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Investigation and analysis of college's water system: the case of Northeastern University

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Abstract

To date there have been many studies of water system optimization which were focused on the water use performance of industrial, regional, and urban areas from a macro-perspective. However, water system optimization colleges and universities are rare, though the amount of water consumption is huge in higher education institutions. We applied a water extended input–output model to investigate and analyze the water system of Northeastern University. Results showed that the water consumption at Northeastern University is 106.72 m^3/year per capita; 74.44% of the total water consumption at Northeastern University takes place in dormitories and other school buildings. In contrast with industrial and agricultural sewage, the pollutants in campus sewage are simple and are easy to render harmless or eliminate. Analyzed results showed that the rate of water recycling is low. In this paper, we present an optimization project for improving water efficiency at Northeastern University. Through measures such as dormitory toilets that reuse washroom sewage, our proposed plan will reduce water consumption per capita by 2.13 m^3/year. If our proposed plan is adopted at other higher education institutions whose size is the same as Northeastern University all over the country, $7,842.77 \times 10^5$ m^3/year of water will be saved, which is equivalent to 3.45×10^6 yuan.

Keywords: Colleges and universities; Single pollutant; Water extended input–output; Water reuse system

1. Introduction

Rational and optimal utilization of water resources for sustainable social and economic development is becoming the focus of correlation researches (Hallale, 2002; Gunson *et al*., 2010).

There has been an increased focus on the water use performance of industrial, regional, and urban areas from a macro-perspective. Most of the initiatives have focused on water quality, for example, purifying sewage (Chen, 2006; Kumar & Pal, 2013). Many have focused on structural optimization, for example, water cycle plans for regional and urban water use (Chen & Chu, 2011; Galvis *et al*.,

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2014) or creation of an industrial water use system (Lim *et al.*, 2008; Gao *et al.*, 2011; Žarković *et al.*, 2011). However, only a few research efforts have focused on water reuse systems in schools (Todd *et al.*, 2003; Larsen *et al.*, 2013), and there have been no studies on the structural optimization of water systems in universities and colleges.

Colleges and universities are distinct societies in which water consumption and sewage discharge occur in significant quantities. There are more than 3,000 colleges and universities in China, and there are 35 million employees and students at these institutions. These societies, which include teachers, students, and staff as well as research facilities, have become one of the main sources of water consumption in the urban water system. Unlike industrial sewage, most of the sewage from these institutions is harmless. However, most of the existing studies on campus water consumption only discuss qualitatively the feasibility and benefits of specific water systems.

Northeastern University (NEU) has about 40,000 students and staff, and they consume 4.0×10^6 m^3 of water annually. We applied the water extended input–output (WEIO) analysis to quantitatively analyze the water consumption at NEU and to create a complete optimization scheme that can be applicable in populated societies such as other schools and governmental agencies.

2. Water extended input–output

Input–output (IO) analysis was used to construct a flow chart and to establish a basic modeling frame for analysis (Leontief, 1936). The analysis is used to trace a substance's migration path regionally or within an economic entity and to explain certain phenomena.

To analyze the case of NEU, we applied the WEIO analysis, which is based on IO. According to this methodology, every architectural element can be considered as a water point. A water point can be a device or the whole society, as long as it involves water utilization and supplication. Because storage is independent of gross water quantity, water utilization and supplication can be divided into three parts: input, output, and dissipation (see Figure 1).

IO analysis is generally applied at the national, provincial, and municipal levels, but is scarcely applied at the campus level. WEIO can be applied at the campus level and reflect the interdependence

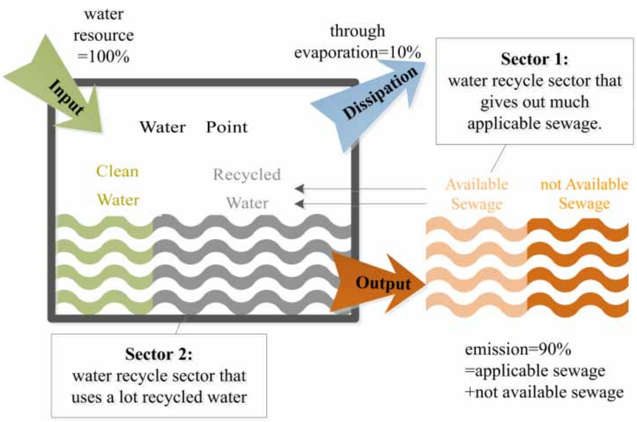

Fig. 1. Water extended input–output analysis.

and feedback effects among architectural elements. In other words, WEIO analysis is applied to study the flow of water and the relationship of water consumption among architectural elements.

Universities have clear partition of function, and different kinds of sewage are classified at the discharge source. Owing to the large water discharge of the campus, there are a number of advantages associated with the management of the pollution control of the water environment and the recycling of the water resource. So, it is necessary to build simple water recycling on campus.

'Input' refers to a water resource input to NEU, namely, tap water. 'Output' is the total amount of various forms of sewage from daily life, and it is approximately 90% of input. 'Dissipation' is the remaining water that dissipates because of evaporation or ground absorption. This water is neither usable nor turned into sewage, and it is approximately 10% of input. The rate refers to a charging scheme for sewage treatment (GB/T, 18920-2002).

In this analytical system, every building is an isolated water point, and different buildings are categorized as 'sewage resource' or 'recycled water use' based on their water consumption and emission features (see the two types presented in Figure 1). A sewage resource acts as a source of applicable drainage, which is output from the buildings. Recycled water use acts as a source of recycled water, which is input into the buildings. A reuse water point should have at least one of the above-mentioned features, i.e., it can be a sewage resource building, a recycled water use building, or both.

The pattern of water use is as follows: intake → delivery → consumers → emission. This is a unidirectional system in which a significant amount of water is wasted. If this structure can be transformed to: intake within measure → delivery → consumers → water reuse → consumers, which is a feedback-recycle flowing process that harmoniously combines the social circulation of water into natural circulation, a constant and circulatory use of water can be established in higher education institutions (National Bureau of Statistics of China, 2010). This optimization system can be seen in Figure 2.

In an optimized system, water consumption is significantly improved. The fact that the majority of sewage is reused contributes to reduce per capita water consumption and per capita water discharge, and alleviate the impact of sewage on the environment, and it also reduces the cost of waste-water treatment. Thus, the optimized system can play a major role in water recycling, water-saving and emission-reduction.

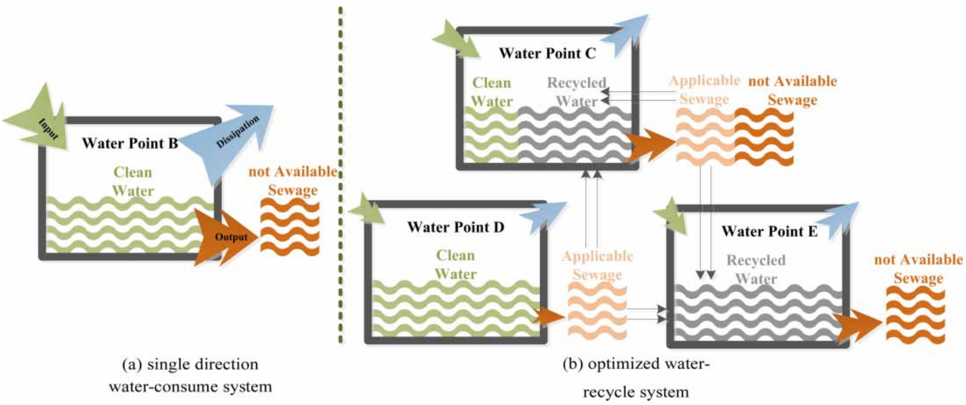

Fig. 2. Contrast before and after optimization scheme.

NEU is located in the capital of Liaoning Province, Shenyang, with 1.23×10^6 m^2 building area, more than 30,000 students, 16 academies, and 53 disciplines. The campus layout is illustrated in Figure 3. NEU is one of the leading academic institutions in northeastern China, and it is facing the same water resource dilemma as other universities and colleges. According to statistics from the China Education Yearbook, water consumption was 177.8 m^3 of water per year per college student in 2009 (National Bureau of Statistics of China, 2010), and that at NEU was 106.7 m^3 in 2012. Both of these figures greatly exceed the average annual water consumption by regular citizens, which is 43.8 m^3 per year (El-Sayed Mohamed Mahgoub *et al*., 2010).

3. Analytical investigation and optimization

The buildings at NEU are not equipped with independent water meters, so we cannot obtain monthly water reports for each building. Thus, the related statistics are mainly from field investigations and observations.

3.1. Analytical model

School buildings are closed during summer and winter holidays; thus, the population is reduced dramatically. Therefore, we consider the days in which water is used as $D = 270$ days in a year. Table 1

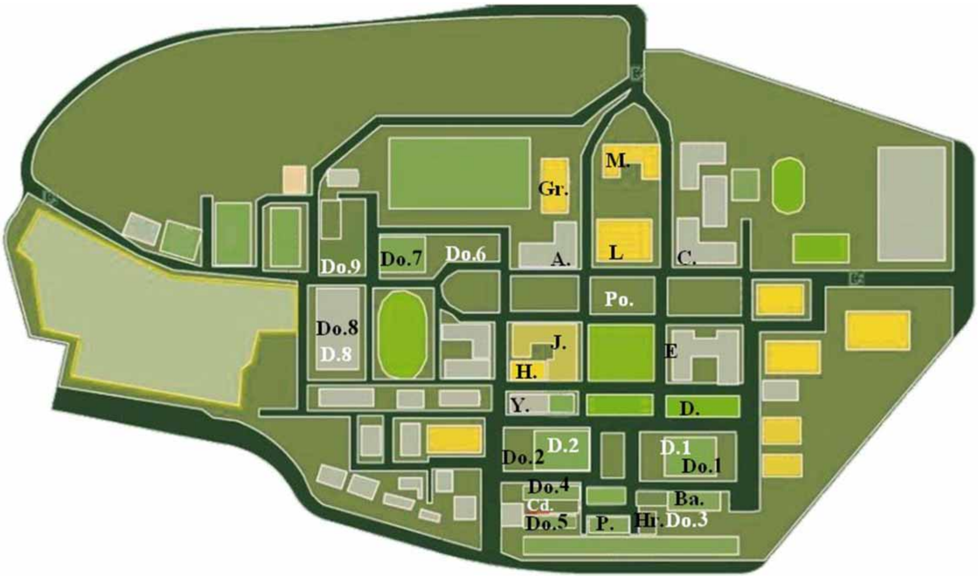

Fig. 3. Layout of Northeastern University; A.: Jianzhu building; Ba.: NEU bath house; C.: Caikuang building; Cd.: Central dining hall; D.: Dacheng building; D.1: 1st dining hall; D.2: 2nd dining hall; D.8: 8th dining hall; Do.1: 1st dormitory; Do.2: 2nd dormitory; Do.3: 3rd dormitory; Do.4: 4th dormitory; Do.5: 5th dormitory; Do.6: 6th dormitory; Do.7: 7th dormitory; Do.8: 8th dormitory; Do.9: 9th dormitory; E.: Yejin building; Fi.: firewater tank; Gr.: gardening center; H.: Heshili building; Hr.: Hui Restaurant; J.: Jidian building; L.: Library; M.: Main building; P.: Peixun dormitory; Po.: pool; Rs.: Rice-purchasing station; Y.: Yifu building.

Table 1. Inspection result of domestic sewage in dormitory (mg/L).

Index	pH	SS	COD	TN	TP	Ammonia
Place of observation						
1st dorm bathroom 1	7.8	210	378	35.2	3.81	23.4
1st dorm bathroom 2	7.6	156	267	43.8	2.70	27.3
1st dorm bathroom 3	7.2	131	220	30.5	2.90	31.2
1st dorm bathroom 4	7.4	270	454	41.0	2.72	20.8

SS: suspended solids; COD: chemical oxygen demand; TN: total nitrogen; TP: total phosphorus.

shows that even the most polluted dormitory sewage is of an acceptable quality and can meet the 'Miscellaneous Urban Water Quality Standard' (GB/T, 18920-2002). This sewage can be reused after simple treatment.

To analyze the current situation of water use at NEU, we must clarify the different water use behaviors of each building, analyze the data, and allocate water reuse resources based on the supply-demand relationship (see Figure 4). We induced sewage resource (output), which is a source of applicable drainage such as drainage from washrooms in school buildings and dormitories, from dishwashing in canteens, and from bathhouses; recycled water use (input) refers to ways of using recycled water, such as for public indoor sanitation, toilet flushing, fire protection, gardening, landscape fountains, etc. Based on the above classification, we investigated and analyzed all the recyclable water at NEU.

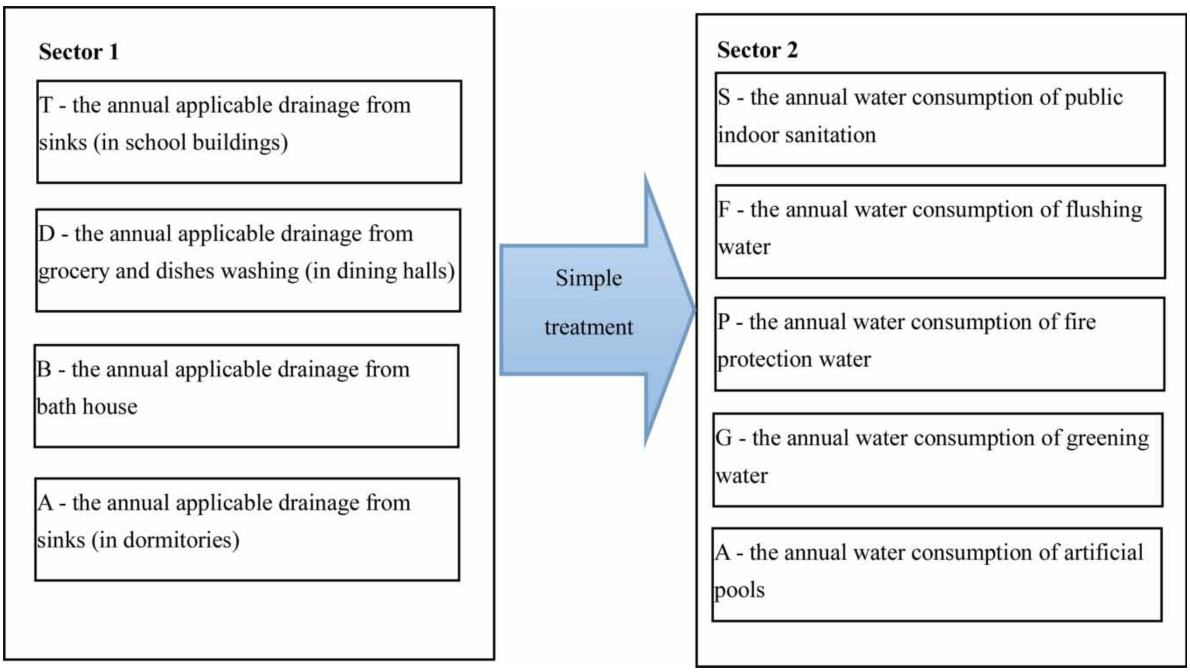

Fig. 4. Supply–demand relationship at Northeastern University.

3.2. Survey scope and methods

In NEU, the sewage resource (output) units are as follows (see Figure 4):

1. T: Dacheng building (D), Heshili building (H), Yifu building (Y), Jidian building (J), Yejin building (E), Library (L), Jianzhu building (A), Caikuang building (C). Because school-run factories, key labs, and integrated office buildings have a small staff, fewer users, inaccessible valid water use data, and are significantly affected by the type of experiments being performed, the water consumption from these facilities was not taken into consideration.
2. D: 1st, 2nd, and 8th dining halls, central dining hall, rice-purchasing station, and Hui restaurant (lower water-consuming canteens are ignored, namely, Peixun canteen and NEU Gourmet Café).
3. B: NEU bath house has a water meter that provides data directly.
4. A: 1st–9th dormitory and Peixun dormitory. (The living conditions of postgraduate students are similar to those of undergraduate students; all the students were given a sampling survey so that we could collect daily water consumption data from both male and female students.)

Recycled water use (input) units are as follows:

1. S: 1. School buildings—Dacheng building (D), Heshili building (H), Yifu building (Y), Jidian building (J), Yejin building (E), Library (L), Jianzhu building (A), and Caikuang building (C). 2. Student apartments—1st–9th dormitory and Peixun dormitory.
2. F: 1. School buildings—Dacheng building (D), Heshili building (H), Yifu building (Y), Jidian building (J), Yejin building (E), Library (L), Jianzhu building (A), and Caikuang building (C). 2. Student apartments—1st–9th dormitory and Peixun dormitory.
3. P: Fire protection tanks.
4. G: NEU gardening center.
5. A: Artificial pools.

3.3. Sewage resource (output) statistical model

Sewage resource is 'Output,' i.e., applicable sewage. We presume Output accounts for 90% of the total drainage because of evaporation or other reasons. Thus, we induce the ratio $R = 90\%$.

3.3.1. The annual applicable sewage from sinks (in school buildings). This is represented by:

$$S_T = b \times n \times v \times \sum N_i \times D \times R \tag{1}$$

where b represents the number of class breaks every day ($b = 15$), n represents the frequency of sink utilization during a class break ($n = 15$/break), v represents the water consumption every time a sink is used ($v = 1\ \text{L} = 1 \times 10^{-3}\ \text{m}^3$), and N_i represents the number of sinks in the i school building.

3.3.2. The annual applicable drainage from food and dishwashing (in dining halls). This is:

$$S_D = R_C \times \left(\sum S_i/30\right) \times D \times R \tag{2}$$

where R_C represents the applicable drainage to total-canteen-drainage ratio. Water supply in dining halls can be divided into the following categories: water for cooking, cleaning, dishwashing and disinfection, and food rinsing. The drainage from dishwashing and disinfection and from rinsing accounts for 40% of the total water consumption, namely $R_C = 40\%$. S_i represents the i dining hall monthly water consumption.

3.3.3. The annual applicable drainage from the bath house. This is:

$$S_B = S_{Ba} \times R \tag{3}$$

where S_{Ba} represents the annual applicable drainage from the NEU bath house.

3.3.4. The annual applicable drainage from sinks (in student apartments). This is:

$$S_A = (N_M \times V_M + N_F \times V_F) \times D \times R \tag{4}$$

where N_M and N_F represent the male and female population, respectively, and V_M and V_F represent the daily water consumption of male and female students, respectively: $V_M = 33.40\ \text{L} = 33.40 \times 10^{-3}\ \text{m}^3$, $V_F = 51.00\ \text{L} = 51.00 \times 10^{-3}\ \text{m}^3$. The above statistics come from a sampling survey at NEU.

3.4. Recycled water use (input) statistical model

3.4.1. The annual water consumption for public indoor sanitation. Indoor corridors and bathrooms require periodic cleaning; school buildings are cleaned during every class break, and student apartments are cleaned three times a day. Sanitary water consumption in school buildings is represented as U_S and in student apartments as $U_S{}'$.

$$U_S = \sum N_i \times T \times V_F \times D \times f \tag{5}$$

$$U'_S = \sum N'_i \times T \times V_F \times D \times f' \tag{6}$$

where N_i and N'_i represent the number of bathrooms in school buildings and dormitories, respectively; T represents the time for cleaning ($T = 10$ minutes); V_F represents the volume flowrate of water use ($V_F = 8.00\ \text{L/min} = 8.00 \times 10^{-3}\ \text{m}^3\text{/min}$); and f and f' represent the daily cleaning frequency in school buildings and dormitories, respectively ($f = 15$ and $f' = 3$).

3.4.2. The annual water consumption for flushing toilets in school buildings. The annual water consumption for flushing toilets is represented by

$$U_F = b \times n \times v \times \sum N_i \times D \tag{7}$$

where b represents the number of class breaks every day ($b = 15$), n represents bathroom uses during a class break ($n = 10$), v represents the water used in the bathroom ($v = 6.00\ \mathrm{L} = 6.00 \times 10^{-3}\ \mathrm{m}^3$), and N_i represents the number of bathrooms in the i school building.

The annual water consumption for flushing toilets in student departments is represented as:

$$U_F' = \left(N_M' \times V_M' + N_F' \times V_F'\right) \times D \tag{8}$$

where N_M' and N_F' represent the number of male and female students, respectively, and V_M' and V_F' represent the daily water consumption of male and female students, respectively ($V'_M = 18.00\ \mathrm{L} = 18.00 \times 10^{-3}\ \mathrm{m}^3$, $V'_F = 54.00\ \mathrm{L} = 54.00 \times 10^{-3}\ \mathrm{m}^3$).

3.4.3. The annual water consumption for fire protection. There are five fire protection pools at NEU, and the capacity of each pool is 420 m^3. Fire protection water must be replaced twice a year.

$$U_F = 4.20 \times 10^3\ \mathrm{m}^3/year \tag{9}$$

3.4.4. The annual water consumption for gardening. Water consumption in the NEU gardening center includes two aspects: (1) growing greenhouse flowers and (2) maintaining lawns and trees. The irrigation period at NEU is from April to October every year because of the climate.

$$U_G = 22.68 \times 10^3\ \mathrm{m}^3/\mathrm{year} \tag{10}$$

3.4.5. The annual water consumption of artificial pools. The water area of artificial pools at NEU is approximately 200 m^2, with an average depth of 1 m. Pool water is replaced once a week.

$$U_P = 10.40 \times 10^3\ \mathrm{m}^3/\mathrm{year} \tag{11}$$

Table 2. Water consumption at Northeastern University (2008–2011).

Year	2008	2009	2010	2011
Item				
Total consumption (10^4 m^3)	318.60	339.50	422.60	398.20
Per capita water consumption (m^3)	91.96	97.99	121.98	114.93

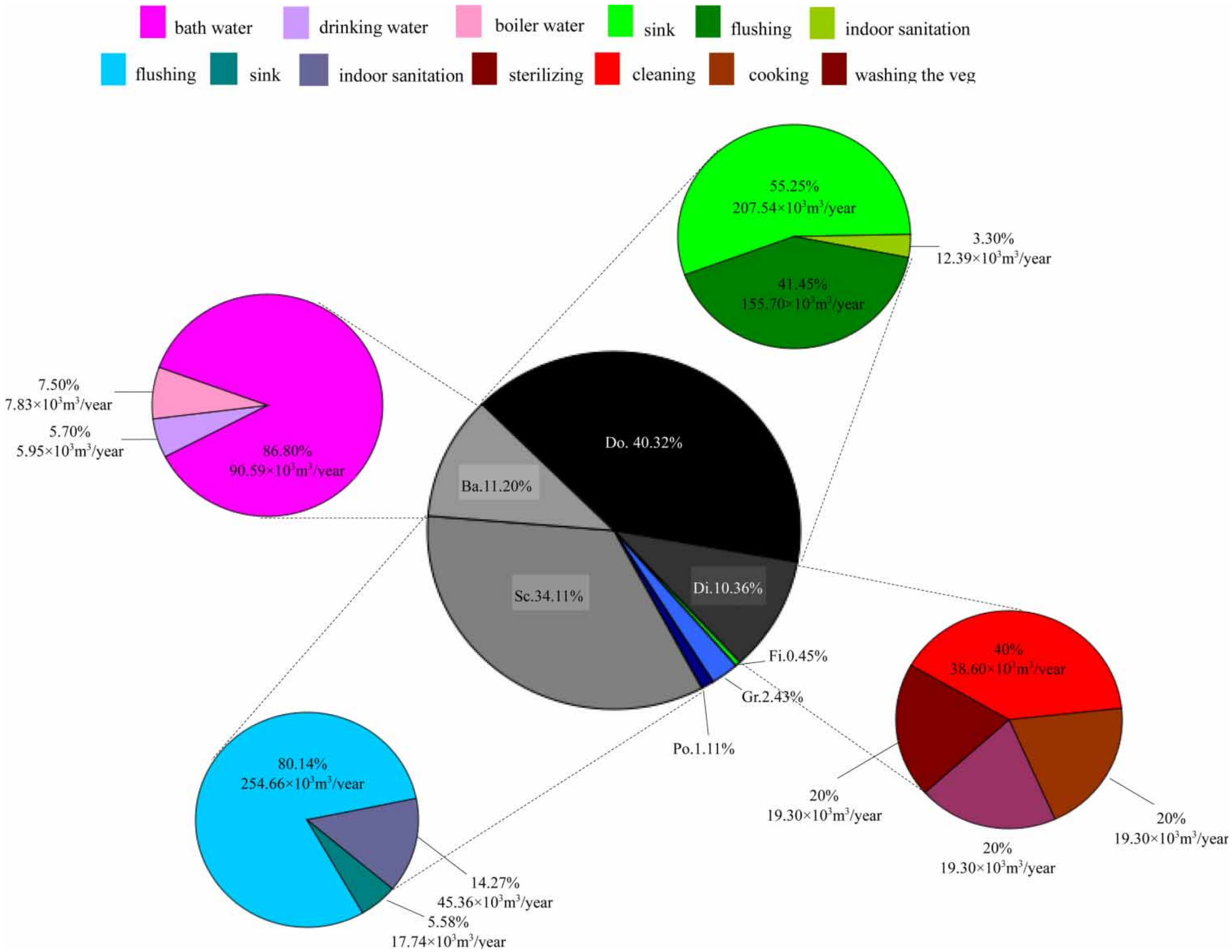

Fig. 5. Water consumption structure at Northeastern University; Di.: dining hall; Sc.: school building; Do.: dormitory; Ba.: bath house; Gr.: gardening center; Fi.: firewater tank; Po.: pool.

4. Results and discussion

The statistical data for the annual water consumption are displayed in Table 2, and the water consumption structure is presented in Figure 5.

The results from the above calculation enable us to identify a pattern of water consumption at NEU (see Figure 5). All of the statistics in this figure can be found in the Appendix (available in the online version of this paper). This will illustrate the consumption ability of a building and the differences among various kinds of buildings.

From Figure 5, we can see that the majority of water is consumed in school buildings and student apartments, i.e., 40.32% and 34.11%, respectively; 11.20% is consumed in both canteens and the bath house. The present water use system at NEU can be instituted as shown in Figure 6.

This open and unidirectional pattern of intake → delivery → consumer's → emission at NEU, is required to be transformed into a feedback–recycle process of intake within measure → delivery → consumer's → water reuse → consumers, enabling a continuous recycling of water on campus.

The following measures and suggestions should be taken into consideration:

1. Add simple filters and disinfection device during the process from sewage resource to recycled water use so that large-particle suspended matter in the sewage is removed and sewage is deodorized and disinfected.
2. For water systems containing both sewage resources and recycled water use sectors, we can consider a near arrangement of single building recycling to reduce costs of pipes.

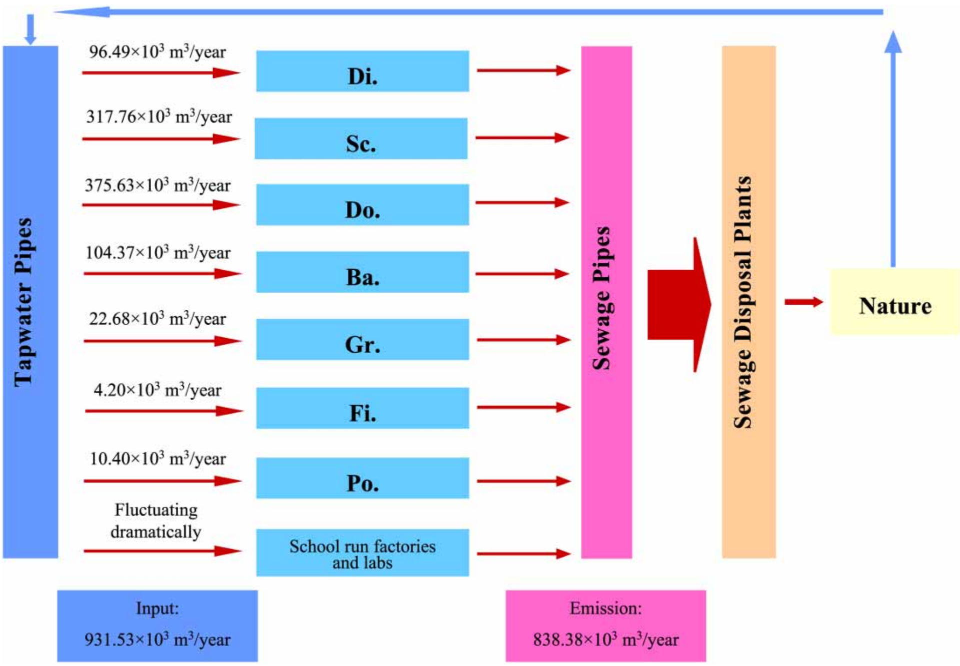

Fig. 6. Water extended input–output analysis of the water consumption system at Northeastern University; Di.: dining hall; Sc.: school building; Do.: dormitory; Ba.: bath house; Gr.: greening center; Fi.: firewater tank; Po.: pool.

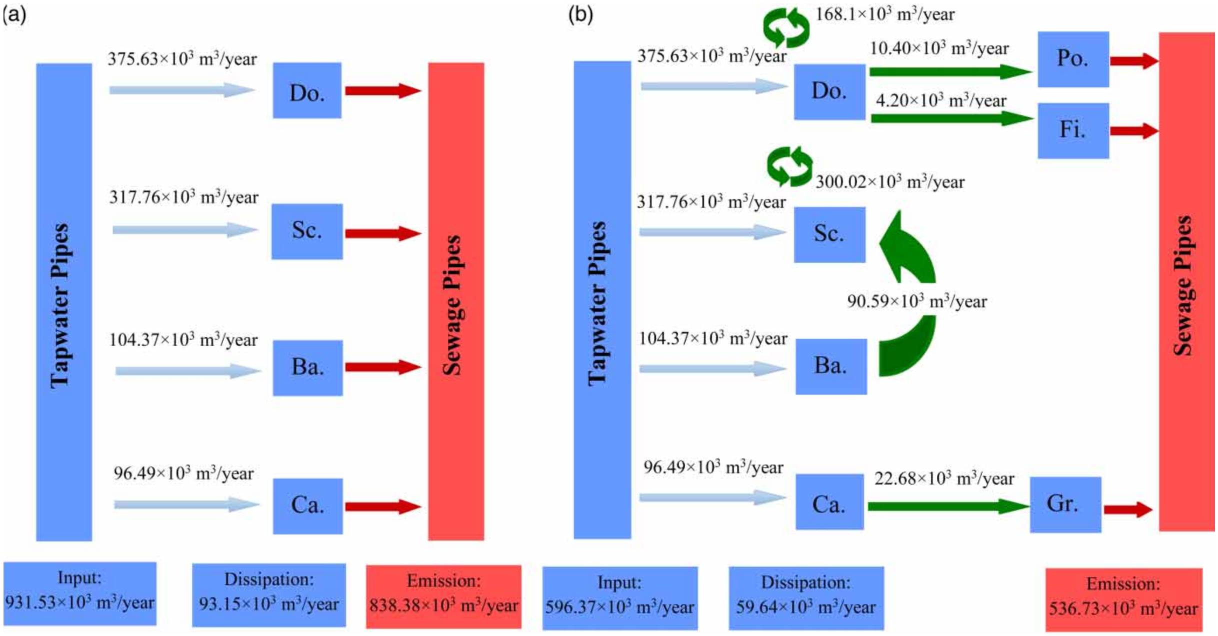

Fig. 7. Contrast between the present (a) and optimized (b) water system at Northeastern University.

3. We also recommend a directional water supply system. For example, sewage from the bath house can be directionally used in a gardening center after simple treatment, forming an independently adjustable circulatory system with a lower cost of pipes and of constructing a control center.

Thus, the water circulation system at NEU can be improved by the optimizing measures, and the differences can be seen in Figure 7.

After completion of the optimized system, the gardening center will be able to receive 40% of its water supply from canteens, the organics in canteen sewage can also benefit vegetation growth, 100% of washroom sewage from dormitories can be reused, and the bath house sewage can be reused entirely after a simple cooling and filtering treatment. We can observe a significant decrease in water consumption and discharge per capita, which reduce from 106.72 m^3/year and 96.04 m^3/year to 92.13 m^3/year and 86.65 m^3/year, respectively. In addition, the volume of sewage is higher than that of recycled water, so there will be no issues regarding storage, over treated sewage, or energy waste.

5. Conclusions

Buildings can be categorized according to their water cycle function as either sewage resource or recycled water use points. An investigation was performed on water quality and quantity, including the reallocation of water resources to strengthen the relationship between sewage resource and recycled water use. It was shown that reducing the total water consumption and per capita water consumption to a significant extent results in a reduction in water cost of about 780,000 yuan annually.

A universal concept was summarized for water system optimization based on the analytical and optimizing processes at NEU. This concept is not limited to higher education institutions and can be applied in other societies and enterprises. If these optimization measures are adopted at all the colleges in the northeastern region of China, 970.80×10^5 m^3/year of water can be saved, which is equivalent to 42.72 million yuan. If the measures are adopted in higher education institutions all over the country, $7,842.77 \times 10^5$ m^3/year of water can be saved, which is equivalent to 345 million yuan. Therefore, if these optimization measures could be taken in the water system of colleges and universities, we could substantially increase the amount of reused water and reduce daily water emissions.

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