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OPTIMIZATION TO WATER SUPPLY SYSTEM DESIGN AND OPERATION SCHEME IN HIGH RISE BUILDINGS

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Abstract

Greenhouse Gas emission from high-rise buildings has been increasing mainly due to excessive energy consumption of the HVAC system, structural system and electrical system. Electricity consumption for pump system accounts for 15% of total electricity usage in building. Therefore the reduction of electricity in operation is crucial to the overall reduction of GHGs in urban areas. In this study, a lab-scale experiment was conducted to test the electricity consumption in applying different design approaches; the energy efficiency of the system was calculated. Finally, this study proposes the advanced water supply design scheme to reduce electricity consumption of the pump system.

Keywords: Water supply system; high-rise building; energy consumption.

1. Introduction

Currently, the process of urbanization has led to a major change in the urban view with rapid growth of high-rise buildings and skyscrapers. Efficient energy use in these buildings in order to reduce emissions and ensure green building elements is a critical demand in many municipalities in Vietnam [1]. According to recent statistics [2], the total energy consumption of buildings accounts for 40–70% of the energy supply for the municipality, in which the high-rise buildings such as hotels, commercial buildings, etc. consume about 35–40% of this part. The cost of electricity to operate the pumps for water supply systems are relatively high (20-40%), based on a study of the 20 - year - life - cycle cost of water supply system in high-rise buildings [3]. Burton [4] showed that raw and treated water pumping can account for up to 95% of water utility's energy use. Similarly, the Electric Power Research Institute [5] suggests that more than 85% of the energy use in water supply operations is consumed by pumps alone.

While Wong [6] rendered that in most cases, the energy efficiency for highrise water supply system is below 25% and more than 75% input energy is wasted. Half of the energy loss attributes to water pumps.

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It is found that two main kinds of systems may cause significant energy wasted [7]. First is a kind of system that incorporates one pump to run continuously, even during low-flow or no-flow periods. This system utilizes a thermal bleed solenoid valve to dump water that is overheated in the pump casing due to the impeller operating below the demand flow rate. Both energy for pumps and water for pumping are wasted in this case. The second is a kind of system that generates a single water pressure for the entire building that is high enough to satisfy the upper-level fixtures and then reduce that pressure through pressure-reducing valves to satisfy lower-level pressure zones in the building. In this case, energy is wasted via the pressure-reducing valves.

Study on high-rise system shows that the design of water supply system for high-rise buildings is often not optimal, so that pump heads are usually 1.2–1.3 times higher than the height of the building (> 100 m H_2O), the pumping efficiency is very low at only 40–60%, electricity used for O&M is very high, resulting in high rate of energy waste and expense lost. According to [8], optimization of the design and operation of indoor water supply and boosting system in mega cities of China can save 25% of energy consumption and reduce annual emission by 8,600 tCO_2e.

Energy saving and use of efficient energy source in high-rise buildings not only reduces budgets of investors but also comply with the Vietnam Government's strategies for energy security, sustainable development and environment protection. Therefore, the objectives of this research are (1) to study the electricity consumption and energy efficiency of different design approaches using lab-scale booster system; (2) to propose the advanced water supply design scheme to reduce electricity consumption of the pump system for highrise building.

2. Materials and Method

2.1. Lab-scale experiment

Two typical systems (roof tank system and booster system) [9] for water supply in high-rise buildings were chosen for the experiment (Fig. 1).

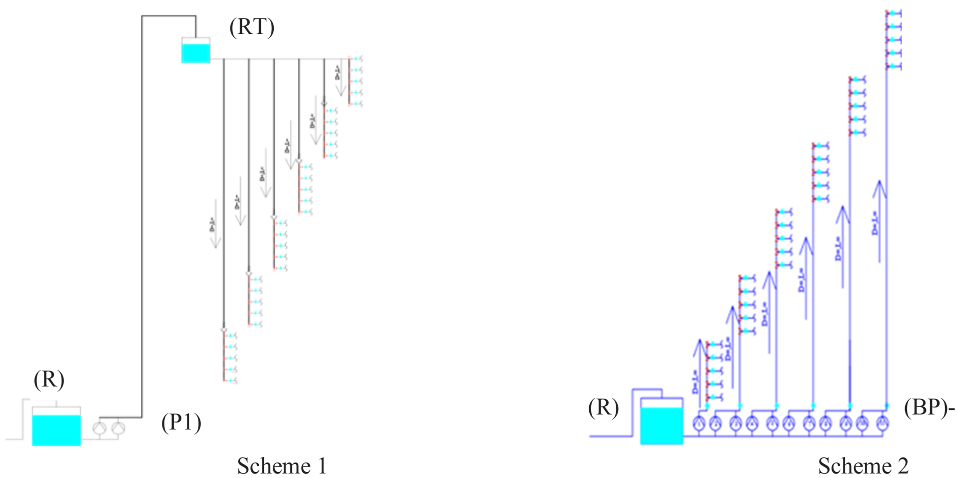


Figure 1. Water supply systems in high-rise buildings

Scheme 1. City water supply to reservoir (R) at the basement of building, water is then lifted from reservoir (R) to the roof-tank (RT) on the most top floors by pump system 1 (P1) at the basement. Water is pumped from the water tank to the upper floors by booster pump (P2);

Scheme 2. City water is provided to a reservoir at the basement of building. Booster pump will supply water with constant pressure to all the floors continuously by booster pumps (BP).

A lab-scale experiment is set up to analyze the pump efficiency of different water supply system designs in high-rise building (Fig. 2). The system consists of: 01 water tank with dimension $B \times L \times H = 1250 \times 750 \times 350$ mm, storage capacity of 280 liter; 02 vertical centrifugal pump unit with variable speed motor, each unit has the capacity of $Q_p = 3.5$ m^3/hr and head $H_{\max} = 30$ m; pump motor $P = 0.37$ kW. The pump unit is installed in parallel on the pump base, connected with the inlet pipe D75 and discharge pipe D75. On the discharge pipe, there were water meter (Grundfos, 0.6-12 m^3/hr), pressure gauge (Grundfos, 0-10 atm), pressure sensor (Danfoss, 0-10 atm), and Watt meter (Grundfos). At one end of the discharge pipe, total 6 water tap was installed. The pump system was controlled by the control panel Grundfos HYDRO-MPC E2XCRE3-05, the screen indicates various system configurations such as: set up pump het (atm), actual pump head (atm), water volume (m^3/hr), and electricity consumption (kW), percentage of motor speed to the full speed of 2950 r/min (%).

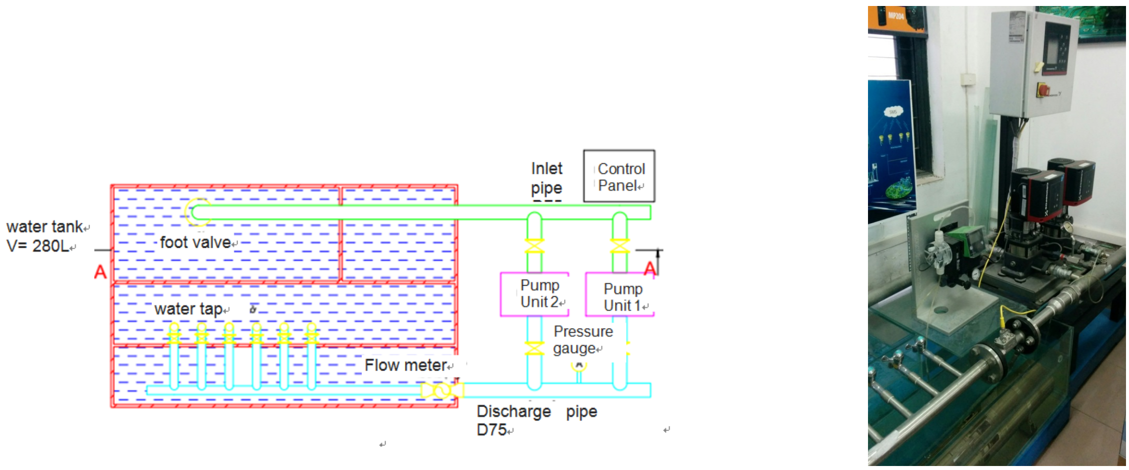


Figure 2. Lab-scale pump system outline and photo

2.2. Pump configurations and data monitoring

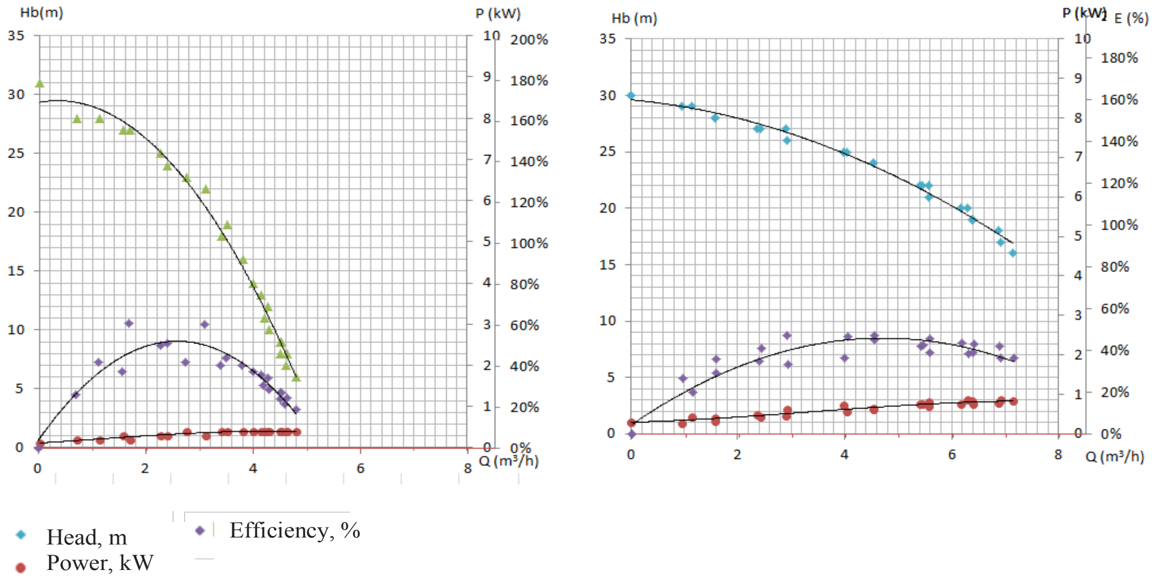
2.2.1. Pump curves

The pump operation curves at different operation modes are constructed by changing the pump discharge output through PLC unit. The pump speed varies at 95%, 90%, 85%, 80%, 75%, 70%, 65%, 60%, 55%, 50% of the full speed. The consumption pattern was changed by opening the valves on the discharge pipe.

The pumps operate individually and in parallel, the output parameters were recorded and the curves were constructed as shown in Figs. 3 and 4.

2.2.2. Pump system configuration

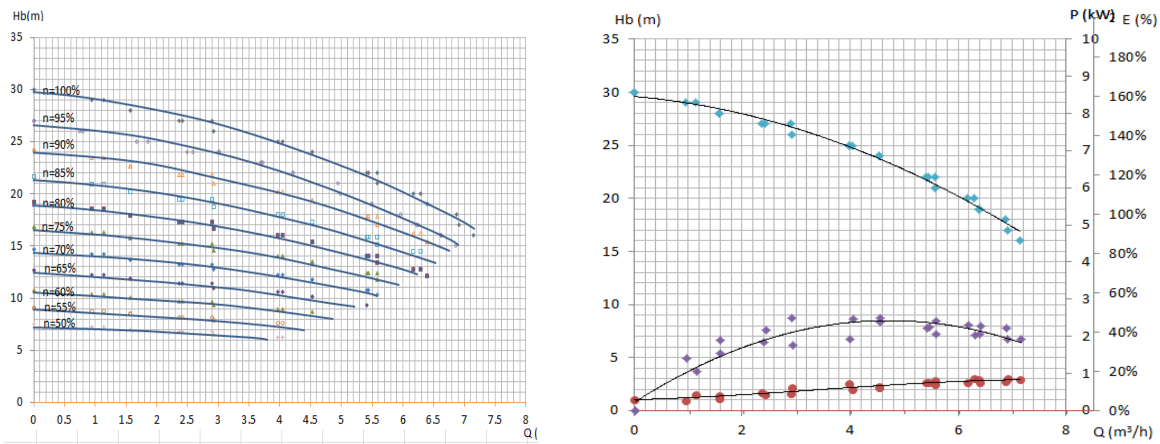
Two lab-scale experiments are built: (1) Roof tank system: $Q_{=}6$ m^3/h, $h = 20$ m, Tank volume 2 m^3; (2) Booster pump system, in which (2a) the first booster pump system with $Q_p = 6$ m^3/h, $h = 20$ m; (2b) the second pump system with $Q_p = 5.85$ m^3/h, $h = 10$ m. Both systems are run with the different Peak factor: $K_h = 2.5; 2; 1.8$ ([10, 11]).



(a) Pump 1 operates individually with full speed

(b) Two pumps operate in parallel with fullspeed

Figure 3. Pump operation curves



(a) Head-Discharge curve

(b) Power-Discharge curve

Figure 4. Pump operation curves when operating in parallel with different operation modes (variable speed pump)

2.2.3. Experiment process

Roof-tank system: From the control panel, set the pump operation at the set point with: $Q_p = 6$ m^3/h, $h = 20$ m. Maintain the operation and record the electricity consumption data by hours in 24 hours.

Booster pump system: From the peak-factor data, each hour set the operation point with corresponding Q_p and h. The water discharge was controlled by the water tap. For each value in an hour, electricity consumption was recorded in 24 hours.

2.2.4. Pump efficiency

Pump efficiency is calculated as followed:

$$\text{Pump Hydraulic Efficiency } (\eta_{pump}, \%) = \frac{\text{Pump Hydraulic Power Output (kW)} \times 100}{\text{Pump input Shaft Power (kW)}} \tag{1}$$

The Pump Hydraulic Power Output is calculated for each design systems with formula as followed:

$$N_{pump} = \frac{\rho \times g \times H \times Q}{102} \text{ (kW)} \tag{2}$$

in which: H: total head (m); Q: flowrate (m^3/s), ρ: density of the fluid (kg/m^3); g: acceleration due to gravity (m/s^2).

Pump output Shaft Power is measured using voltage and current meter. Head and Flow are recorded based on information display on the control panel of the pump system.

2.3. Case study

Based on the lab scale data, we design water supply system for a commercial apartment building (35 floors, 1 basement) with 03 different design approach:

- Roof-tank system 1.1: City water supply to reservoir (R) at the basement of building. Water is then lifted from reservoir (R) to the water tank (WT) on the most top floors by pump system 1 (P1) at the basement. The water tank will supply water to the below floors at the same time reserves water for the upper floors. The water tank supplying water to the upper floors by booster pump (P2). The system is divided into 04 zones (roof tank system).

- Intermediate-tank system 1.2: City water was stored in a reservoir at the basement of building. Water supply system is divided into different water pressure zones. Each zone consists of 15-20 floors. Every zone has a water tank and served by its own booster pump. The pump only supplies water to the tanks of the above zones. At the most top-floor a booster pump is installed. In case of emergency, electricity breakdown, the tank will be able to provide water in12 hours. (intermediate tank system).

- Booster pump system 1.3: City water is provided to a reservoir at the basement of building. Booster pump will supply water with constant pressure to all the floors continuously with the support of Variable Frequency Drive (VFD). The system consists of 02 sets of booster pumps to supply water to 02 pressure zones (Booster system).

2.4. Life-cycle cost

Life cycle cost calculations for pumping systems of a 35 floor-building are conducted with three parameters taken into account: (i) capital costs; (ii) Maintenance cost and (iii) Operation costs.

- Capital cost for pump system, reservoir, water tank, piping and valves, C_i, is obtained from the manufacturer of the system supplying equipment with the equivalent capacity.

- Maintenance costs - C_m is obtained from manufacturer (estimation for booster sets is 50% of booster's initial purchase price, pipe and pressure reduction valves 5% of initial investment, roof, base and break tanks 20% of tanks initial costs).

Operation cost - Energy costs - C_e: Energy consumption is the result obtained from lab-scale experiment.

So the Life cycle cost (LCC) is the sum of the three components:

$$LCC = C_i + C_m + C_e \tag{3}$$

3. Results and discussion

3.1. Experimental results

Comparing the Energy consumption between roof tank and pump booster systems are showed in Fig. 5. Overall, the energy consumption for roof tank system was about 30% higher than that of booster pump system. This result is consistent with the previous study by [2]. The explanation lies in the fact that the water is often pumped through where it is required (extra energy applied) and a number of pressure reducing valves have to be installed. The energy consumption in the maximum-water-using day of booster system was reduced around 27% to 33%.

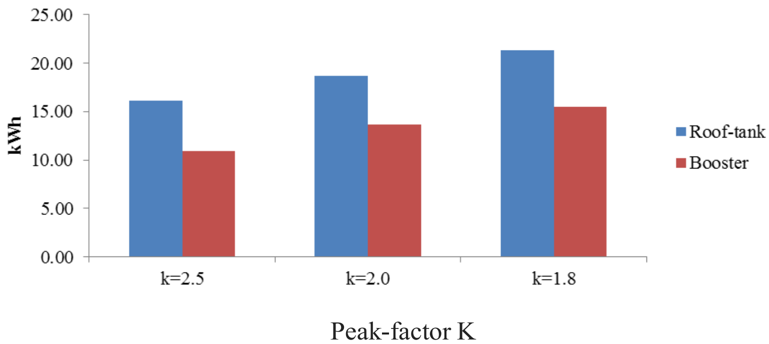


Figure 5. Electricity consumption of two water supply systems with different K_h in the maximum-water-using day

Studying the working chart of direct booster pump systems shows that the electricity consumption of the systems changes closely with the water use patterns according to the different non-harmonic water use coefficients.

The pumps are controlled by the inverter system so that when changing the flow by closing or opening the valves, the speeds of pump are changed automatically to suit the installation pressure of the system. The pump efficiency is still higher than 50% (Figs. 6, 7, 8).The high efficiency range of pump is from 40% to 55% (Fig. 7). The pump efficiency reduces to under 10% in the low water use

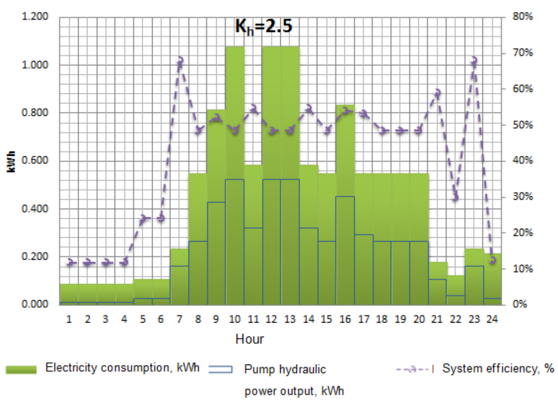


Figure 6. Electricity consumption of booster pump system with peak factor $K_h = 2.5$

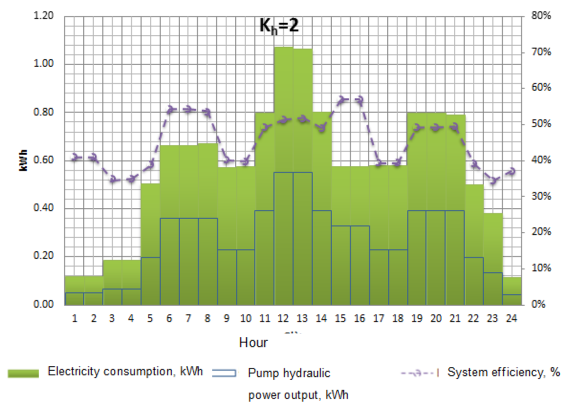


Figure 7. Electricity consumption of booster pump system with peak factor $K_h = 2.0$

period time (From 0 am to 5 am) (Figs. 6 and 8), at this period time the flow is very low compared to the average flow but the pump is still working with the installation pressure point so that the pumps work in the low efficiency zone. However, with the operation in 24 hours, the electricity consumption of booster system is much lower than the roof tank system.

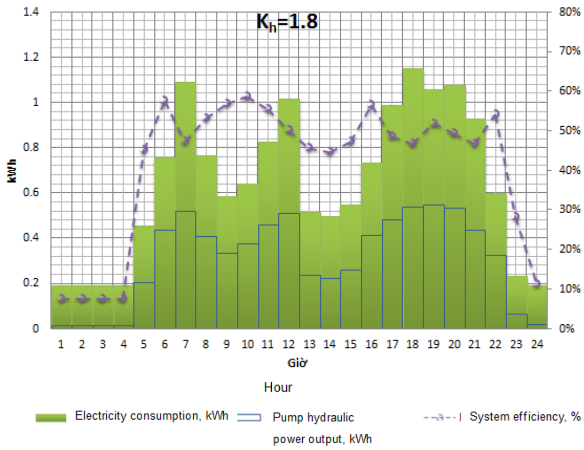


Figure 8. Electricity consumption of booster pump system with peak factor K_h = 1.8

3.2. *Case study results*

The result from case study shows that the optimization of the water supply system can be studied under various design approaches (Figs. 9, 10, 11):

- System 1.1 has lowest initial costs: less investment for pump system, tanks. In contrast, this system has highest electricity consumption because all of the pump power is used to lift water to the top floors.

- System 1.2 has higher initial costs compared to system 1.1 because of higher costs for purchasing intermediate pump systems and break tanks, but the total LCC reduces because the electricity consumption cost reduces.

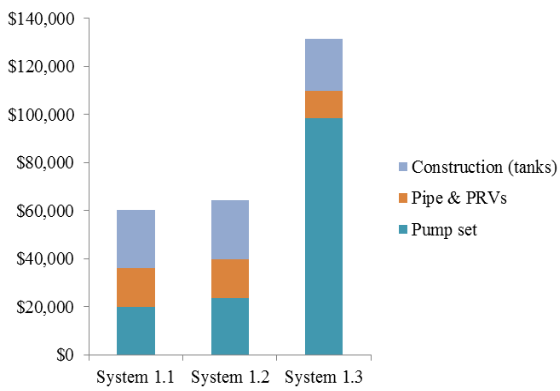


Figure 9. Capital cost for different water supply systems

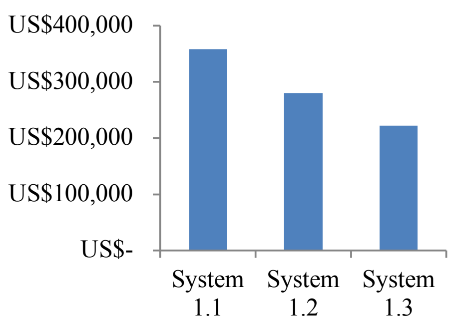


Figure 10. Operational cost (mostly electric consumption) for the total life span of 20 years

- System 1.3 has highest initial costs because of the highest costs for pump installation. The booster pump sets equipped with frequency converter is more expensive than the normal pump sets. However, other costs for pipes and construction costs reduce because there is no need for break tanks in the system. In addition, the electricity consumption is the lowest compared to the other systems. The results show that electricity consumption for this booster system can reduced by 1.6 times. Regarding the electricity consumption per volume of water consumption, the booster systems consume much 6.1 times less then the other systems (Fig. 10).

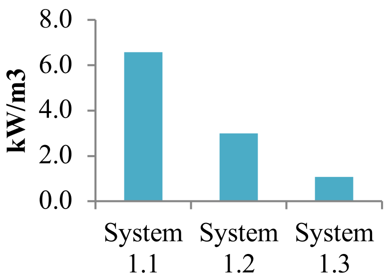


Figure 11. Electricity consumption per volume water supply (kW/m^3)

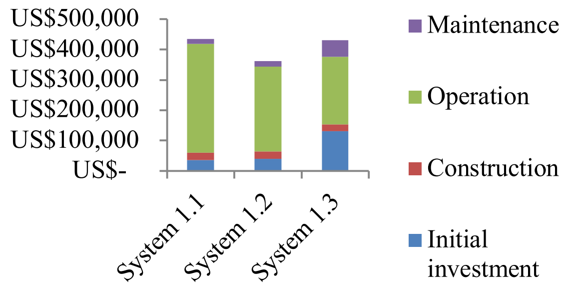


Figure 12. Life-cycle cost assessment results for case study

These findings again are similar to those in previous study [3, 12] in which they found that the booster system and intermediate tank system are superior to the roof tank solution - both when it comes to initial investment, maintenance and energy efficient operation. Some reasons were rendered to explain, for instance, booster configurations with several booster sets and low pressure levels can create even pressure when there is little or no flow, while break tanks made it possible to use water on stock in order to adapt to peak flow situations. Thus, these two booster system and intermediate systems can provide enough water at acceptable low power consumption.

The system LCC assessment for 20 years (Fig. 12) shows that booster system (system 1.3) has the lowest electricity consumption (46% of total LLC) but highest initial investment costs (45% of total LCC). This makes sense in a way that for the booster system, more pumps are installed. This should be kept in mind that using booster system shall be vulnerable in case of pump failure and quite sensitive to electrical fall outs. The intermediate system has the lowest operational cost for total life span of 20 years, but it normally requires spaces on service floor, which eventually take away potential revenue-generating space and has high risk of micro-bacterial growth in break tanks [2].

4. Conclusions

The results from experiment shows that energy consumption for booster system does not have much difference with the intermediate tank systems, this might be the results of operating conditions (the flow is adjusted with the water tap that effect the pump efficiency). This suggests that booster pump set could have better energy performance if the water consumption is more stable (smaller difference between the max/min flow) i.e. large buildings.

The result from case study calculation shows that: Roof tank system (system 1.1) and intermediate system (system 1.2) has not much difference in the total life cycle costs. Depending the number of floors and the water consumption pattern (building type), we can design a suitable system.

The result from case study for LCC assessment for 20 years shows that booster system (system 1.3) has lowest electricity consumption (46% of total LLC) but highest initial investment costs (45% of total LCC).

Based on this study's results, when optimizing the indoor water supply systems the engineers need to consider the various factors include: Energy saving, small carbon footprint, lower life cycle cost, type of buildings (number of floors, purpose of building). The author suggests utilizing a booster system for long-term economical and environmental impact.

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