CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 9

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Factor Analysis on Variable-flow Reconstruction of Chilled Water System

Yong Ding#1, Hao Tang#2, Xue Liu#3

#Joint International Research Laboratory of Green Building and Built Environment, Ministry of Education, Chongqing University
No.174, Shapingba Street, Chongqing, China

[1]dingyongqq@126.com

[2]1157663718@qq.com

[3]cheerps12@126.com

Abstract

By comparison testing, this paper obtained the energy-saving rate of 12 buildings which had been reconstructed for energy saving purpose in Chongqing, China. The result showed that energy-saving rate was significantly associated with building type. Hospital building and hotel building made best use of reconstruction in four kinds of buildings, 43.92% and 34.5% respectively. That reflected how building running time and load rate effected on energy conservation in chilled water system, they determined the energy-saving potential directly. Further analysis revealed that energy-saving rate has negative correlations with air-conditioning area and annual water pump energy consumption. It was caused by pipe network resistance and the control strategy using fixed pressure differential set-point together. Besides, pump efficiency under part load, characteristic of pipeline network and other factors hard to quantify limited energy conservation too. Take a building in testing as example, in typical air-conditioning period, calculations show that energy-saving potential of chilled water system is 46.8%, the loss caused by control strategy using fixed pressure differential is 12.9%, the loss caused by pump efficiency is 5.8%, the loss caused by factors which are hard to quantify is 4.1%, actual energy-saving rate is 24%.

Keywords – chilled water system; variable-flow reconstruction; energy-saving efficiency; factor analysis; pre-evaluation

1. Introduction

Refer to 2014 Annual Report on China Building Energy Efficiency, energy consumption of public building accounted for 26.4% of entire building energy consumption in 2012 in China, and the per building area energy consumption of public buildings which are over 20,000 square meters and using central air condition system is 2-3 times of ordinary public buildings [1]. Large public building using central air condition system had been a main target in existing building energy-saving reconstruction. In 2012, Chongqing was officially announced as a model city of energy-saving reconstruction on existing public building by Ministry of Housing and Urban-Rural Development of China. In subsequent three years, 4,000,000 square meters of existing public building was reconstructed for energy saving purpose in Chongqing.

A core content of energy-saving reconstruction is changing constant flow primary pump system into variable flow primary pump system. At this stage, constant flow primary pump system is still applied in many public building constructed at the beginning of present century in China [1]. This system was accused of wasting energy because pumps always run at nearly full capacity and large amounts of energy are expended in regulating valves. In energy-saving reconstruction, with the application of variable-frequency technology, constant flow primary pump system was transformed into variable frequency primary pump system. In the variable flow system, chilled water flow can be adapted to real-time air condition load, as shown in Fig. 1.

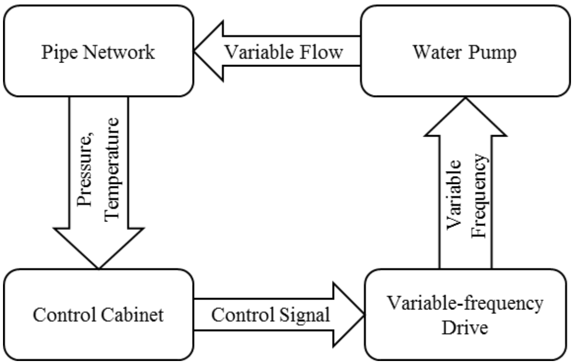

Fig. 1 Schematic diagram of variable flow system

At present, the most general way to evaluate energy-saving efficiency of variable-flow reconstruction is testing. But as a post-evaluation, testing cannot predict possible energy-saving efficiency before reconstruction, which is not helpful in reducing risks. To propose a pre-evaluation of variable-flow reconstruction on chilled water system, this paper analyzed factors effecting on energy-saving efficiency based on the comparison testing of 12 buildings in Chongqing. And a building in testing was taken as an example to show how this pre-evaluation was applied.

2. Methodology

From July 2015 to August 2015, typical air condition season in Chongqing, a series of comparison testing aimed at efficiency of variable-flow reconstruction was carried out on 12 buildings which had been reconstructed on chilled water system. In testing, the chilled water system of each building worked at fixed frequency and variable frequency for 3 work days with similar weather condition separately, recorded daily energy consumption of chilled water system. Calculate the energy-saving rate by (1).

$$\alpha = (\alpha_1 - \alpha_2) \div \alpha_1 \quad (1)$$

In (1), α is the energy-saving rate, α_1 is the sum of energy consumption at fixed frequency, α_2 is the sum of energy consumption at variable frequency.

Before reconstruction, constant flow primary pump system was used in the 12 buildings; after reconstruction, they were transformed into variable flow primary system with fixed pressure differential set-point strategy. The result of testing and more building information are shown in Table 1.

Table 1. Energy-saving rate and building information

Number	Type of building	Energy-saving rate (%)	Air-conditioning area (m^2)	Annual energy consumption before reconstruction (kWh)
1	Hotel	36.00	41322	270810
2	Hospital	34.00	56090	338400
3	Hospital	49.60	21118	271920
4	Office building	33.21	46668	127060
5	Hospital	50.02	29462	240000
6	Department Store	33.00	21074	253748
7	Hospital	42.00	31500	323136
8	Hospital	44.00	39460	304150
9	Department Store	29.00	43734	436760
10	Office building	32.00	31421	978150
11	Hotel	33.00	45680	301245
12	Department Store	24.00	70000	632948

3. Discussion

3.1. Correlation with building type

To explore the correlation between building type and energy-saving efficiency, the result in Table 1 was classified by building type and average energy-saving rate of four building types was calculated, as shown in Table 2.

Table 2. Average energy saving-rate of four building types

Number	Type of building	Sample counts	Average energy-saving rate (%)
1	Hotel	2	34.5
2	Hospital	5	43.92
3	Office building	2	32.61
4	Department Store	3	28.67

Table 2 shows that hospital building has the best energy-saving efficiency in four kinds of buildings, the hotel building comes second. Different buildings vary at many aspects such as building design, building running time, load, environment, etc. But for air condition system, building running time and load rate are directly correlated. Building running time only affects the amount of energy saving if other factors are constant, but with the changes in load rate of air condition, it has a significant influence on energy-saving rate.

For hospital building, its air condition system runs 24 hours at work days in typical air-conditioning period, on the other hand, load of air condition system in night is only about half of load in day refer to operating records, and the same for hotel building. Apparently, the building with considerable load fluctuations and long running time especially for whose air condition system working around-all-clock, has a considerable energy-saving potential.

Take No.12 building in testing as an example, normalize real-time air condition load of each time in the testing day with design cooling load as 100%, as shown in Fig. 2.

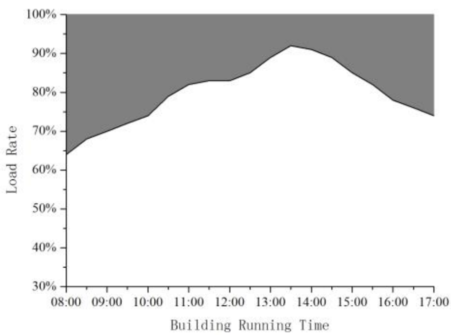

Fig. 2 Air condition load rate of each time

The shadowy part in Fig. 2 is formed by 100% load rate line and actual load rate curve, represents energy-saving potential of chilled water system in this building.

The average load rate in a certain period was defined as average load rate β_a , as shown in (2).

$$\beta_a = \frac{\int \beta dt}{t}. \quad (2)$$

In (2), β is hourly load rate of air condition system, t is building running time.

On principle of the law of energy conversation, load rate of air condition system equals to real-time water flow ratio. As a closed system, chilled water pipe network meets the similarity law of pumps. The real-time input power ratio equals to the third power of real-time water flow ratio. The mathematical relationship between the ideal energy-saving rate α and average load rate β_a is shown in (3).

$$\alpha = 1 - \beta_a^3. \quad (3)$$

According to (2) and (3), the average load rate and the ideal energy-saving rate of No.12 building is 81% and 46.8% while measured energy-saving rate is 24%, only account for 51% of the ideal energy-saving rate. Although building running time and load rate determined the energy-saving potentials, some other factors weakened energy-saving efficiency during system operation.

3.2 Correlation with control strategy

All of 12 buildings in testing apply the control strategy using fixed pressure differential set-point. Under this control strategy, a fixed pressure differential is set for ensuring that terminal devices will get enough chilled water flow. In practice project, the general approach is to set a minimum frequency point on water pump. The minimum frequency set-point is determined by the resistance of pipe network. The building with bigger air-conditioning area and more amount of energy consumption on water pumps has higher pipe network resistance, and it also means higher pressure differential set-point and minimum frequency set-point on water pumps.

To avoid effects of the building type, selected five hospital buildings in testing to explore the correlations between energy-saving rate and air-conditioning area, energy-saving rate and energy consumption of chilled water pumps before reconstruction, as shown in Fig. 3 and Fig. 4, respectively.

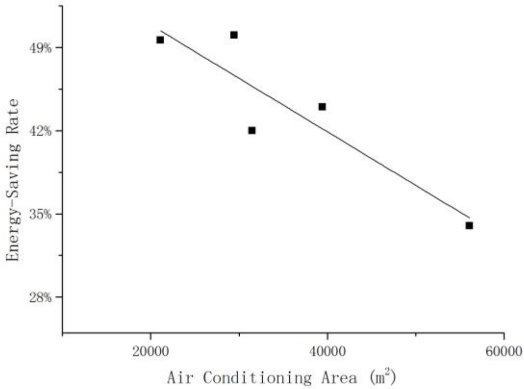

Fig. 3 Correlation between energy-saving rate and air-conditioning area

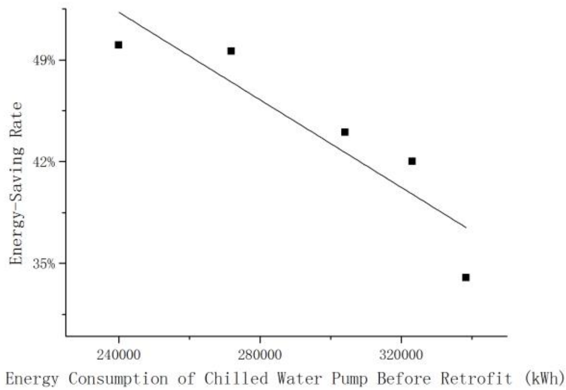

Fig. 4 Correlation between energy-saving rate and energy consumption of chilled water pumps before reconstruction

Due to fewer sample counts, the regression line in Fig. 3 and Fig. 4 cannot reflect the function relation accurately, but it still can tell a general trend. The trend verified that under control strategy using fixed pressure differential set-point, energy efficiency is negative correlate with air-conditioning area and energy consumption of water pumps. A relatively accurate function relationship could be obtained with more testing.

If the resistance of pipe network can be estimated, it is feasible to do a quantitative analysis of energy-saving rate loss caused by the control strategy using fixed pressure differential set-point. For No.12 building, in practice project, the minimum frequency of chilled water pumps was set on 43 Hertz while rated frequency was 50 Hertz. On principle of the similarity law of pumps, frequency ratio equals to chilled water flow ratio, so the minimum chilled water flow ratio is 0.86. On principle of the energy conservation law, load rate of air condition system equals to chilled water flow ratio, so the minimum load rate can be adjusted is 0.86. The energy-saving potential taking adjustment ability into account is shown in Fig. 5.

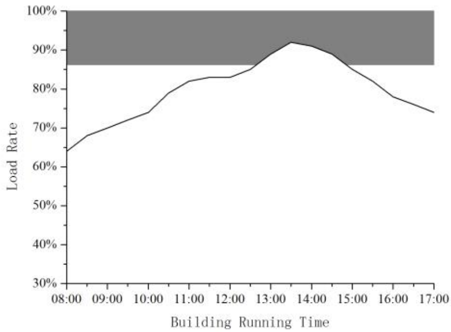

Fig. 5 Energy-saving potential taking adjustment ability into account

The shadowy part in Fig.5 is formed by 100% line, 86% line and actual load rate curve, represents energy-saving potential taking adjustment ability into account.

Calculate by (2) and (3), after taking adjustment ability into account, the average load rate and ideal energy-saving rate changed to 87.1% and 33.9%. Due to the control strategy using fixed pressure differential set-point, energy-saving rate reduced from 46.8% to 33.9%. This analysis is only for typical air-conditioning period, but for transition season, actual load rate of air condition system is lower than minimum adjustable rate at most time, the energy-saving loss caused by the control strategy using fixed pressure differential set-point will be more serious. In fact, considering that selection of chilled water pumps subjects to the most disadvantage load, the control strategy using fixed pressure differential set-point has a significant negative influence on energy-saving effect for the full year.

A research showed that compared to the control strategy using fixed pressure differential set-point, the control strategy using variable pressure differential set-point and optimal pump sequence control saved about 10-30% of the energy consumption in complex air condition system [2].

3.3 Correlation with water pump efficiency

Obviously, the reduction of water pump efficiency in part load weakens energy-saving effect directly. There are many studies on water pump pointing out that comprehensive efficiency will sharply decrease when water flow through pumps less than half of rated flow, accompanied by violent shake [3-6]. Even pumps work under the condition with above half of rated water flow, efficiency is still lower than the rating inevitably.

Based on the similarity law of pumps, determined the pump efficiency under different working conditions with variable water flow. For chilled water pumps used in No.12 building, its comprehensive efficiency under 85% of the rated flow is 83% of the rated efficiency. So after taking chilled water pumps efficiency into account, energy-saving rate reduced from 33.9% to 28.1%. The same as influence of control strategy, influence of pump efficiency varies in different season. In transition season, water flow through pumps becomes lower and so does efficiency.

3.4 Correlation with factors hard to quantify

There are many regulating valves in chilled water pipe network of which opening varies with the change of load. When load decreases, the opening of valves decreases and characteristic curve of pipe network becomes relatively steeper, otherwise it becomes relatively flatter. That makes (3) inapplicable and needs to be corrected. But it is hard to accurately describe the characteristic curve of a complex water pipe network by theoretical calculations. Only based on large amount of testing under different load, the result could be reliable. And for different water pipe network, result could be entirely different.

Other factors hard to quantify like errors in adjustment, time-delay in feedback system, etc. The influence of those factors is hard to quantify by theoretical calculation. A possible way is through lots of testing and find a similar relation by utilizing the statistical theory.

For No.12 building, taking control strategy and pump efficiency into account, energy-saving rate is 28.1%, higher by 4.1% than measure value 24%. The 4.1% is considered as loss caused by factors which are hard to quantify.

In summary, for No.12 building, effects of each factor on energy saving is shown in Fig. 6.

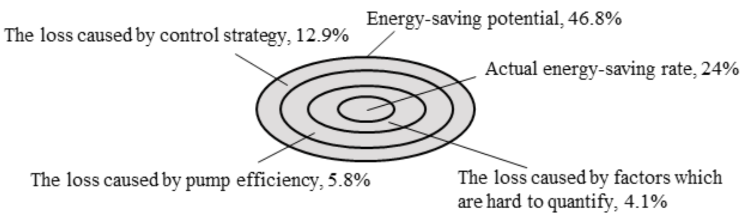

Fig. 6 Effect of factors on energy saving for No.12 building

This result is based on typical air-conditioning period. As mentioned in section 3.1, 3.2 and 3.3, at transition season, the energy-saving potential, the loss caused by control strategy and the loss caused by pump efficiency will be higher. But according to practice experience, the energy saving still mainly happens at transition season.

4. Conclusion

This is a study on factors and pre-evaluation of energy-saving efficiency. Based on the comparison testing, the effect of factors were analyzed and calculated.

As a result of this study, the energy-saving potential of variable-flow reconstruction on chilled water system is determined by building running time and average load rate of air condition system. During system operation, energy-saving efficiency is weakened by control strategy, pump efficiency and other factors hard to quantify.

For No.12 building in testing, in typical air-conditioning period, calculations show that energy-saving potential is 46.8%, the loss caused by control strategy using fixed pressure differential is 12.9%, the loss caused by pump efficiency is 5.8%, the loss caused by factors which are hard to quantify is 4.1%, actual energy-saving rate is 24%.

Acknowledgment

This study is supported by the 12th "Five-year" National Technical Support Subjects (2013BAL01B03-6) and the Social Undertakings and Livelihood Safeguarding Technology Innovation Project of Chongqing. Their financial contribution is gratefully acknowledged.

References

[1]Building Energy Conversation Research Center, Tsinghua University, 2014 Annual Report on China Building Energy Efficiency, Public Building Energy Conversation, China Architecture & Building Press, Beijing, 2014 38-39.

[2]Zhenjun Ma, Shengwei Wang, Energy Efficient Control of Variable Speed Pumps in Complex Building Central Air-conditioning Systems, Energy and Buildings, 41 (2009) 197-205.

[3]Durmus Kaya, E. Alptekin Yagmur, K. Suleyman Yigit, Energy Efficiency in pumps, Energy conversation and Management 49 (2008) 1662-1673.

[4] C. Capponia, M. Ferranteb, M. Pedronic. Real Data Analysis and Efficiency of the TEA Mantova Casale (Italy) Variable-speed Pumping Station, Procedia Engineering, 2014 248–255.

[5] Terry Moses, Varible-primary Flow:Important Lessons Learned, HPAC Engineering, 2004 73(7):40-43.

[6] Rakibuzzamana, Sang-Ho Suha, Kim Kyung-Wuka. A Study on Multistage Centrifugal Pump Performance Characteristics for Variable Speed Drive System, Procedia Engineering, 105 (2015) 270-275.