Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 61 (2014) 335 – 338
Energy Procedia

The 6th International Conference on Applied Energy – ICAE2014

Pump efficiency of water supply systems in buildings of Hong Kong

Wong L.T.[a,]*, Mui K.W.[b], Lau C.P[c], Zhou Y[d]

[a,b,c,d]*Department of Building Services Engineering,The Hong Kong Polytechnic University, Hong Kong*

Abstract

Energy efficiency of water supply systems in high-rise residential buildings becomes a concern for sustainable development nowadays. It has been reported the energy efficiency for high-rise water supply systems is below 25% and more than 75% input energy is 'lost', about half of the energy loss attributes to water pumps. Water pump operating at low efficiency is highly undesired. This paper investigates the in-use water pump efficiency for water supply systems in high-rise buildings of Hong Kong. The pumping efficiencies evaluated from a survey of 20 high-rise water supply systems were presented as a function of installation time. Expressions of in-use pump efficiency were proposed and pump replacement time was suggested. Better performed pumps got longer suggested service period and poorer performed ones got shorter payback periods. More frequent replacement was suggested for larger pumps and the payback period was generally shorter.

Peer-review under responsibility of the Organizing Committee of ICAE2014

Keywords: Water supply system; Energy efficiency; Pump efficiency; High-rise building

1. Introduction

Energy efficiency improvement of water supply systems in buildings is a way of reducing carbon emission nowadays [1]. It was reported that the water supply system consumes 1-4% of electricity and was the largest single consumer over a city. Energy consumption in water distribution systems takes an important part of energy use in urban water supply cycle [2]. The specific energy the water supply system varies from 1.1 to 1.4kWh/m^3 in some Asia cities [3]. As the energy consumption is proportional to building height, the in-use pump efficiency is therefore a matter of concern. Hong Kong is a dense, high-rise environment. About half of the energy loss in water supply is reserved to pumping system [4]. Aged, poor maintained and mismatched water pumps operating at low efficiency are highly undesired. This paper investigates in-use water pump efficiency for water supply systems in high-rise buildings of Hong

* Corresponding author. Tel.:+852-2766-7783; fax:+852-2765-7198.
*E-mail address:*beltw@polyu.edu.hk.

Peer-review under responsibility of the Organizing Committee of ICAE2014
doi:10.1016/j.egypro.2014.11.1119

Kong. Pumps of deteriorated performance would be replaced and justifications were made by energy cost saving.

2. Methodology

The water supply systems energy efficiency can be determined using an equation below [4],

$$\alpha = \frac{E_{out}}{E_{pump}} \tag{1}$$

Pumping energy of lifting water up to the tank E_{pump} and potential energy of the water demands E_{out}, are given below, where η_c is the overall transmission efficiency of pump set, H_o is the desired minimum water pressure head available at the tank inlet, H_f is the friction head required in the up-feed water pipe which is taken as a portion of the pipe length, h_l is the water lift height which is the sum of the height measured from the tank base to the tank inlet h_c – approximated by the tank volume V_c, the height difference between the top demand location and the tank base h_b, and the height difference between the water surface of the break tank and the top demand location h_n, and the bottom demand location h_1, Σv is the demand volume [4],

$$E_{pump} = \frac{\rho g (H_o + H_f + h_l)\sum v}{\eta_c}\,;\; E_{out} = \left(\frac{h_1 + h_n}{2}\right)\rho g \sum v\,;\; h_l = h_n + h_b + h_c\,;\; h_c \sim V_c^{1/3} \tag{2}$$

The overall transmission efficiency of a pump set for water supply system η_c is given by, where pump total pressure ΔP, total pumped volume Σv, line current I_L and line voltage V_L of the electric pump motor over a period of operating time $\tau = t_1 - t_0$,

$$\eta_c = \frac{\Delta P \sum v}{\sqrt{3} V_L I_L \tau} = \frac{\rho g (H_o + H_f + h_l)\sum v}{\sqrt{3} V_L I_L \tau} \tag{3}$$

20 water supply systems, included 11 commercial buildings, 4 residential buildings, 3 school buildings and 2 of elderly care buildings were investigated. During the investigation, pump installation and operation records were accessed including operation and maintenance manual, installation years, installation cost, pump motor ratings, flow rate and pressure, water supply system schematic drawings.

3. Results and discussion

Larger motor-pump sets were generally installed for buildings of larger floor area, higher delivery demand locations and larger population. The surveyed motor ratings were found correlated to the total floor area (R=0.72, p<0.01, t-test), the delivery height (R=0.64, p<0.01, t-test), and the population (R=0.71, p<0.01, t-test). The average daily energy consumption E_{pump} (kWh) was found correlated with the pump motor ratings W_m (kW) (R=0.91, p<0.01, t-test),

$$E_{pump} = 1.232\, W_m^{1.27} \tag{4}$$

The sample correlation coefficient of the system efficiency α with the average demand height $(h_1+h_n)/2$ and pump efficiency η_c is R=0.42 and 0.72 respectively. It indicated a strong association of pump efficiency to the overall system efficiency over the demand height. Figure 2 shows a significance correlation (R=−0.54, p=0.01, t-test) between pump efficiency η_c with the year of pump service Y_s (year),

$$\eta_c = 0.678 - 0.015\, Y_s ;\ 1 \le Y_s \le 20 \quad (5)$$

A general trend of efficiency drop against installation time of a water pump was reported. In average, pump efficiency at the first year of installation was 67.8% and the efficiency drop was 1.5% per year of installation. The performance drop probably was due to corrosion, scaling of impeller, casing and other parts of pumps. The efficiency drops were collectively bounded by two trend lines shown in expressions below, which indicated the pump efficiency drops, from the best to the worst scenarios were 1.18% to 2.84%.

$$\eta_c = \begin{cases} 0.7632 - 0.0118 Y_s \\ 0.7169 - 0.0284 Y_s \end{cases} ;\ 1 \le Y_s \le 20 \quad (6)$$

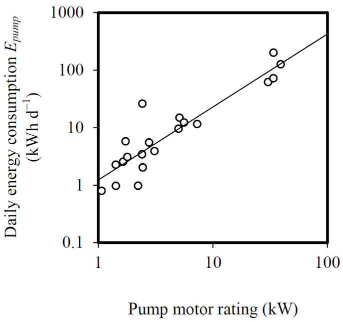

Fig. 1. Average daily energy consumption of 20 water supply systems

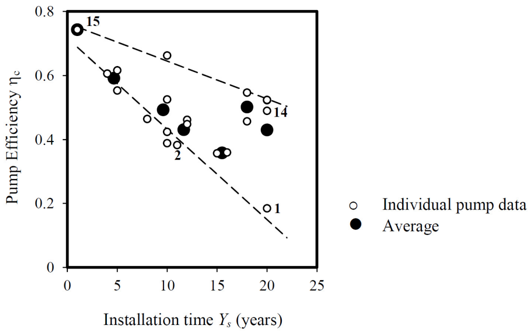

Fig. 2. Pump efficiency of 20 water supply systems.

Systems 14 and 15 (both numbered in Fig. 2) were of identical designs except that the pumps of System 14 were used over 20 years but the pump age in System 15 was 1 year old, but with very different pump efficiencies, 0.54 and 0.74, respectively. The average efficiency drops were approximated by the best scenario line from Eq. (6). Pump replacement can improve the overall system efficiency.

Pump efficiency in System 1 was found lowest (η_c=0.18) among all systems. Deterioration of pump performance was reflected by increasing pumping energy consumption. Replacement of pump can reduce the energy expenditure but required installation cost. Replacement cost θ_m (HKD$) of pump set was given by Eq. (7) for budgeting purpose. It was calculated from a basis of installation cost plus a cost proportional to the pump motor ratings W_m (kW). Taking an energy cost of HKD$1 per kWh, the yearly energy cost θ_e (HKD$) for the water system was given by Eq. (8),

$$\theta_m = 3700 + 1780 W_m \quad (7)$$

$$\theta_e = 365 E_{pump} = 450 \left(\frac{W_m}{\eta_c} \right)^{1.27} \quad (8)$$

Pump replacement is suggested in order to minimize the total cost that the accumulated extra energy cost at time n_t (year) as compared with new installation is justified with the installation cost,

$$\sum_{i=1}^{n_t}\left(\theta_{e,i}-\theta_{e,1}\right)\geq\theta_m\text{; } i=1,2,\ldots n_t \Rightarrow 450\sum_{i=1}^{n_t}\left(\left(\frac{W_m}{\eta_{c,i}}\right)^{1.27}-\left(\frac{W_m}{\eta_{c,1}}\right)^{1.27}\right)\geq 3700+1780W_m \tag{9}$$

Corresponding payback periods n_p (years) shown in Table 1 were determined by Eq. (10). Better scenarios in general lengthened the suggested service period and poorer scenarios shortened the payback periods. More frequent replacement was reported for larger pumps and the payback period was generally shorter.

$$\theta_m-\sum_{i=1}^{n_p}\left(\theta_{e,n_t+i}-\theta_{e,i}\right)=0\text{; } i=1,2,\ldots n_p \tag{10}$$

Table 2. Designated service period n_t and payback period n_p for example pumps

Pump ratings	Service period n_t and payback period n_p		
	Best scenario	Average scenario	Worst scenario
40 kW	n_t=10, n_p=4.2	n_t=8, n_p=3.1	n_t=6, n_p=2.1
1 kW	n_t=24, n_p=9.5	n_t=19, n_p=6.0	n_t=13, n_p=3.6

4. Conclusion

Energy efficiency in buildings is a sustainable development strategy in Hong Kong. It is necessary to develop a systematic approach to address energy efficiency justified to the expenditure for high-rise water supply systems. This paper presented pumping efficiencies as a function of installation time evaluated from a survey of 20 high-rise building water supply systems. Expressions of in-use pump efficiency as a function of pump age were proposed. Better performed pumps got longer suggested service period and poorer performed ones got shorter payback periods. More frequent replacement was reported for larger pumps and the payback period was generally shorter.

Acknowledgment

The work described in this paper was partially supported by a grant from the Research Grants Council of the HKSAR, China (PolyU 5272/13E).

References

[1] Shimizu Y, Toyosada K, Yoshitaka M, Sakaue K. Creation of Carbon Credits by Water Saving. *Water* 2012;**4**:533–544.

[2] Plappally AK, Lienhard JH. Energy requirements for water production, treatment, end use, reclamation, and disposal. *Renewable and Sustainable Energy Reviews 2012;***16**:4814–4848.

[3] Cheng CL. Study of the inter-relationship between water use and energy conservation for a building. *Energy and Buildings* 2002;**34**:261-266.

[4] Cheung CT, Mui KW, Wong LT. Energy efficiency of elevated water supply tanks for high-rise buildings. *Applied Energy* 2013;**103**:685–691.