESR*(energy saving ratio) are introduced to assess the operation performance and energy conservation level of VAV system.

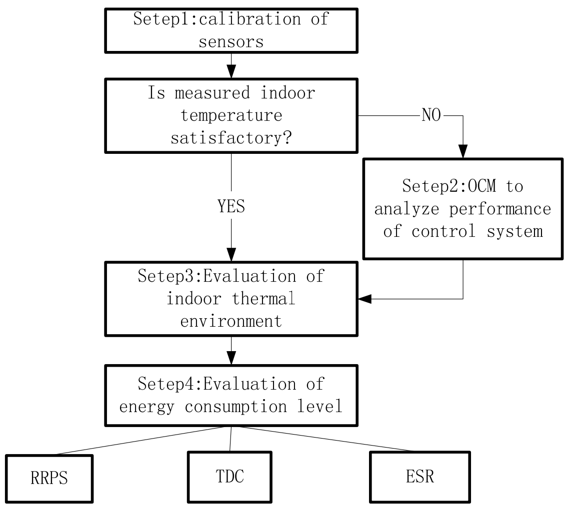


Fig.3 Integrated analysis method for continuous Cx

Lots of techniques, models and measurement methods can be found for step1 and step3, while research and application of OCM in this project has been explained by Zheng Han[9]. This paper mainly focuses on the three parameters applied in step4, which is a new series of index to evaluate the operation performance of VAV system.

4.1 RRPS

Because fan's pressure can't be measured correctly in practice, the operation efficiency can't be calculated directly. To avoid complex measurement, a new method is developed in this paper, which applies *RRPS* (Relative Ratio of Power to Speed) to describe fan's operation efficiency indirectly. Based on similar law, *RPS*(Ratio of Power to Speed) is defined as:

$$RPS = \frac{N}{n^3} = \frac{N_r}{\eta_1 n_r^3} = \frac{N_r}{\eta_1} \qquad (1)$$

where: N——input power of electromotor, kW; η_1——efficiency of electromotor; n——practical fan speed ratio, %; N_r——fan's shaft power of similar condition under rated speed ratio, kW; n_r——rated fan speed ratio,＝100%.

Furthermore, define *RRPS*= *RPS*/RPS_0, in which subscript "0" stands for fan's rated condition, and we can obtain

$$RRPS = \frac{1}{\eta_1} \cdot \frac{N_r}{N_0} \,. \qquad (2)$$

As shown in Fig.4, A is the practical working condition of fan, B is the similar condition, and C is rated condition of fan. If electromotor's efficiency keeps high value, *RRPS* of working condition A is a little smaller than 1. Calculate all working condition's *RRPS*, and the following rules can be achieved:

(1) if *RRPS* values with nearly 100% speed ratio distribute around 1, fan's capacity matches with duct system;

(2) if most *RRPS* values are less than 1, the resistance coefficient is larger than the design value; if most *RRPS* values are greater than 1, the resistance coefficient is smaller than the design value or electromotor's efficiency is low.;

(3) the farther the distance of *RRPS* to 1 is, the lower the fan efficiency is.

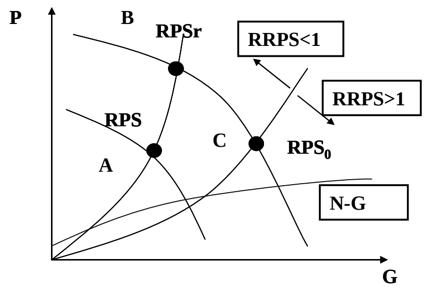


Fig.4 Schematic depiction of *RRPS*

4.2 TDCA

The main objective of VAV system control is to reduce electricity consumption when cooling/heating load decreases. Therefore, *TDCA*(Transport Distribution Coefficient of Air) is applied to describe system efficiency, which is defined as transported cooling and heating amount by fan with per unit electricity consumption. *TDCA* can be calculated by

$$TDCA = \frac{Q_c + Q_h}{E_c + E_h} \qquad (3)$$

where: Q_c/Q_h——transported cooling/heating amount by fan, kWh; E_c/E_h——cooling/heating electricity consumption of fan, kWh.

Substituting *RRPS* into Eq.(3), we obtain that

$$TDCA = \frac{\rho C_p G \Delta T}{\frac{G \Delta P}{\eta \eta_1}} = \frac{\rho C_p \eta_0}{N_0} \cdot \frac{G_r \Delta T}{RRPS \cdot n^2} \,, \qquad (4)$$

where:G_r——air volume of similar condition under rated fan speed ratio,m^3/h; □T——SAT difference,□;η——efficiency of fan;

As seen in Eq.(4), *TDCA* is not only decided on fan's *RRPS*, but also depends on the SAT difference and fan speed ratio.

4.3 ESR

When CAV system is retrofitted into VAV system, the energy saving ratio (*ESR*) mainly depends on annual average fan speed ratio and fan efficiency, which can be defined as:

$$ESR = \frac{E_1}{E_2} \,. \qquad (5)$$

In Eq.(5), E_1 is annual electricity consumption of fans after retrofitting and E_2 is annual electricity consumption of fans before retrofitting.

Although *ESR* is the main objective of VAV system, it is not only decided by the performance of

HVAC system, but also decided by the annual HVAC partial load ratio, which depends on thermal properties of room. In this case, we can't evaluate the performance of VAV system only by *ESR*, which can't indicate the energy saving potential. As a result, *RRPS* is developed to evaluate the fan's operation efficiency and *TDCA* is developed to evaluate the system operation efficiency.

4. Cx RESULTS

4.1 CONTROL SYSTEM PERFOMANCE

One month's data respectively in summer(sum.), winter(win.) and intermediate seasons(IS) are chose to analyze control system performance according to OCM, and the temperature deviation are exhibited in

Tab.3.

Conclude the main faults diagnosed in by OCM as follows:

(1)The SAV of VAV Boxes can't meet the required value , such as VAV21 and VAV09;

(2)Indoor temperature setpoint is too high or too low, such as VAV19, VAV22, and VAV07;

(3)Big difference between indoor temperature setpoint results in high SAT in summer and hunting of control system, such as the system of I.Z.B.

(4)Modification of fan speed ratio by valve opening signals can't work well and large SAV deviation is found.

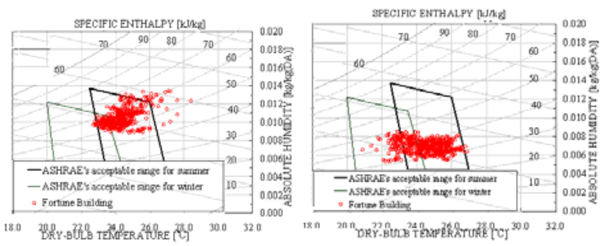
4.2 INDOOR ENVIRONMENT QUALITY

Two wide-opened office rooms located on the 12th floor of section B were respectively chosen to test indoor CO_2 concentration and thermal parameters.

One room directs north and the other directs southeast. Totally ten American infrared CO_2 and OA measuring apparatus Telaire-7001 were disposed on the work desk in different places in the room, and tow temperature and RH measuring apparatuses were disposed respectively in the interior and perimeter zones.

Tab.2 Measured CO_2 concentration

Season	North	Southeast
Transition season	500～650	500～600
Summer	/	450～500
Winter	500	500～600



Aug.1st ~5th Dec.26th ~30th

Fig.5 Thermal parameters in southeast room

Tab.3 Temperature deviation of all the VAV Boxes[1]

Zone	Box	win.	IS	sum.	Zone	Box	win.	IS	sum.
SE.P.Z.B	VAV16	√	↑1.4	↑1.7	SE.P.Z.A	VAV14	√	√	√
	VAV17	√	√	√		VAV15	√	↑1.2	↑1.3
N.P.B	VAV22	↓1.2	√	√	W.P.Z.A	VAV6	√	√	√
	VAV23	√	√	√		VAV7	↓2.6	√	√
	VAV24	√	√	√		VAV8	√	↑1.6	↑1.4
	VAV25	√	√	√		VAV9	√	↑1.8	↑2.9
I.Z.B	VAV12	√	√	↑1.2	I.Z.A	VAV1	√	√	√
	VAV13	√	√	√		VAV2	√	√	√
	VAV18	√	√	√		VAV3	√	√	√
	VAV19	√	√	↓1.5		VAV4	/	/	/
	VAV20	√	√	↑1.3		VAV5	√	√	√
	VAV21	√	↑1.1	↑1.4		VAV10	/	/	/
						VAV11	√	√	√

[1] "√"——temperature deviation between -1~1℃; "↑" temperature deviation is larger than 1℃; "↓" temperature deviation is larger than -1℃.

Measured values are shown in Tab.2, and CO_2 concentration in both rooms is below 1000 ppm, which is the limited value in national code[10].

Indoor temperature and RH data in winter and summer in southeast room are exhibited in Fig.5, and they are recorded every ten minutes from 8:00 to 18:00. Data in summer are generally distributed within ASHRAE's acceptable range for summer, while temperature in winter mainly varies between 22℃ and 26℃, which results in data in winter distributing beyond the ASHRAE's acceptable range for winter.

4.3 ENERGY CONSUMPTION

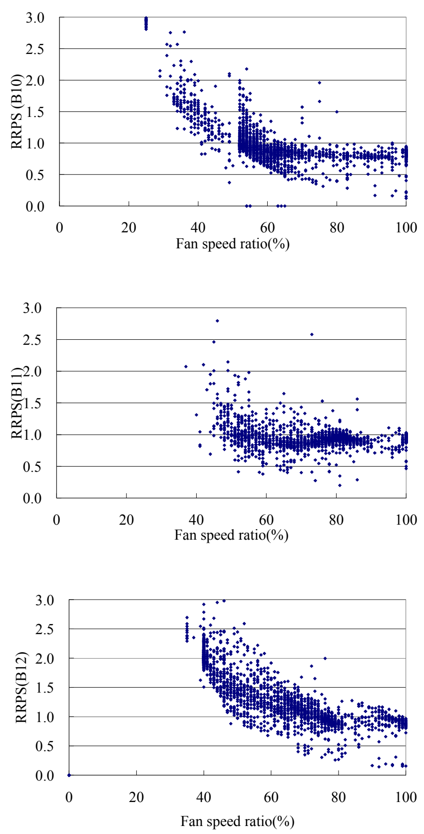


Fig.6 *RRPS* of fans in section B

Based on measured data from December, 2004 to February, 2005, *RRPS* of fans in section B are calculated in Fig.6. All the three fans' *RRPS* under rated speed ratio nearly equal to 1, which indicate that design value of fan matches with duct system. When speed ratio between 60~100%, *RRPS* vary around 1 and fan can work under high efficiency. When speed ratio less than 60%, *RRPS* increase apparently, especially that of B12. This may results from decrease of elecromotor's efficiency under low speed ratio.

Calculate *TDCA* of all the AHUs in the year of 2005, and compare the SAT with *TDCA* in Fig.7 and Tab.4. We can conclude that:

(1) Big difference of *TDCA* exists for different zones.

(2) *TDCA* have strong relevance to SAT difference. In winter *TDCA* is less than 6 with SAT difference less than 3℃; In summer SAT difference is mainly between 8~10℃ in southeast perimeter zones, and *TDCA* is greater than 8.

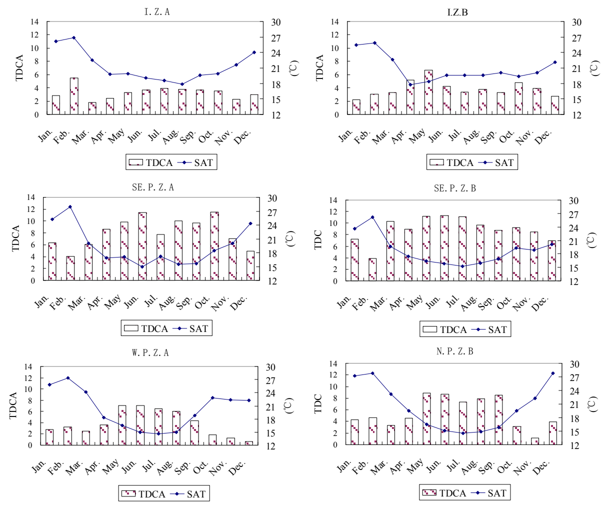


Fig.7 *TDCA* and SAT of all AHUs

Tab.4 annual average *TDCA*

	I.Z.B	N.P.Z.B	SE.P.Z.B	I.Z.A	W.P.Z.A	SE.P.Z.A
TDCA	3.9	4.7	9.2	3.2	4.2	8.4

Total electricity consumption of supply fans on 12th floor in the year of 2005 is 44,500 kWh (excluding that of OA fans), which is 31.5 kWh per air-conditioned area per year. Annual electricity consumption indexes of each zone are shown in Fig.8.

Before retrofitting, VAV system nearly worked as CAV system, and the power of fans hardly changed even at part load. Assuming fan worked under power rating, the electricity consumption index of 12th floor was 50.8 kWh/(m^2.a), and energy saving ratio of 38% is achieved after retrofitting. The energy saving ratio of each zone is shown in Fig.8. The reason for the low *ESR* of W.P.Z.A is that the whole year's average load is higher than those of other zones, and the average speed ratio of fans is usually high.

In comparison with *TDCA*, although high *ESR* is obtained by I.Z.B and I.Z.A, their *TDCA* are relatively low. In other word, these two zones may have large energy saving potential, especially in summer when *TDCA* are low. N.P.Z.B and W.P.Z.A may also have large energy saving potential from Oct. to Dec., when *TDCA* are lower than other zones.

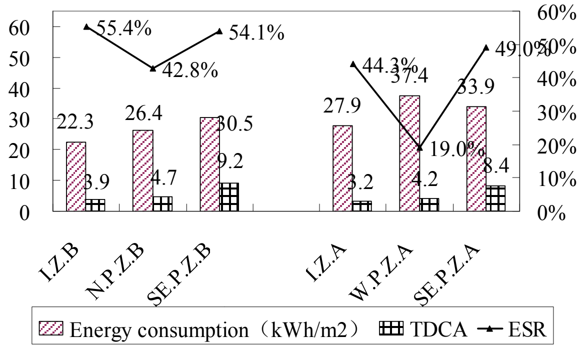


Fig.8 Electricity consumption index of each zone

5. CONCLUSION

According to one year's integrated Cx on Beijing Fortune Building, comprehensive and fundamental data-base of this project has been established, which may contribute to the development of Cx in China. Based on case study of Cx, a systematic Cx method is developed, which includes four steps and provides a feasible process for continuous Cx on VAV system. Furthermore, not big difficulties exist for extending to other high performance HVAC system. Meanwhile, OCM is developed to control system analysis, and a series index including *RRPS*, *TDCA* and *ESR* are proposed to evaluate operation performance and demonstrate energy saving potential.

In this project, control system can realize control objective except several faults. Low CO_2 concentration has been measured and energy consumed for heating/cooling fresh air may be reduced. Proper thermal environment in typical room is obtained in summer, but indoor temperature in winter is relatively high. 38% of *ESR* is obtained compared with CAV system before retrofitting. Analyze *RRPS*, *TDCA* and *ESR*, and large energy saving potential may exist in interior zones, N.P.Z.B and W.P.Z.A.

6. ACKNOWLEDGEMENT

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