

Field Measurement of Heating System in a Hotel Building in Harbin¹

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Abstract: Heating energy consumption in winter is an important component of the whole building energy consumption in the severe cold zone in north China. This paper presents a heating water system of a hotel building in Harbin, finishes the testing of its heating energy consumption in winter under operational conditions, and presents an estimation index of the performance of an exchanger, pump and motor. Analysis of device running conditions based on testing data is conducted. Results show that low stream supply temperature and wide-range flow fluctuation mainly lead to unhealthy working conditions of the device and excessive energy consumption, and a corresponding improved method is presented.

Key words: hotel building; heating water system; heating energy consumption; efficiency; measure

1. INTRODUCTION

Winter heating consumption is the main part in building energy consumption [1-4], Fig.1 presents variable status of gas and power consumption of a building in Harbin from May 2005 to Feb 2006 which shows a huge proportion of winter heating consumption (presented by gas consumption) in whole building energy consumption.

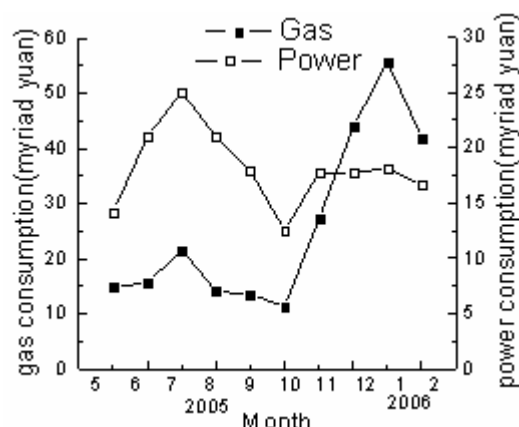


Fig.1 Energy consumption in Huayi building

Heating water system is in charge of heat medium transportation; its running condition not only affects working performance of whole heating system, but also is the key effect on heating consumption. However, in actual systems, miscellaneous problems

as irrationality system form, low equipment efficiency and incorrect management leads an excessive energy waste of winter heating energy consumption.

Therefore, an actual measurement to a heating&air-conditioning (H&AC) water system of one public building in Harbin is conducted, based on analysis of test data, evaluation of system energy consumption and running condition is presented and corresponding improved method is suggested.

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 42500 m² including 12000m² 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. H&ac system is designed according to function subarea with full water system form. Heat source is equipped with steam boiler taking charge of heating and hot water supply load; two boilers with 4T/h capacity are in operation during testing period. Heating device is equipped with combined exchanger consists of plate heat exchanger and shell-tube exchanger (shown in Fig.2), the nameplate capacity is shown in Tab.1. Each exchanger is equipped with one circulatory pump whose nameplate capacity is shown in Tab.2. The exchangers serving for low zone located at 2th underground including two for heating use which are shut down and three for fan coil medium supply with one is in operation due to the relative warm weather. Vapor supply period for exchanger is from 6: 00 to 9: 00, 11: 00 to 13: 00, 18: 00 to 24: 00. Two exchangers serving for high zone located at 15th floor with one is in operation during testing period

¹ Supported by National Natural Science Foundation of China (50578049)

Nomenclature			
A	Design exchanger area, m^2	R	Coil winding of motor, Ω
c	Specific heat of water, $J/kg^\circ C$	R_p, R_m	Power ratio of pump and motor
ER	Efficiency ratio of pump-motor device	t_d	Design temperature of exchanger
h_o	Outdoor relative humidity, %	t_o	Outdoor temperature, $^\circ C$
H, H'	Rated and measured head of pump, mH_2O	Δt	Design temperature difference of exchanger, $^\circ C$
I	Rated current of motor, A	T	Measured point temperature of exchanger, $^\circ C$
n	Rated rotational speed of motor, r/min	V, V'	Rated and measured flow of pump, m^3/h
N	Rated shaft power of motor, kW	V_c	Condensate flow of exchanger, m^3/h
N_e, N_e'	Rated and measured useful power of pump, kW	ρ	Water density, kg/m^3
N_m, N_m'	Rated and measured input power of motor, kW	η	Rated efficiency of pump
P_d	Design pressure of exchanger, MPa	η_e	Heat transfer efficiency of exchanger
p_{in}, p_{out}	Measured inlet and outlet pressure of pump, Pa	η_p	Heat transfer efficiency of plate heat exchanger
$\square P$	Design pressure loss of exchanger, mH_2O	η_s	Heat transfer efficiency of shell and tube exchanger
Q	Heating load between measured points of exchanger, kW	$\eta_{total}, \eta'_{total}$	Rated and measured efficiency of pump-motor device

which is from 6: 00 to 9: 00, 14: 00 to 16: 00. Living hot water supply devices are equipped with heat accumulating exchangers including one located at 2th underground serving for natatorium, kitchen and staff living room with whole day operation, one located at 6th floor serving for guest room with whole day operation, one located at 15th floor serving for office room with periodic operation. System terminals are equipped with fan coil and radiator with fan coil distributing in function area and guest rooms in low zone and radiator distributing in office rooms in high zone. All condensation water afflux in the condensate tank located at 2th underground. A simplified schematic of water system is shown in Fig.3.

pressure and flow; test objects consist of exchangers, cooling pumps, chilled pumps, motors and outdoor condition. Test parameters under each object are shown in Tab.3 with corresponding test method.



Fig.2 Photo of combined exchanger and equipped pump

3. TEST SCHEME AND METHOD

Test parameters consist of temperature, power,

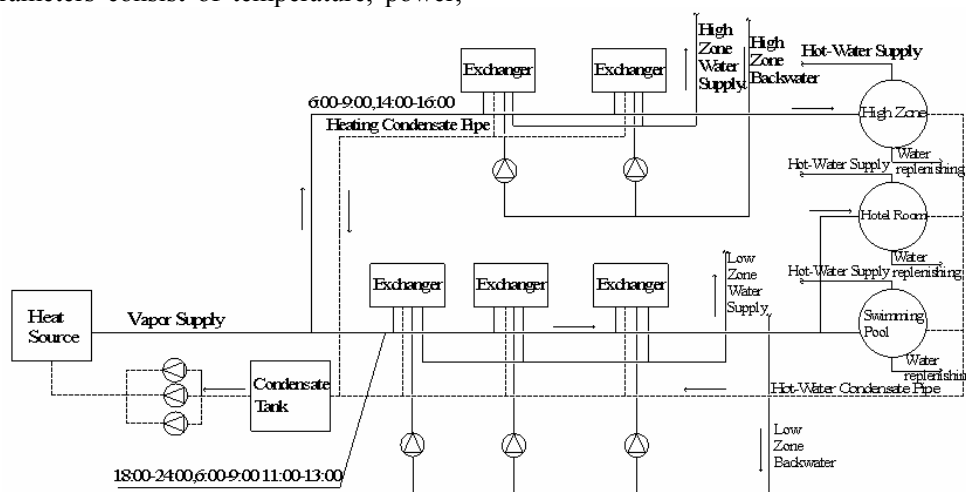


Fig.3 Schematic diagram of water system

Tab.1 Rating parameter of combined exchanger

Model number	P_d	t_d	$\square P$	$\square t$	A	
SWJ03 16 150	35	1.6	150	10	10	35

Tab.2 Rating parameter of circulatory pump

Model number	V	H	n	I	η	N
100DLR100-20	100	40	1450	35.9	72	18.5

Seven temperature test points are chosen at each exchanger for accurate measurement, test point layout are shown in Fig.4 while corresponding description is shown in Tab.4. Considering radiation effect on return water pipe of exchangers, point T1 located at pump inlet ahead is chosen, point T3 located at exchanger outlet is also chosen for convenient heating analysis. As shown in Fig.4, glass tubing thermometers are installed at T1 and T4 associated with infrared thermometer which test for pipe wall temperature. In the test using infrared thermometer, four test points are chosen around pipes and mean numerical readings is adopted for getting rid of radiation effect.

System condensate mainly consists of heating condensate and living hot water supply condensate; flow test points located are chosen at the two main pipe lines for flow measurement. Compared with circulating flow test, instability of condensate flow pattern brings great difficulties in condensate flow test. In the test, single range of supersonic flowmeter is from 20% to 40% which is an unacceptable numerical reading. Therefore, another test method by means of recording water height is adopted with a 1:1 distribution of heating condensate flow and living hot water supply condensate.

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.5. Testing period is from Feb 28th to Mar 2th.,2006.

4. ESTIMATION INDEX OF DEVICE PERFORMANCE

4.1 Exchanger

- (1) Heat transfer efficiency of exchanger

$$\eta_p = Q_{32} / Q_{67} \tag{1}$$

- (2) Heat transfer efficiency of shell and tube exchanger

$$\eta_s = Q_{43} / Q_{56} \tag{2}$$

- (3) Heat transfer efficiency of exchanger

$$\eta_e = Q_{41} / Q_{57} \tag{3}$$

Where, the number subscripts refer to heat flow between two corresponding test points with subsequence submitting to temperature.

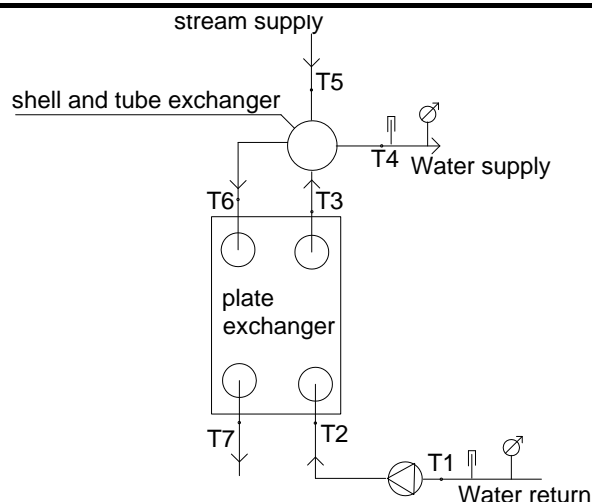


Fig.4 Temperature test point layout

Tab.3 Test parameter and method

Device	Parameter	Method
Combined exchanger	T_1, T_4	Glass thermometer
	T_2, T_3, T_5, T_6, T_7	Infrared thermometer
	V_c	Supersonic flowmeter
Pump	p_{in}, p_{out}	Manometer
	V'	Supersonic flowmeter
Motor	N_m'	Multi-parameter power meter
Outdoor condition	t_o, h_o	Temperature and humidity recorder

Tab.4 Temperature test point description

Point	Description
T1	Inlet of hot water pump
T2	Inlet of backwater pipe of plate exchanger
T3	Outlet of supply water pipe of plate exchanger
T4	Outlet of supply water pipe of shell and tube exchanger
T5	Inlet of stream supply pipe
T6	Inlet of condensate water pipe of plate exchanger
T7	Inlet of condensate water pipe of plate exchanger

Tab.5 Work distribution chart

Number	Test work
Group 1	V_c, V'
Group 2	p_{in}, p_{out}, N_m'
Group 3	$T_1, T_2, T_3, T_4, T_5, T_6, T_7, t_o, h_o$

Note: Test frequency is 2 times per day

4.2 Pump

- (1) Rated useful power: Effective capacity of pump under rated condition

$$N_e = \rho g H V / 3600 \tag{4}$$

- (2) Rated useful power: Effective capacity of pump under actual measurement condition

$$N_e' = \rho g H' V' / 3600 \tag{5}$$

- (3) Power ratio: Ratio of pump working power to rated value, evaluating indicator of working condition of pump

$$R_p = N_e' / N_e \tag{6}$$

4.3 Motor

(1) Rated input power: Input power of motor under rated current flow

$$N_m = I^2 R \quad (7)$$

(2) Power ratio: Ratio of motor working power to rated value, evaluating indicator of working condition of motor

$$R_m = N_m' / N_m \quad (8)$$

4.4 Pump-motor Combination Unit

(1) Rated efficiency: Ratio of rated pump output power to rated motor input power

$$\eta_{total} = N_e / N_m \quad (9)$$

(2) Measured efficiency: Ratio of measured pump useful power to measured motor input power

$$\eta_{total}' = N_e' / N_m' \quad (10)$$

(3) Efficiency ratio: Ratio of measured efficiency to rated value, evaluating indicator of working condition of pump-motor device

$$ER = \eta_{total}' / \eta_{total} \quad (11)$$

5. RESULT ANALYSIS

5.1 Outdoor Parameters

Variation of outdoor temperature and relative humidity during test period is shown in Fig5 which displays that lowest outdoor temperature present around 6 o'clock while highest value present around 15 o'clock and outdoor relative humidity varied with reverse trend.

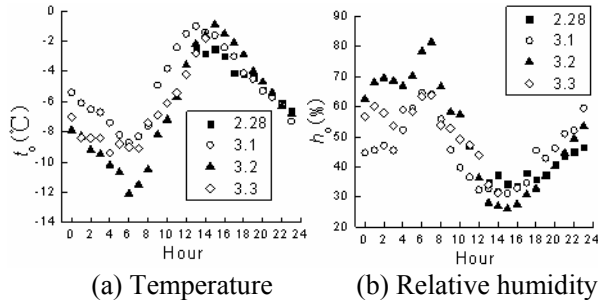


Fig.5 Variation of outdoor temperature and relative humidity

5.2 Exchanger

Numerical reading of infrared thermometer is consistent with that of glass thermometer which shows rationality of temperature test scheme using infrared thermometer. Due to the low precision of glass thermometer installed on the pipes, test data read from infrared thermometer is chosen as test result in this paper.

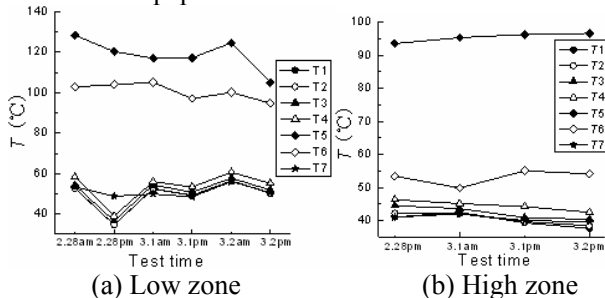


Fig.6 Variation of test point temperature of exchanger

Fig.6 presents variation of test point temperature

of exchanger. It is shown that exchanger in low zone have unstable temperature change at each test point compared with that in high zone while the temperature fluctuation of water side (T_1-T_4) is wider ($39^\circ\text{C}-60^\circ\text{C}$) than that of stream condensate side (T_5-T_7) with same variable trend which is related with heating load fluctuation caused by building function in low zone.

As the key parameters affecting exchanger efficiency, temperature difference (Fig.7) $\{T_{14}(T_1-T_4), T_{57}(T_5-T_7)\}$ present heat transfer condition of exchanger in whole. As shown in Fig.7, there are smaller fluctuation of T_{14} in high zone and low zone with majority deviating rated value while T_{57} in low zone is distinctly higher than that in high zone which is related with a higher stream supply temperature T_5 in low zone. Exchanger efficient is calculated in terms of flow measurement (using water height test method) which is shown in Fig.8.

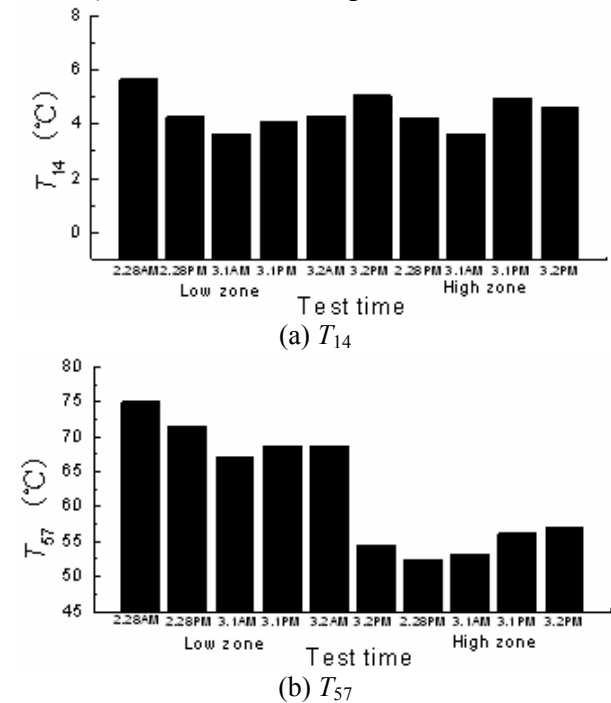


Fig.7 Variation of temperature difference

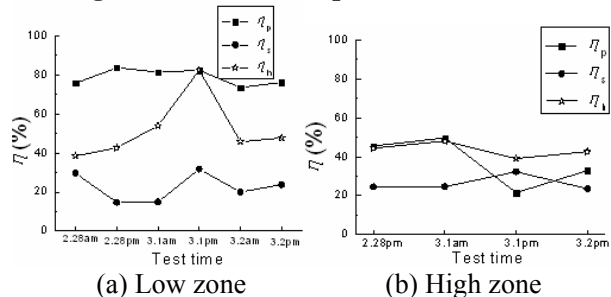


Fig.8 Calculating result of exchanger efficient

As Fig.8 shown, fluctuation of η_e in low zone has a wider range (38%-82%) than that in high zone which is related with the instability of circulatory flow. In the meantime, η_p holds a distinctly high value compared with η_s , although the fluctuation of T_5 affects the variation of η_s in certain degree, the instability of circulatory flow is considered to be the

key factor. η_h in high zone has a lower value and smaller range (39%-48%) compared with that in low zone due to the low measured circulatory flow which is presented well at 3.1PM test point, the steep dropping of η_p is directly related with flow variation and reduction of η_s is stopped (even leads a rising η_s) by rising T_{43} (T_4-T_3) caused by reducing flow.

5.3 Pump and Motor

Test results are shown in Fig.9; R_p commonly has low value under 0.6 while R_p in high zone has a bigger deviation range to rated condition. Measured data show that running head of pump is near rated value and flow variation (flow in high zone is only half of that in low zone) is the main factor affecting R_p . Comparing to pump, motor is in stable working condition which is presented as near rated point running condition of motor in low zone and overload condition of motor in high zone. The irrational match of pump and motor (severe condition in high zone) mostly leads to a low ER .

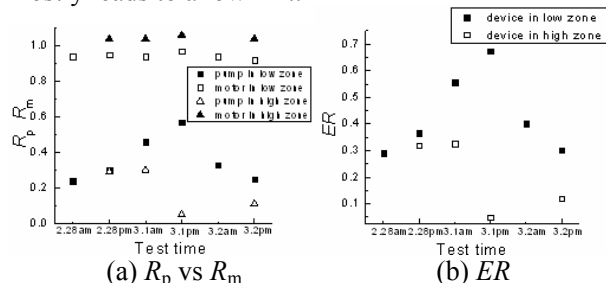


Fig.9 Test result of pump-motor combined device

6. DISCUSSION

(1) Low efficiency of exchanger is mainly caused by irrational match of shell and tube exchanger and plate exchanger. In Fig.9, η_p is distinctly higher than η_s which is led by the mismatch of condensate flow and circulatory flow (1:50), heat transfer condition is deteriorated by excessive hot water velocity comparing to stream velocity. In the test, due to the large varied range of living hot water supply condensate, there is an uncertainty of the condensate distribution. Therefore, how to allocate the two parts of condensate in order to obtain an accurate heating condensate data is a subject to be concerned.

(2) Comparatively, the working condition of exchanger in low zone is better than that in high zone which is mostly presented by the difference of η_p (40%-75%). Low measured stream supply temperature (12°C lower than that in low zone) caused by throttling loss in direct stream deliver process is the ultimate factor affecting heating transfer effect. On the other hand, most heating terminal is radiator in high zone, low supply water temperature (10°C lower than that in low zone) led by low stream supply temperature deteriorate indoor heating transfer condition greatly. Likewise, some occupiers in high zone complain about the indoor thermal environment during the test period.

Increasing stream supply temperature by means of several ways that could reduce the throttling loss, such as stream supply form modification is considered to be the critical way to improving efficiency of exchangers in high zone.

(3) Test data presents pump capacity is oversized and flow fluctuation not only induce low pump efficiency, but also lead to instability performance of exchangers (Fig.8, Fig.9).

(4) The approach degree between R_p and R_m is main factor affecting ER . Pump in 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 heating water system of a hotel building in winter 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) Irrational match of shell and tube exchanger and plate exchanger is critical factor which leads a low efficiency of combined exchanger. For exchangers measured in this paper, more shell and tube exchangers which are added to increase the ratio of condensate flow and circulatory flow. The adverse effect of low stream supply temperature on exchanger efficiency is presented by performance comparison between exchanger in low zone and high zone.

(2) For measured pump in this paper, low R_p which is led by distinct flow deviation to rated value is the main factor affecting ER . In the meantime, variation of exchanger efficiency is caused by wide-range flow fluctuation. Frequency-transformer addition or matched motor substitute is feasible program to obtain a higher pump efficiency and more stable working performance of exchangers.

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