# Energy Consumption Measuring and Diagnostic Analysis of Air-conditioning Water System in a Hotel Building in Harbin[1]

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**Abstract:** This paper introduces an air-conditioning water system in a hotel building in Harbin, finishes its air-conditioning energy consumption measurement in summer conditions, and presents an estimation index of performance of chiller, pump and motor. By means of testing data analysis, it is indicated that several problems such as unsuitable operation schedule of the chiller, low COP, irrational matching of pump and motor, unbalanced conditions of chilled water flow, and low working stability and efficiency ratio of the pump are existent. The paper presents suggestions for improvement with relevance based on the induction and analysis of system fault found in measurements.
**Keywords:** air-conditioning water system; testing; load ratio; efficiency ratio

## 1. INTRODUCTION

Energy conservation for public building has been attracted more and more attention in recent years. As the main composition of building energy consumption, air-conditioning system naturally becomes important object in building energy conservation[1-4]. For existed public buildings, cooling load is mainly charged with chilled water, which leads a huge and complex air-conditioning water system, as a result, complex pipeline layout and wider device investment are needed while large delivery energy is cost by pump. Therefore, initial design, device matching, control mode and operational guidance of air-conditioning water system are the main factors affecting air-conditioning energy consumption. For existent public building, research on rationality of above aspects in actual system operation is the basis of further energy consumption investigation. In this paper, a typical public building in Harbin is selected for air-conditioning water system test taken place in August 2005, including analysis of energy consumption, flow and temperature variation of cooling and chilled water, and energy conservation potentiality of pump.

## 2. GENERAL SITUATIONS OF BUILDING AND AIR-CONDITIONING SYSTEM

The building in consideration, Huayi Edifice, located at 15th Songhua River Street, Nangang district, Harbin, is an integrated building including 5A class intelligent office room and 4 class hotel. The buildings consist of a main building of 30 floors with 99.95m height, an attached building of 5 floors and a basement of 2 floors. The building covered area is 42500m$^2$ including 12000m$^2$ for office use. The building is divided into low zone and high zone according to function, low zone is for residential, dining and recreation use, including floors from 1th to 14th, high zone is for office use, including floors from 16th to 30th. Air-conditioning system is designed according to function subarea with air-conditioning area more than 85% of total recreation area.

Air-conditioning system type is all fresh air with fan-coil unit while water system type is direct return system; fresh air unit is installed in each floor. The normal occupancy period of the low zone and high zone air-conditioning system is all day, from 8:00am to 5:00pm, respectively. The cold source located at 2th underground are equipped with four lithium bromide absorption chillers produced by Dalian Sanyo with two chillers serving for high zone and low zone respectively. The nameplate capacity is shown in Tab.1.

The working time of chillers is from 5:00am to 12:00pm including half hour stoppage in am and pm with manual start-stop control respectively. In measurement period, two chillers respectively serving for low zone and high zone are in operation while recycled water is flowing through other two shut-off chillers. The heat source located at building boiler house are equipped with three gas steam boilers produced by Wellman Robey including one 4t/h and two 6t/h stream supply rating. The working time of boilers is from 5:00am to 12:00pm or later with manual start-stop control. Three cooling pumps and three chilled pumps separately serve for high zone and low zone while one cooling pump and one chilled pump are in operation with constant rotational speed in measurement period; the nameplate capacity

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Nomenclature

| | | | |
|---|---|---|---|
| $c$ | Specific heat of water, J/kg℃ | $R_p$, $R_m$ | Power ratio of pump and motor |
| COP' | Coefficient of performance | $R_{cp}$, $R_{ep}$ | Power ratio of cooling and chilled pump |
| $E$ | Cooling load ratio of chilling unit | $R_{cm}$, $R_{em}$ | Power ratio of cooling and chilled pump motor |
| $ER$ | Efficiency ratio of pump-motor device | $t_{ein}$, $t_{eout}$ | Rated inlet and outlet temperature of chilled water, ℃ |
| $ER_c$, $ER_e$ | Efficiency ratio of cooling and chilled pump-motor device | $t_{ein}'$,$t_{eout}'$ | Measured inlet and outlet temperature of chilled water, ℃ |
| $H$, $H'$ | Rated and measured head of pump ,$mH_2O$ | $t_{cin}$, $t_{cout}$ | Rated inlet and outlet temperature of cooling water, ℃ |
| $I$ | Rated current of motor, A | $t_{cin}'$, $t_{cout}'$ | Measured inlet and outlet temperature of cooling water, ℃ |
| $n$ | Rated rotational speed of motor, r/min | $t_o$ | Outdoor temperature, ℃ |
| $N$ | Rated shaft power of motor, kW | $t_r$ | Regeneration temperature, ℃ |
| $N_e$, $N_e'$ | Rated and measured useful power of pump, kW | $t_{sc}'$ | Measured temperature of stream condensate, ℃ |
| $N_m$, $N_m'$ | Rated and measured input power of motor, kW | $V$, $V'$ | Rated and measured flow of pump, $m^3/h$ |
| $p_{ein}'/p_{eout}'$ | Measured inlet and outlet pressure of chilled water, Pa | $V_e$, $V_e'$ | Rated and measured flow of chilled pump, $m^3/h$ |
| $p_{cin}'/p_{cout}'$ | Measured inlet and outlet pressure of cooling water, Pa | $V_c$, $V_c'$ | Rated and measured flow of cooling pump, $m^3/h$ |
| $Q_e$, $Q_e'$ | Rated and measured refrigerating output of chilled unit, kW | $\rho$ | Water density, $kg/m^3$ |
| $Q_c'$ | Measured condenser heat of chilled unit, kW | $\eta$ | Rated pump efficiency |
| $Q_s'$ | Measured stream heating load of chilled unit, kW | $\eta_{total}$, $\eta_{total}'$ | Rated and measured efficiency of pump-motor device |
| $R$ | Coil winding of motor, Ω | | |

is shown in Tab.2.Pumps are in regular service with manual start-stop control in chillers' stoppage period. Schematic diagram of air-conditioning water system are shown in Fig.1.

## 3. TEST SCHEME AND METHOD

Test parameters consist of temperature, power, pressure and flow; test objects consist of chillers, cooling pumps, chilled pumps, motors and outdoor condition. Test parameters under each object are shown in Tab.3 with corresponding test method. Measuring point layout is shown in Fig.1.

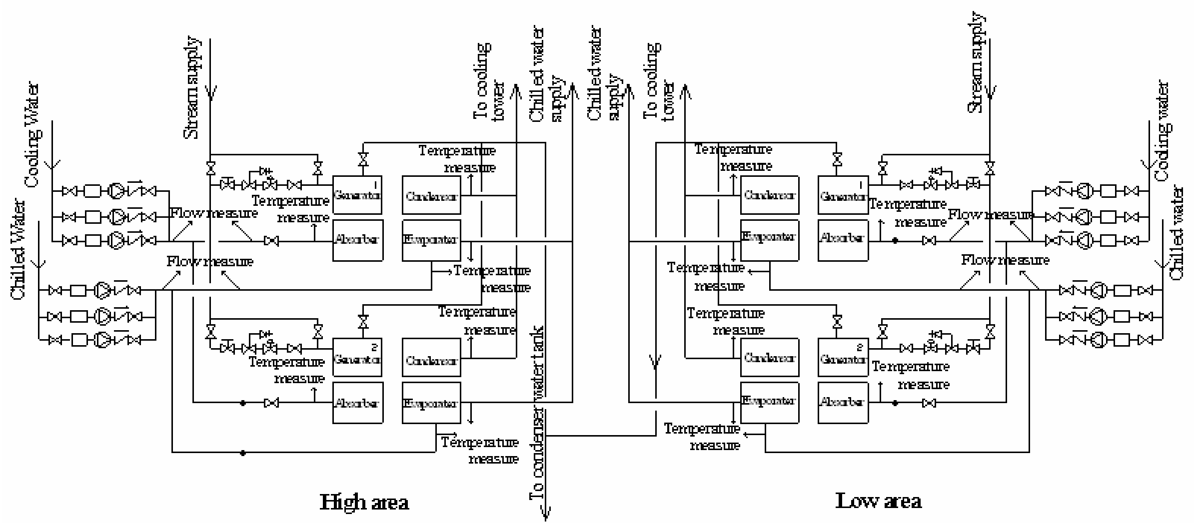



**Fig.1 Schematic diagram of air-conditioning water system**

Considering test concurrence, high efficiency and rational personal placement, three groups are categorized which is in charge of flow test, temperature test and power and pressure test respectively. Detailed work distribution chart is shown in Tab.4. Testing period is from August 2th to

8th, 2005.

**Tab.1 Rating parameter of chilled unit**

| Parameter | $Q_e$ | $t_{ein}/t_{eout}$ | $V_e$ | $t_{cin}/t_{cout}$ | $V_c$ |
|---|---|---|---|---|---|
| Low zone | 1336 | 7/12 | 230 | 32/37.6 | 380 |
| High zone | 704 | 7/12 | 121 | 32/37.6 | 200 |

**Tab.2 Rating parameter of pump**

| Parameter | | $V$ | $H$ | $n$ | $I$ | $\eta$ | $N$ |
|---|---|---|---|---|---|---|---|
| Low zone | Chilled pump | 374 | 28 | 1480 | 84.2 | 70 | 45 |
| | Cooling pump | 346 | 38 | 1480 | 103 | 70 | 55 |
| High zone | Chilled pump | 160 | 32 | 1450 | 56.8 | 78 | 22 |
| | Cooling pump | 200 | 32 | 1450 | 102 | 78 | 30 |

**Tab.3 Test parameter and method**

| Device | Parameter | Method |
|---|---|---|
| Chiller | $t_{ein}'/t_{eout}'$ <br> $t_{cin}'/t_{cout}'$ | Glass thermometer <br> Chiller meter |
| | $t_{sc}'$ | Chiller meter |
| | $t_r$ | Chiller meter |
| | Valve opening | Chiller meter |
| Pump | $p_{ein}'/p_{eout}'$ <br> $p_{cin}'/p_{cout}'$ | Manometer |
| | $V_c'$, $V_e'$ | Supersonic flowmeter |
| Motor | $N_m'$ | Multi-parameter power meter |
| Outdoor condition | $t_o$ | Temperature recorder |

**Tab.4 Work distribution chart**

| Number | Test work |
|---|---|
| Group 1 | $V_c'$, $V_e'$ |
| Group 2 | $p_{ein}'$, $p_{eout}'$, $p_{cin}'$, $p_{cout}'$, $N_m'$ |
| Group 3 | Chiller meter parameters, $t_{ein}'$, $t_{eout}'$, $t_{cin}'$, $t_{cout}'$, $t_o$ |

Note: Test frequency is 2 times per day, reading of $t_{ein}'$, $t_{eout}'$, $t_{cin}'$, $t_{cout}'$ are from glass thermometer

## 4. ESTIMATION INDEX OF DEVICE PERFORMANCE

4.1 Chiller

(1) Refrigerating output：Estimation index of refrigerating ability of chiller its expression is shown in Eq.1

$$Q_e'=\rho V_e' c(t_{ein}'- t_{eout}')/3600 \qquad (1)$$

(2) Condenser heat can be expressed as Eq.2

$$Q_c'=\rho V_c' c(t_{cout}'- t_{cin}')/3600 \qquad (2)$$

(3) Stream heating load：Estimation index of energy consumption of chiller，which can be expressed as Eq.3

$$Q_s'=k(Q_c'-Q_e') \qquad (3)$$

Where $k$ refers to efficiency coefficient, $k$=1.1

(4) Coefficient of performance: Estimation index of working efficiency of chiller，which can be expressed as Eq.4

$$\mathrm{COP}'=Q_e'/Q_s' \qquad (4)$$

(5) Cooling load ratio：Ratio of actual refrigerating output to rated value, Estimation index of working condition of chiller, which can be expressed as Eq.5

$$E=Q_e'/Q_e \qquad (5)$$

4.2 Pump

(1) Rated useful power：Effective capacity of pump under rated condition, which can be expressed as Eq.6

$$N_e=\rho gHV/3600 \qquad (6)$$

(2) Rated useful power：Effective capacity of pump under actual measurement condition，which can be expressed as Eq.7

$$N_e'=\rho gH'V'/3600 \qquad (7)$$

(3) Power ratio：Ratio of pump working power to rated value, evaluating indicator of working condition of pump, which can be expressed as Eq.8

$$R_p=N_e'/N_e \qquad (8)$$

4.3 Motor

(1) Rated input power： input power of motor under rated current flow, which can be expressed as Eq.9

$$N_m=I^2R \qquad (9)$$

(2) Power ratio：ratio of motor working power to rated value, evaluating indicator of working condition of motor, which can be expressed as Eq.10

$$R_m=N_m'/N_m \qquad (10)$$

4.4 Pump-motor combination unit

(1) Rated efficiency: ratio of rated pump output power to rated motor input power, which can be expressed as Eq.11

$$\eta_{total}=N_e/N_m \qquad (11)$$

(2) Measured efficiency: ratio of measured pump useful power to measured motor input power, which can be expressed as Eq.12

$$\eta_{total}'=N_e'/N_m' \qquad (12)$$

(3) Efficiency ratio: ratio of measured efficiency to rated value, evaluating indicator of working condition of pump-motor device, which can be expressed as Eq.13

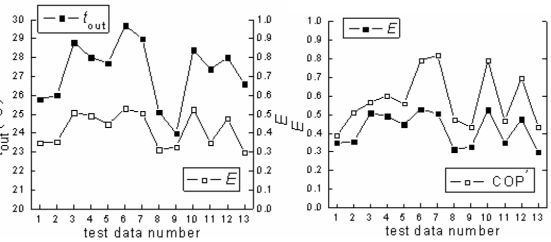
$$ER=\eta_{total}'/\eta_{total} \qquad (13)$$

## 5. RESULT ANALYSIS

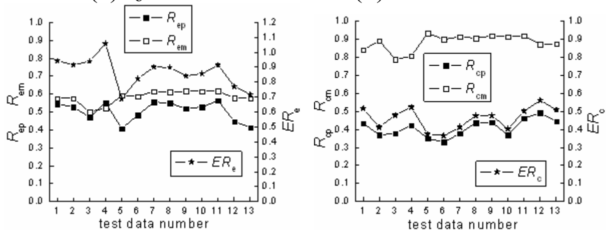
Under working condition, alteration of outdoor meteorologic condition leads to a variable cooling load ratio which is the essential reason affecting running condition of each device. Therefore, writer converts test data to tendency chart between cooling load ratio and device performance parameters for a clear display of device working condition.

Test results of low zone are shown in Fig.2. As Fig.2(a) shown, the variational tendency of $E$ agrees with that of $t_o$, in the test period, maximum of $E$ is 0.53 which leads a low COP shown in Fig.2(b), for example, the first test data shows a 0.34 $E$ brings a lowest COP',0.97. As Fig.2(c) shown, the variational range of $R_{ep}$ is from 0.4 to 0.57 while $H'$ is only about half of $H$, the abnormal working condition of pump directly affects that of motor. Comparing to $R_p$, $R_m$ has a stable range from 0.5 to 0.6. The fluctuation of $R_{ep}$ dominates variational tendency of $ER_e$ which has a range from 0.71 to 1.05, the approach degree between $R_{ep}$ and $R_{em}$ is main factor affecting $ER_e$ which also reflects in the operation curve of cooling pump in low zone as shown in Fig.2(d), the wider deviation between $R_{cm}$ and $R_{cp}$ ($R_{cm}$ fluctuates from 0.8 to 0.94 while $R_{cp}$ is around 0.4) leads a low $ER_c$. The variational tendency of $ER$ mostly agrees with that of $R_p$ through the test data analysis.

Test results of high zone are shown in Fig.3. As Fig.3(a) shown, due to mostly office use in high zone, randomness of conference time and personnel load leads a wider fluctuation of $E$ from 0.25 to 0.68 while its whole variational tendency consists with $t_o$. As a result, high zone COP' varies with low-value minimum and severe fluctuation. As shown in Fig.3(c), $R_{ep}$ varies from 0.35 to 0.57 while motor works around rated point with a better stability. Led by master effect of $R_{ep}$, $ER_e$ has a wider fluctuation and working condition of device is instable. As shown in Fig.3(d), $ER_c$ is bigger due to a closer approach degree between $R_{cp}$ and $R_{cm}$. Although the stable change of $R_{cm}$ counteracts the fluctuation of $R_{cp}$ to a certain extent, $ER_c$ keeps a wider range from 0.77 to 1.02 which is mainly caused by the fluctuation of $E$.

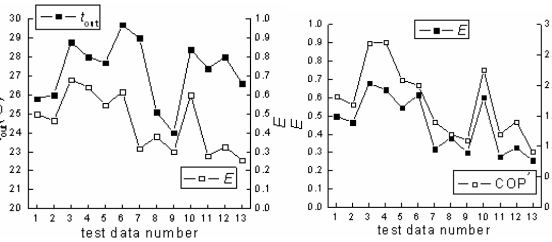



(a) $t_o$ vs $E$ (b) COP vs $E$

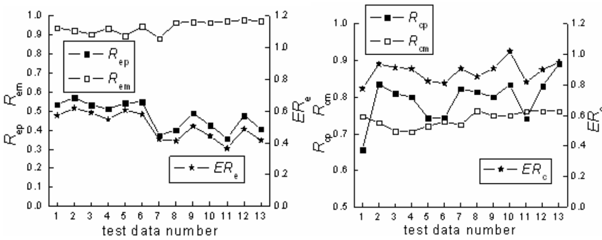



(c) Chilled pump (d) Cooling pump

**Fig.2 Test result of low zone**




(a) $t_o$ vs $E$ (b) COP vs $E$




(c) Chilled pump (d) Cooling pump

**Fig.3 Test result of high zone**

## 6. DISCUSSION

(1) Test period is in peak time of annual cooling load; however, $E$ keeps a low value. Due to the building function (mostly hotel house), leak value of $E$ probably appears in night time. Due to the limitation of test time, though test data can't generally present operation condition of chillers in low zone, disadvantageous effect of part-load chiller operation to COP' is reflected obviously. Further operation deterioration is led by low temperature difference between supply and return water (3-4℃, lower than rated 5℃).

Peak value of $E$ in high zone appears in higher to or high frequency period of conference use ratio, test data present a huge fluctuation of $E$ with a 0.68 maximum which indicates capacity excess of chillers exist in high zone.

(2) Multiple operation of two chillers (one is on, another is off) is irrational. Firstly, chilled water flow through by-pass chiller which is shut down leads a higher $t_{eout}$' (maximum reaches 12℃); secondly, resistance difference between working chiller pipe and off-stream chiller pipe leads unbalanced flow distribution in parallel pipe with unbalanced ratio from 10% to 30% which increases by-pass flow supply of chilled pump and energy consumption.

(3) Generally, $R_p$ is low and there are definite differences between actual condition and rated one. Test data shows excess capacity of chosen pump exist which is a ubiquitous problem in existent water system.

(4) Comparing to the fluctuation of $R_p$ with $E$, $R_m$ keeps a stable range, cooling pump motor of low zone and chilled pump motor of high zone works near rated point. Test data show rational match of pump and motor is the critical aspect improving $ER$. As mentioned above, the approach degree between $R_{ep}$ and $R_{em}$ is main factor affecting $ER_e$. Cooling pump of low zone is taken for example, though its stable and near-rating working condition of motor, $ER$ is low due to the great disparity between $R_p$ and $R_m$. Therefore, synthetical analysis to test data of motor and pump is needed in whole device operating condition assessment and good working order of any single unit can't indicate a high $ER$.

## 7. SUMMARY AND CONCLUSIONS

This paper conducts an actual measurement to air-conditioning water system of a hotel building in summer condition and presents evaluating indicator of critical device. Based on test data, existent problems of water system are found and analyzed. Results show that

(1) Variation of $E$ impact a lot with operating condition of water system, building function and autologous characteristic of cooling load are important factor affecting $E$.

(2) Irrational operating mode of chillers mainly leads low COP', test data present poor chiller performance in part-load condition. For the building investigated, operating mode modification is the general planning to improve chiller performance, rational flow adjustment based on variation of $E$ is ultimate scheme for COP' improvement.

(3) Low $R_p$ is the major factor affecting $ER$. In addition, rational match of pump and motor is another effective way for $ER$ improvement. For pumps measured in this paper, frequency-transformer addition or matched motor substitute is feasible program.

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