Evaluation of the potential of CO_2 emission reduction achieved by using water-efficient housing equipment in Dalian, China

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Abstract
Introduction of water-efficient housing equipment leads to a reduction in electricity and fuel consumption for operating water supply and sewerage systems, and thus contributes to a reduction in GHG emissions. The authors have computed the average CO_2 emission factor associated with water use in Japan, but to the best of the authors' knowledge, such investigation has been carried out in a few countries. In this study, the city of Dalian in China was selected for a case study, and the CO_2 emission factor associated with water use here was computed from the quantity of water treated and the energy consumed at the water systems in Dalian. Next, the use model of the residential plumbing equipment was set up on the basis of a survey on water use in ordinary homes. The CO_2 emission reduction achieved by the widespread adoption of water-efficient housing equipment was calculated. On the basis of this calculation, the authors speculate that a maximum reduction of 16,000 t-CO_2/year can be achieved by the widespread adoption of water-saving toilets.

Keywords
Dalian, Saving-water, Plumbing Equipment, CO_2 reduction, CO_2 Emission Factor

1 Introduction
In a number of Asian nations, including China, the problem of water shortages is becoming more and more serious due to the continued growth in demand for water in concurrence with population increases and rapid economic growth. Water-saving measures are, in addition to the preservation of water resources, directly connected to a reduction in the amount of power required to operate water supply and sewerage

systems. They thus also contribute to the reduction of greenhouse gases or GHGs (hereafter referred to as CO_2 by using CO_2 as a representative) as a result. Such measures are attracting attention as actions with co-benefits, or multiple effects.

As a flexibility mechanism to address the CO_2 reduction objective in the Kyoto Protocol, the Kyoto Mechanism has been adopted. Under this mechanism, emission permits purchased from other countries and CO_2 reductions implemented in other countries can be considered CO_2 reductions of another country if its CO_2 emissions exceed its allocated emission level. The Japanese government has proposed to the international community the Bilateral Offset Credit Mechanism as a new system added to the Kyoto Mechanism. Under this system, CO_2 reductions achieved by providing advanced technologies, products and so forth from Japan to a developing country and implementing projects jointly can be counted as part of Japan's CO_2 reductions.

As a feasibility study for the Bilateral Offset Credit Mechanism, the Ministry of the Environment in Fiscal 2011 conducted a "New mechanism feasibility study for energy saving by reducing water consumptions through diffusion of water-efficient toilet systems to households in Dalian,China" as a joint research project by government, industry and academia.[1)] This article reports on the results of an evaluation of the CO_2 reduction potential implemented as a part of this project.

2 Calculation method

In this study, we compared a scenario in which the latest water-saving toilet bowls, utilizing the highly advanced water-saving technology of Japan, are introduced into residential households in the city of Dalian (hereafter referred to as the Project Scenario) and another scenario in which the project is not implemented (hereafter referred to as the Reference Scenario). We then conducted a calculation of the CO_2 reduction potential as the different between these two scenarios (**Fig.-1**).

First, we developed the Reference Scenario by conducting a door-to-door survey of 10 residential households and a survey on toilet dealers in the city of Dalian. The outline of

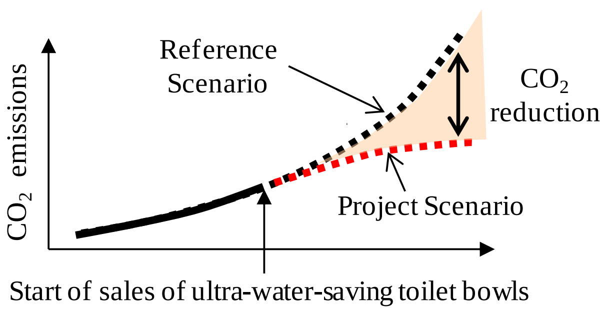

Fig. 1 Concept of CO_2 reduction potential

the door-to-door survey is presented in **Table-1**. Next, we developed the usage model for toilet bowls (the number of flushing times) by conducting a questionnaire survey regarding the use of water in residential households (**Table-2**). The CO_2 emission factor associated with water use was calculated based on the amount of water treated for water supply and sewerage systems in Dalian and the amount of electricity and fuel required for the treatment. The CO_2 reduction effect resulting from the widespread adoption of the latest water-saving toilet bowls was calculated by these results.

Table 1 Outline of door-to-door survey

No	Dates implemented	Number of family members [people]	Form of residence	Age of building [years]	Footprint [m^2]	Location
1	Oct. 10 – 12, 2011	4	Owned/apartment	15	70	Xigang, Dalian
2		4	Owned/apartment	5	159	Shahekou, Dalian
3		5	Owned/apartment	8	68	Ganjingzi, Dalian
4		4	Owned/apartment	2	70	Development Zone, Dalian
5	Oct. 29 – 30, 2011	3	Owned/apartment	5	145	Shahekou, Dalian
6		5	Owned/apartment	4	180	Shahekou, Dalian
7		2	Owned/apartment	10	70	Shahekou, Dalian
8		2	Owned/apartment	0	63	Shahekou, Dalian
9		3	Owned/apartment	18	64	Ganjingzi, Dalian
10		1	Rented/apartment	0.5	85	Ganjingzi, Dalian

Table 2 Outline of questionnaire survey

Dates implemented	Sept. 26 – Oct. 11, 2011
Subject of survey	Residential households in the city of Dalian (Jinzhou New District, Development Zone, Ganjingzi, Dalian Hi-tech Zone, Shahekou, Xigang, and Changhai)
Survey method	Questionnaire survey (forms were distributed to households and collected via mail.)
Number collected	561 respondents (237 households)
Survey details	Items regarding the use of residential plumbing equipment - Attributes of respondent - Facts regarding toilet usage (Whether full/half flushing volumes are used, number of eliminations inside and outside of the household on weekdays and holidays, number of flushing times, reason for flushing multiple time, method of cleaning up after elimination)

3 Results and discussion

3.1 Reference Scenario

A door-to-door survey of 10 residential households showed that toilet bowls with 6-L (full) and 3-L (half) flushing volumes—the volume of water used per flush—were used in 8 households, and 6-L bowls for single flush were used in 2 households. According to a survey of toilet dealers, the 6-L (full)/3-L (half) bowls were the most popular. In addition, 9-L (full)/6-L (half) bowls were available at reasonable prices. Few bowls with capacities of 5-L or less (full flushing) were sold.

The GB25502-2010 national standard for toilet bowls in China, which was announced in 2010, classifies the water efficiency of bowls into 5 categories (**Table-3**), specifying Class 5 as “standard” and Class 2 or lower as “water saving.” On the basis of these survey results, we set up the Reference Scenario as shown in **Table-4**. The Project Scenario was set up as per the latest model in Japan, and is also shown in the table.

3.2 Water-use model

(1) Attributes of the respondents

The attributes of the respondents to the questionnaire survey (**Table-2**) are shown in **Fig.-2**. We received responses from a wide range of age groups, centering on the working population in their 20s to 30s. The gender ratio was equivalent to that of the working population, and the fact that many households had two incomes was discovered. The average number of people per household was 2.4 people/household, which was slightly smaller than the average for Dalian (2.9 people/household).[2)]

Table 3 Toilet flushing standard under GB25502-2010[L/time]

Standard	Class 1	Class 2 (water-saving)	Class 3	Class 4	Class 5 (standard)
Full flushing volume	4.5	5.0	6.5	7.5	9.0
Half flushing volume	3.0	3.5	4.2	4.9	6.3

Table 4 Bowl flushing volume for each scenario

	Reference flushing volume	Project flushing volume
Full	5 L	3.8 L
Half	3.5 L	3 L

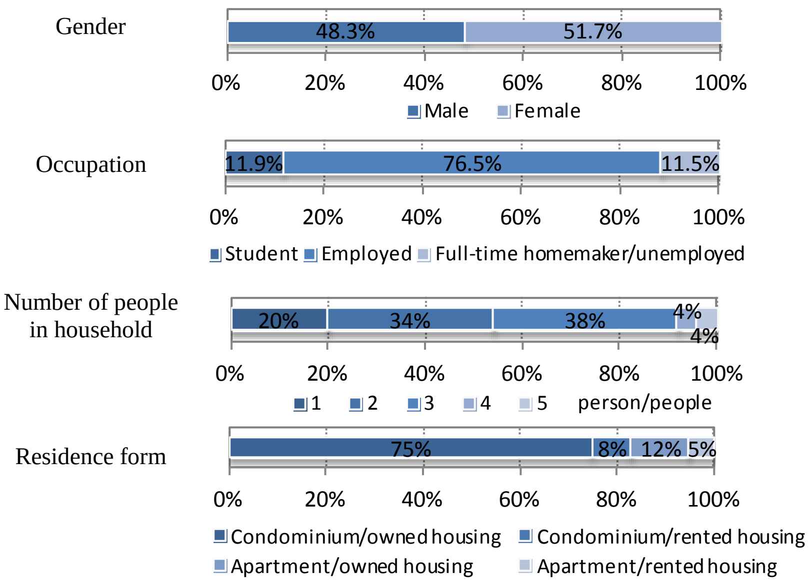

Fig. 2 Attributes of respondents

(2) Usage of toilet bowls in homes

We asked the survey participants if they used dual flush in their toilet bowls at home, and found that around 70% did. The results for those who used bowls with different flushing volumes when questioned as to which volume they used for defecation and urination are shown in **Fig.-3**. We learned that toilet bowl manufacturers designed the bowls by assuming the use of a full flushing volume for defecation and a half volume for urination, and that approximately 80% of users used the bowls in accordance with this design concept.

Measures taken to clean up after elimination are shown in **Fig.-4**. While “wiping with paper and throwing it into the bowl” and “washing with water or warm water (when a warm-water bidet function is provided)” were popular in Japan, the ratio of “wiping with paper and throwing it into a trash bin” was high in this survey. It was found that throwing used paper into trash bins, which is not a very sanitary measure, was commonplace. It was also found that the survey participants do not dispose of used paper in toilets bowls, or that sometimes flush the toilet twice, because the performance of the toilets bowls (excrement flushing and draining performance) is not satisfactory.

The total number of eliminations per person per day (total for both defecation and urination) is about 8 on average on both weekdays and holidays, which is nearly equivalent to survey results in Japan.[3)] We conducted a correlation analysis of the total number of eliminations according to the attributes of the respondents using quantification method I, and no significant differences were found.

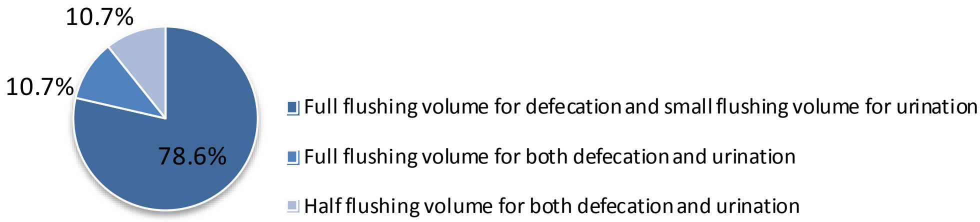

Fig. 3 Use of full/half volume flushing lever

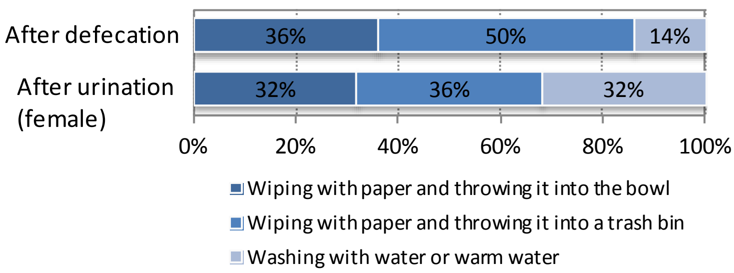

Fig. 4 Cleaning up after elimination

The results of the correlation analysis of the number of eliminations on weekdays inside and outside of the home are shown in **Table-5**. The average number of eliminations at home on weekdays was 4.6, which was slightly larger than that for outside at 3.3 eliminations. There was a high correlation according to occupation for eliminations both inside and outside the home with a significant difference the two.

In answer to the question how many times on average they flushed the toilet per use, more than 70% replied “once,” and the resulting average was 1.25 times (**Fig.-5**). When asked the reason as to why they flushed multiple times, more than 60% replied “because the bowl does not clear with one flush" (**Fig.-6**). As described earlier, this seems to be the result of the poor performance of the toilet bowls in excrement flushing and draining. To standardize the number of flushing times based on the model of the number of eliminations, we made corrections based on the difference in type of elimination and flushing volume. Although based on the assumption that a "full flushing volume" is used for defecation and a "half flushing volume" for urination, we included the value for "number of full flushings for urination" in the "full flushing volume" for each category in consideration of the percentage of people who use a full flushing volume for urination. This "number of full-volume flushings for urination" was calculated by multiplying the number of urinations inside and outside of the home by occupation as shown in **Table-6** by 0.11, which was the rate of use of the full flushing volume for urination (**Fig.-3**). However, it was decided that the reply for "using a half flushing volume for both defecation and urination" would not be taken into consideration in this calculation as it may cause pipe blockages due to an insufficient volume of water to carry away the excrement.

We calculated the number of flushing times for various occupation by multiplying the number of flushing times for both defecation and urination calculated above by the average number of flushing times per elimination (use of toilet) (**Fig.-5**): 1.25 times (**Table-6**).

Table 5 Results of correlation analysis on number of eliminations on weekdays

Attribute		Inside household		Outside household	
		Partial correlation factor	Average [times/person・day]	Partial correlation factor	Average [times/person・day]
Total			4.6		3.3
Gender		0.04		0.00	
Age		0.26		0.21	
Occupation	Student	0.46	4.7	0.45	3.5
	Employed		4.3		3.7
	Full-time homemaker/unemployed		6.9		0.9

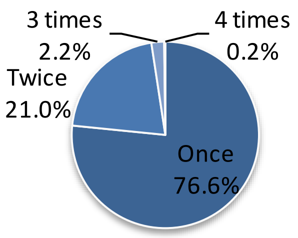

Fig. 5 Number of flushing times
(times/per toilet use)

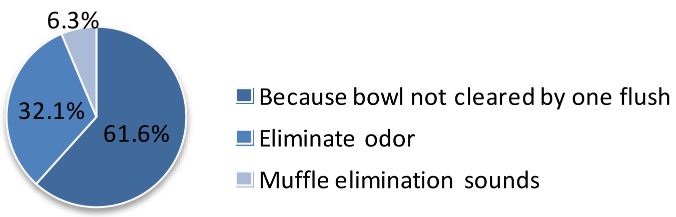

Fig. 6 Reason for flushing multiple times

We included the effect of the reduced number of double flushings as the result of the improved transport performance of drainage water arising from the implementation of the project, as it was found that double flushing is often conducted because the transport performance of drainage water is insufficient in existing toilet bowls. The reference toilet bowl model, with 1.8 uses/person･day for full flushing and 4.3 uses/person･day for half flushing (**Table-6**) was obtained by taking into consideration the number of flushing times per use of toilet: 1.25 times. Since the number of flushes per use of toilet would change after implementation of the project due to a reduced need to double flush, we examined the rate of change.

First, we assumed that people who currently flush multiple times will start flushing only once for the 61.6% (**Fig.-6**) reply rate for the reason "because bowl is not cleared by flushing only once," and calculated the rate of change as shown in **Table-7**. Based on this table, we calculated the average number of flushing times per use of toilet for the project bowl as shown below:

<u>Average number of flushing times per toilet use for project bowl</u>
= $\Sigma(A\times D)$
= *1 time * 91.0% + 2 times * 8.1% + 3 times * 0.8% + 4 times * 0.1%*

= ***1.10 times/person･day***

The number of flushing times per person per day after project implementation calculated above is presented in **Table-8**.

Table 6 Number of eliminations/flushing times at home

Type	Number of eliminations inside household					
	Defecation	Urination	Total	Full flushing times	Half flushing times	Total
Employed (company employees)	1.0	3.7	4.7	1.7	4.1	5.8
Student	1.1	3.9	5.0	1.9	4.4	6.3
At home (full-time homemaker/unemployed)	1.1	4.8	5.9	2.0	5.4	7.4
Standard model	**1.0**	**3.8**	**4.8**	**1.8**	**4.3**	**6.1**

Table 7 Changes in number of flushing times before and after project implementation

Number of flushing times per use of toilet (A)	Baseline	After project implementation	
	Ratio of reply to (A) (B)	Ratio to change to one flush among (B) (C)=(B) x 61.6%	Ratio of reply (D)=(B)-(C)
1	76.6%	-	91.0%(*)
2	21.0%	12.9%	8.1%
3	2.2%	1.4%	0.8%
4	0.2%	0.1%	0.1%

* (B) + Σ(C)

Table 8 Fixture use model after project implementation

Conditions of use		
Full flushing	1.6	times/day・person
Half flushing	3.8	times/day・person

3.3 Calculation of CO_2 emission factor associated with water use and CO_2 reduction potential

In this study, we determined the CO_2 emission factor associated with water use by dividing the CO_2 emission volume associated with the use of electricity and fuel in water supply and sewerage systems as shown in **Fig.-7** per volume of treated water. The CO_2 emission factors for electricity and fuel used in the evaluation are shown in **Table-9**. It is evident that the emission factor for electricity is about 3 times as large as that of Japan.[4)]

The CO_2 emission factors associated with water use calculated based on the 9 purification plants managed by Dalian Water Supply Company Limited, the largest water purification and management business in Dalian (**Table-10**), and the data on 10 sewage treatment plants obtained from the Urban Construction Bureau of Dalian (**Table-11**) are shown in **Table-12**. Although general treatment methods similar to those in Japan are used in Dalian, including rapid filtration in water-purification plants and an activated-sludge process in sewage-treatment plants, the CO_2 emission factor associated with water use became larger than that of Japan because of the emission factor for electricity, as more than 90% of the CO_2 emission factor associated with water use is related to electricity.[4)]

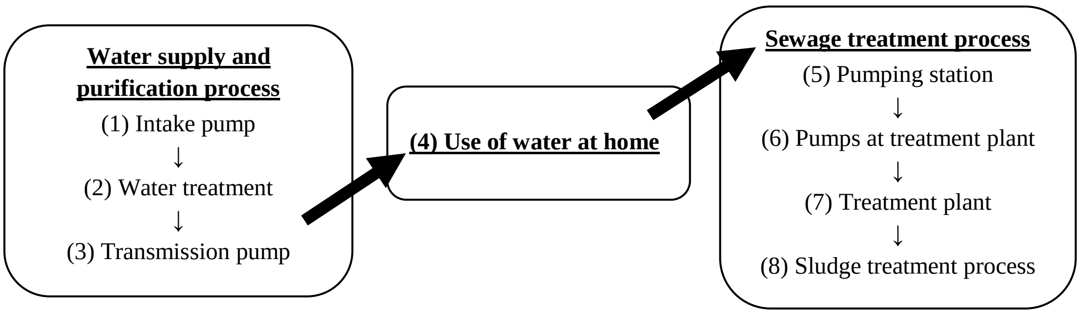

Fig. 7 Flow of water and processes covered by this evaluation

Table 9 CO_2 emission factors for electricity and fuel

Electricity[*1]	0.84195	t-CO_2/MWh
Diesel oil[*2]	3.10	t-CO_2/kg

*1: Calculated using the CDM electricity emission factor tool based on the grid power system data of the National Development and Reform Commission (2011).
CM (combined margin) value adopted.

*2: Source: China Energy Statistical Yearbook (2009)

Table 10 Historical data on water purification facilities of Dalian

Water supplied population	3.2 million
Number of treatment plants	9
Annual quantity of purified water	407,340,000 m^3/year
Annual electricity used (pumping stations)	347,337,651 kW・h/year
Annual electricity used (treatment plants)	109,625,955 kW・h/year

Table 11 Historical data and analogical values for sewage treatment in Dalian

Sewage population	2.9 million
Number of treatment plants	10
Annual sewage disposal amount	300,000,000 m^3/year
Annual electricity used (pumping stations)	1,968 kW・h/year
Annual electricity used (treatment plants)	55,053,234 kW・h/year
Annual electricity used (sludge treatment)	4,700,000 kW・h/year
Annual use of fuel for heating (pumping stations)	8,000 t/year
Annual use of fuel for heating (treatment plants)	80,000 t/year

* Diesel oil is used for fuel.

Table 12 Calculation results for CO_2 emission factor associated with water use in Dalian

	Water purification process	Sewage treatment process
Annual CO_2 generation (electricity)	384,741 t-CO_2/year	66,382 t-CO_2/year
Annual CO_2 generation (fuel)	0 t-CO_2/year	234 t-CO_2/year
CO_2 emission factor associated with water use	0.94 kg-CO_2/m^3	0.17 kg-CO_2/m^3
Energy efficiency	4,085 kJ/m^3	825 kJ/m^3

Based on the above results of this study, the CO_2 reduction potential when the project is implemented for the entire city of Dalian (population: 5,864,000, number of people per household: 2.9 people/household)[2)] was calculated to be 15,622t-CO_2/year as follows:

Volume of water saved per person

*= (5 [L/time] * 1.8 [times] + 3.5 [L/time] * 4.3[times])*
*—(3.8 [L/time] * 1.6 [times] +3 [L/time]* 3.8[times])* 365[days]*1/1000*
= 2.4 [m^3]

Volume of water saved per person × total population of Dalian × CO_2 emission factor associated with water use

*= 2.4 [m^3] * 5,864,000 [people] * 1.11 [kg-CO_2/m^3]*

= 15,622 t-CO_2/year

4 Conclusion

In this study, we found that a CO_2 reduction potential of approximately 16,000 t-CO_2/year can be expected by popularizing the use of the latest water-saving toilet bowls from Japan in the city of Dalian, China. It is assumed that there will be impacts equivalent to or larger than those in Japan through the CO_2 reduction potentials of Asian nations with CO_2 emission factors larger than Japan that can be addressed by saving water. In the future, we plan to develop a model for water use and its CO_2 emission factor associated with water use for the entire Asian region by expanding the study area.

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