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WATER MASS BALANCES FOR THE SOLAIRE AND THE 2020 TOWER: IMPLICATIONS FOR CLOSING THE WATER LOOP IN HIGH-RISE BUILDINGS[1]

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ABSTRACT: Building water mass balances were performed for one 150-story conventional building scenario for comparison with three scenarios of the 2020 Tower, a hypothetical 150-story high-rise building with on-site wastewater treatment and reuse. To ensure that the assumptions for the hypothetical building are appropriate, a one-year water balance was also conducted of the existing 27-story Solaire building that partly closes the water/wastewater loop, meters major water flows and implements low-flow/water conserving fixtures and appliances. For comparison, a conventional 27-story building scenario with the same low-flow/water conserving fixtures as the Solaire but no water reuse was also assessed. The mean daily indoor water use in the Solaire was 246 l/(d cap) which exceeds mean daily water use found in the literature. The water mass balances showed that an urban high-rise building needs another source of water even when potable reuse water is produced because of losses during water end use and treatment (i.e., evaporation, water in treatment residues). Therefore, water conservation (i.e., modification of human behavior) and water efficiency improvements (i.e., equipment, appliances and fixtures) are important major factors in reducing the municipal water needed in all scenarios.

(KEY TERMS: water conservation; water supply; sustainability; planning.)

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INTRODUCTION

Sustainable building practices are intended to reduce resource consumption, energy consumption, life-cycle costs and production of pollutants and wastes, while improving human productivity. Ideally, self-sustaining buildings produce their own energy and engender safe, regenerative, closed-loop construction and operational material flows (e.g., reuse of water in the building). Two key questions are how close we can come to this ideal and whether self-sustaining buildings can optimize the use of materials and energy while fulfilling the economic and social needs of the owners, the occupants and the surrounding city.

As part of a planning grant funded through the National Science Foundation, Material Use: Science, Engineering and Society (NSF MUSES) program, a tradeoff analysis of the water/wastewater infrastructure of the 2020 Tower, a hypothetical self-sustaining 150-story mixed use high-rise building, is being conducted. As a first step, water mass balances were performed for one 150-story conventional building scenario for comparison with three scenarios of the

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2020 Tower. To ensure that the assumptions for the hypothetical building are appropriate, a water balance was also conducted of an existing 27-story residential high-rise building that partly closes the water/wastewater loop. For comparison, a conventional 27-story building scenario with the same low-flow/water conserving fixtures as the Solaire but no water reuse was also assessed.

Major functions of water in the 2020 Tower and the Solaire are not different from those of conventional buildings. The buildings provide drinking water, water for personal hygiene and cleaning; remove waste products; distribute heat; and provide chilled water for the Heating Ventilation and Air Conditioning (HVAC) system. However, the reuse of water in each case is quite unconventional.

Scenario-based water mass balance analyses for the 2020 Tower (1 conventional scenario, 3 reuse scenarios), and for the existing Solaire building (1 conventional scenario, 1 reuse scenario) were conducted. All scenarios implement water conservation measures. The objective is to identify implications (e.g., feasibility of loop closing, identification of key water flows, and role of water conservation) for the implementation of self-sustaining high-rise buildings.

MATERIALS AND METHODS

In this study, water is modeled by a simple scenario-based mass balance analysis. Mass balance analysis is a technique for tracking and assessing inputs, accumulations, generations, and outputs of a particular material or chemical element within a defined space (Schnoor, 1996). Based on the law of mass conservation, the method involves establishing a mass balance for materials and chemical elements. At steady-state, there are no accumulations within the system boundary and for inert or nonreactive materials and chemical elements there is no generation of materials or chemical substances. In this study, water is considered a nonreactive material.

The mass balance analysis methodology was selected for a number of reasons. Mass balance analysis is a widely accepted method used in assessing fate and transport of materials and elements but also identifies potential environmental problem shifts. In addition, the mass balance analysis is the basis for a more comprehensive tradeoff analysis or life-cycle/life-cycle cost analysis.

A mass balance model includes the following steps (Schnoor, 1996): (1) system definition in space, (2) knowledge of inputs and outputs, (3) knowledge about the transport mechanisms within and across the system boundary, and (4) knowledge of the generation or disappearance of materials and chemical elements within the boundary.

Buildings

The Solaire, an existing upscale residential "green building" in New York City, and the 2020 Tower, a hypothetical building designed for the 2003 Big & Green exhibition of the National Building Museum by Kiss + Cathcart Architects with the collaboration of Arup Engineers (Gissen, 2002), were selected as case study buildings.

Solaire. The 27-story Solaire in Battery Park City bordering the west side of New York's financial district was completed in 2003. The building is the first residential high-rise built under the Environmental Residential Guidelines of the Hugh L. Carey Battery Park City Authority (Pataki *et al.*, 2000) and received the LEED (Leadership in Energy and Environmental Design) Gold Rating of the U.S. Green Building Council (USGBC, 2006).

Among other environmental features, all 293 rental units (typically 577 occupants) provide low-flow/water conserving fixtures and appliances, including front loading clothes washers (38-68 l/load), low-volume toilets (6 l/flush), and low-volume showerheads (9.45 l/min). A feature of the Solaire is the treatment of wastewater in the building and reuse of the water. The design capacity of the wastewater treatment facility in the Solaire is 94.5 m^3/d (25,000 gal/d). The treatment plant consists of an aerated feed tank, a trash trap, a three-stage biomembrane reactor with an anoxic stage, an aerobic stage and filtration stage with ultrafiltration membrane. It is followed by ozonation and ultra-violet light radiation and a reuse water storage tank. The sewage sludge from the wastewater treatment plant is discharged to the sewer. The reuse water is utilized for toilet flushing and cooling water within the building. The cooling water is used by two induced draft, crossflow cooling towers (Model No. BAC 33552A and BAC 33552A-MM, Baltimore Aircoil Company, Baltimore, Maryland) with a total cooling capacity of about 800 nominal tons. The remaining portion of the reuse water is used as irrigation water in the nearby Teardrop Park (started in March 2005), which features upstate New York woodland. To create this specific habitat, there are certain requirements on dissolved ion levels of the irrigation water. Therefore, the reuse water for irrigation is treated by reverse osmosis. In the future, the irrigation of Teardrop Park will be expanded and reuse water will be also be used as flushing water in an adjacent building.

The Solaire has a vegetated roof. The stormwater from the vegetated roof (914 m^2) and the nonvegetated part of the roof (644 m^2) is collected in a 37,800 l. storage tank which is used for drip irrigation of the vegetated roof. The vegetated roof has also a water retention layer below the soil that can hold up to 50 mm of rain before overflowing into the storage tank.

2020 Tower. The 2020 Tower is a hypothetical 150-story high-rise building designed for construction in the year 2020. The building is unique among the sustainable high-rise building projects because it is intended as a self-sustaining building. For example, in the 2020 Tower, there are large irrigated green areas every 30 floors and all wastewater is treated for reuse in the building. As another example, the 2020 Tower has a large surface area to maximize solar energy generation instead of a compact building shape implemented in conventional buildings. The 2020 Tower is designed for mixed residential and commercial use. Data about institutional and commercial water use are scarce. The best information is available for schools, offices, supermarkets, restaurants, and hotels. Therefore, as previously suggested by Dziegielewski *et al.* (2000), the model only includes these businesses and institutions. The following design parameters were used:

(1) 35% of the total floor space of 621,500 m^2 (6,690,000 ft^2) in the 2020 Tower is for residential and 65% for commercial use (8% hotels, 5% restaurants, 40% office space, 6% schools/research centers, 6% supermarkets).
(2) Assuming 46 m^2/resident (500 ft^2/resident) and 14 m^2/working person (150 ft^2/working person), 4,683 people live and 28,990 people work in the 2020 Tower.

System Boundary and Scenarios

There are various ways to select a system boundary and the selection can affect the results of a study (Schnoor, 1996; Björklund *et al.*, 1998). Therefore, it is important that the system boundary is consistent for different scenarios and is clearly defined and documented. The system boundary in this study is around the water/wastewater infrastructure of the buildings, because the building infrastructure is the focus of this study.

Solaire. Two different scenarios were modeled for the Solaire: (1) conventional building with the same water conservation and rain water collection measures as the existing building, but all wastewater is discharged to the central Newtown Creek wastewater treatment plant, and (2) existing building with wastewater treatment of portion of the wastewater and reuse of water. The entire flow path of the water for both scenarios can be found in Figure 2. The conventional building scenario is included for comparison.

2020 Tower. Four different scenarios (Figure 1) were modeled for the 2020 Tower: (1) conventional building; (2) 2020 Tower with treatment of wastewater to potable water; (3) 2020 Tower with treatment of source-separated streams to nonpotable water; and (4) 2020 Tower with treatment of source-separated streams to nonpotable water and separation of concentrated nutrients (urine). All scenarios implement collection of rain water and water conservation measures, such as low-flow appliances. For the conventional building (Scenario 1), all wastewater goes to a central municipal wastewater treatment plant, and for the 2020 Tower (Scenarios 2-4), municipal water is used for make-up water, and wastewater treatment to potable or nonpotable water is performed in the building. Potable wastewater treatment in Scenario 2 implements secondary wastewater treatment, microfiltration, reverse osmosis, and disinfection (UV and ozonation). Similar approaches are implemented in Singapore (PUB, 2002) and in the Water Factory 21 in the Orange County Water District, California (Tchobanoglous *et al.*, 2003). However, the reclaimed water from these facilities is not directly used as potable water. Scenario 3 was described by Wilderer (2004) and follows an approach more commonly proposed in Europe with source-separation of waste streams, treatment of these separate streams and implementation of anaerobic digestion for feces and food waste. Individual treatment processes are known, but they have not been implemented in this configuration yet. In Scenario 3, dual water pipes, and dual wastewater pipes are applied. Scenario 4 is the same as Scenario 3, but urine separation is added. Urine separation is only chosen as a modification of Scenario 3, because this modification was suggested in Europe, but urine separation could also be combined with Scenario 2. In Scenario 4, dual water pipes, and three wastewater pipes are applied to allow urine separation. Urine separation requires less flushing water in the toilets compared to other scenarios.

Residual management is not considered beyond the building boundary in this study, but requires more study for Scenarios 2-4.

Identification of Relevant Inputs and Outputs and Flows Within the Building

Assuming steady-state and a nonreactive nature of the water, there are no accumulations or generations

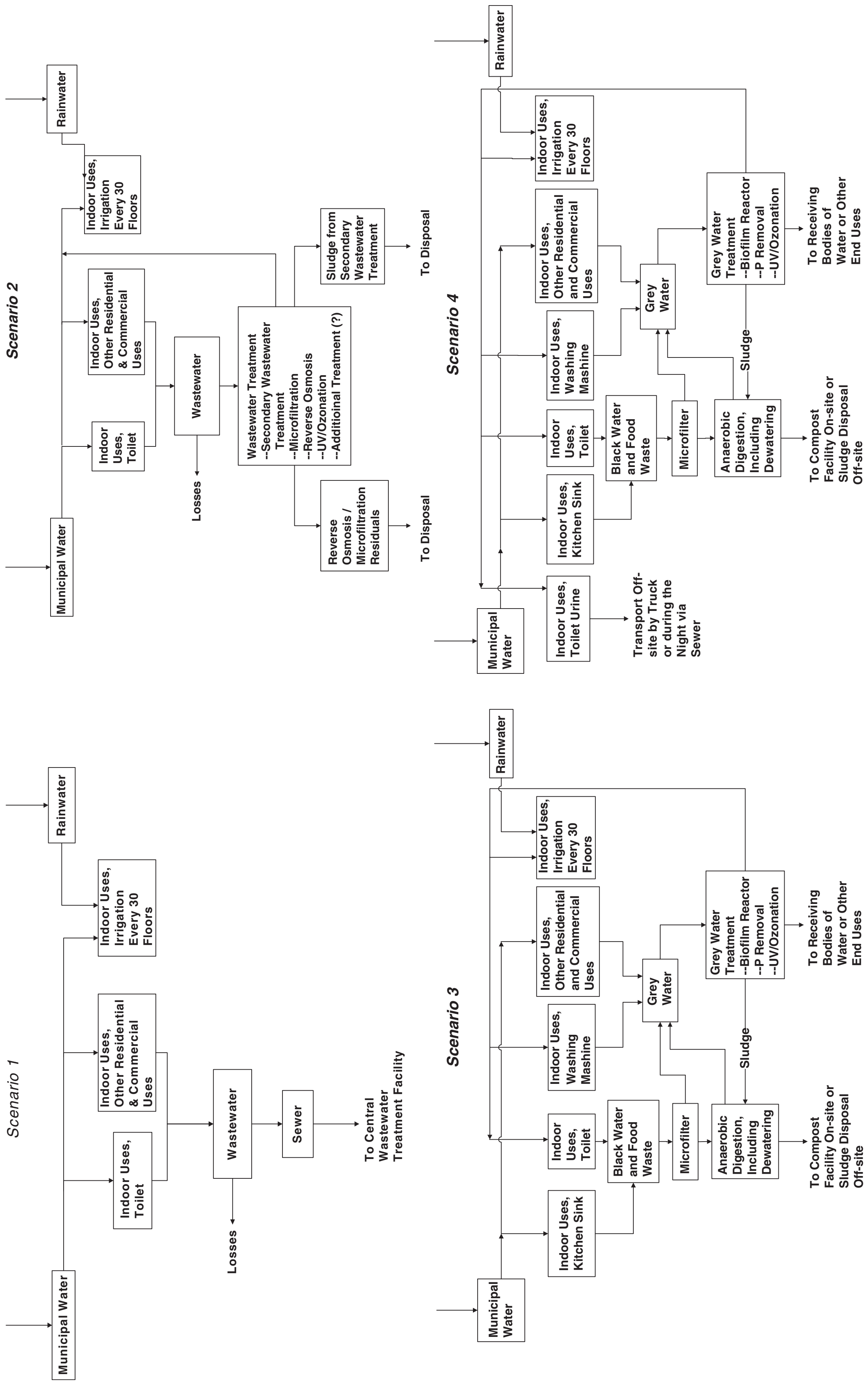

FIGURE 1. Water/Wastewater Scenarios for 2020 Tower [Scenario 1: conventional building; Scenario 2: 2020 Tower with treatment of wastewater to potable water; Scenario 3: 2020 Tower with treatment of source-separated streams to nonpotable water; Scenario 4: 2020 Tower with treatment of source-separated streams to nonpotable water and separation of concentrated nutrients (urine)].

of water within the system boundary of the case study buildings.

Solaire. Inputs of water into the building include: (1) municipal water from the New York City public water supply, (2) rain water, and (3) humidity in indoor air collected in dehumidifiers.

Outputs include: (1) evaporative losses (e.g., cooling tower; humidifier; roof, including vegetated roof; showering; cleaning floors), (2) irrigation of the nearby Teardrop Park, (3) sewer to central wastewater treatment facility, and (4) stormwater sewer with subsequent discharge to the Hudson River.

Actual water meter readings of these inputs and outputs and all major water flows in the Solaire building from October 1, 2004 until September 30, 2005 were analyzed.

Over 30 water and wastewater meters (Neptune Technology, Tallassee, AL; ABB Inc., Norwalk, CT; Badger, Milwaukee, WI) are installed in the Solaire building. The water meters for the following three flows are certified meters and are approved and inspected by the New York City Department of Environmental Protection: (1) municipal water entering the building, (2) reuse water leaving the reuse water storage tank, and (3) municipal water to cooling tower since March 7, 2005 (reuse water to the cooling tower until March 7, 2005). The water meters are read daily by a staff member at the beginning of the work day. Most water meters were operated the whole year, however, a few meters monitoring minor flows were not available before April 2005. One major output flow that is not metered, but determined by mass balance calculation is the sewer discharge. Other flows in the building that are determined by mass balance calculations are the flushing water in the toilets and the municipal water used in the apartments.

Some water is lost during use (e.g., showering, watering indoor flowers, respiration of occupants and pets). However, this amount is unknown. It is assumed that 5% of water that becomes wastewater is lost in the building. This includes water lost through respiration and evapotransporation. Tchobanoglous *et al.* (2003) reported water losses of 10-30%. The lower losses are found in the winter and in colder climates. Assuming that 50% is from outdoor losses, a loss of 5% is assumed. This value is quite uncertain and should be further studied, but it is in the same order of magnitude as suggested previously by van der Vleuten-Balkema (2003).

2020 Tower. Inputs for the 2020 Tower are: (1) municipal water, and (2) rain water.

Humidity in the indoor air is not included as input, because the hypothetical building does not have sufficient design detail. In addition, the actual mass balance data for the Solaire indicates this flow is very small.

Outputs for the 2020 Tower are: (1) evaporative losses (e.g., showering, cleaning floors); (2) irrigation water for green areas every 30 stories; the irrigation water will be partly collected in dehumidifiers after evaporation; (3) water in residuals such as sludge or compost; (4) sewer to central wastewater treatment facility; and (5) discharge of treated water to receiving body of water or for uses outside the building such as irrigation or toilet flushing in other buildings.

For the 2020 Tower, geothermal heating/cooling was proposed, and therefore, no cooling water and only make-up water for the geothermal system was included in the design. Depending on the location, this might not be an option. The present study followed the original design.

The 2020 Tower is a hypothetical building and therefore operating data are not available. Several assumptions were made based on literature review and best professional judgment. For the water balance analyses, the following design specifications and operating parameters were used:

(1) The residential indoor water use is 170 l/(d cap) (45 gpcd, adapted from USEPA (1998); 44.7 gpcd and Vickers (2001): 45.2 gpcd). In Scenario 4, due to urine separation the indoor water use is reduced to 150 l/(d cap) (40 gpcd).
(2) Commercial water use depends on the types of businesses and institutions that reside in the building. Based on a study conducted by Dziegielewski *et al.* (2000), the following water consumption was assumed: hotels, 2970 l/(m^2 yr) (73 gal/(ft^2 yr)); restaurants, 4516 l/(m^2 yr) (111 gal/(ft^2 yr)); offices, 366 l/(m^2 yr) (9 gal/(ft^2 yr)); schools/research centers, 326 l/(m^2 yr) (8 gal/(ft^2 yr)); supermarkets, 936 l/(m^2 yr) (23 gal/(ft^2 yr)). Dziegielewski *et al.* (2000) determined a range for the commercial water use. In this study, the lower value of the range was chosen, assuming additional water conservation measures are implemented by 2020. For restaurants and supermarkets, the benchmarks included the cooling water. The values in this study were modified accordingly to exclude the cooling water.
(3) For Scenarios 3 and 4, a separation into different water end use streams is required. Limited data for residential single family homes are available (Mayer *et al.*, 1999); however, the data for multi-story buildings and commercial water end use are scarce or are not available. Values used in the study can be found in Table 1.

TABLE 1. Distribution of Residential and Commercial Water End Uses (%).

		Commercial[2]				
	Residential[1]	Hotels	Restaurants	Offices	Schools	Grocery Stores
Toilets/urinals	23	21	17	40	47	15
Faucet/bathroom	8	1	1	2	2	1
Faucet/kitchen	15	14	52	11	11	20
Showers/baths	25	38	0	0	0	0
Dish washers	2	4	14	3	3	5
Clothes washers	23	11	0	0	0	0
Other	4[3]	11	16	44	38	59

[1]Adapted from USEPA (1998). Assumed 1/3 of faucet use in bathroom and 2/3 of faucet use in kitchen.
[2]Modified from Gleick *et al.* (2003). Cooling water and outdoor uses were removed.
[3]Leaks.

(4) As with the Solaire, a 5% loss of the wastewater was assumed.
(5) Rain water amounts of 18,348 l/d (4,854 gpd) are collected (47.3 in rain per year for New York City (U.S. Department of Commerce, 1991) on a roof of 5,574 m^2 (60,000 ft^2)).
(6) Conventional wastewater treatment generates 0.24 kg dry sewage sludge/m^3 (2 lb/1000 gal) (Tchobanoglous *et al.*, 2003) and the sludge is dewatered to 25% solids by a belt filter press (Tchobanoglous *et al.*, 2003).
(7) 30% brines are assumed for the reverse osmosis (PUB, 2002).
(8) Irrigation of indoor green areas every 30 floors (half of floor space planted, irrigation with 2.9 l/(m^2 d) (0.5 gal/(week ft^2)).
(9) Typical water and wastewater treatment efficiencies are used.

RESULTS AND DISCUSSION

Water Mass Balance for the Solaire

Main water end uses in the Solaire are the water use in the apartments (Figure 2, toilet and other residential uses) and the water use for the cooling tower. The other end uses for the operation of the building (Figure 2, chilled and hot water make-up; backwash for sand filter for cooling water; humidifier) are small.

From October 1, 2004 until September 30, 2005, on average 127,380 l/d (33,700 gpd) of municipal water entered the building, which is 56,580 l/d (14,900 gpd) less (31%) than the input flow of 183,960 l/d (48,600 gpd) to a conventional building that implements the same low-flow/water conserving fixtures and appliances (Figure 2). The reductions of the discharge to the sewer are similar. The reduction will increase to the design capacity of the on-site wastewater treatment plant (94,500 l/d (25,000 gpd)) when additional end users are online (full implementation of irrigation in nearby park, toilet flushing in adjacent new building). Excluding the cooling water, a reduction of 40,390 l/(d cap) (10,700 gpd) municipal water use (28%) was found (Figure 3). The water balance for the Solaire (Figure 3) was determined without the cooling tower to be comparable to the water balances of the 2020 Tower below. The municipal water for the cooling tower and for the backwash water and the backwash wastewater were excluded.

The reductions in municipal water use and sewage discharge demonstrate that the Solaire is able to partly close the water/wastewater loop. As expected, however, complete loop-closing in the building is not possible if the reuse water is only used as nonpotable water in the building (cooling water, toilet flushing water) and if only a portion of the flushing water and the cooling water is reuse water. In the Solaire, on average 33% of the cooling water and 78% of the toilet flushing water were reuse water (October 1, 2004 to September 30, 2005). A portion of the reuse water in the Solaire is used outside the building. One of the end uses is seasonal irrigation of a nearby park.

Whether other water/wastewater treatment scenarios come closer to closing the loop within the building will be further explored when evaluating the 2020 Tower scenarios below.

Water Mass Balances of the 2020 Tower

In the water balance analysis of the 2020 Tower, rain water as an input, and irrigation of plants in indoor green areas every 30 floors and perspiration/respiration as outputs have minimal impacts on the results (Figure 4).

All water consumed in the conventional high-rise building (other than rain water) is from municipal sources (Scenario 1). The water reuse options (Scenarios 2-4) show a reduction in municipal water

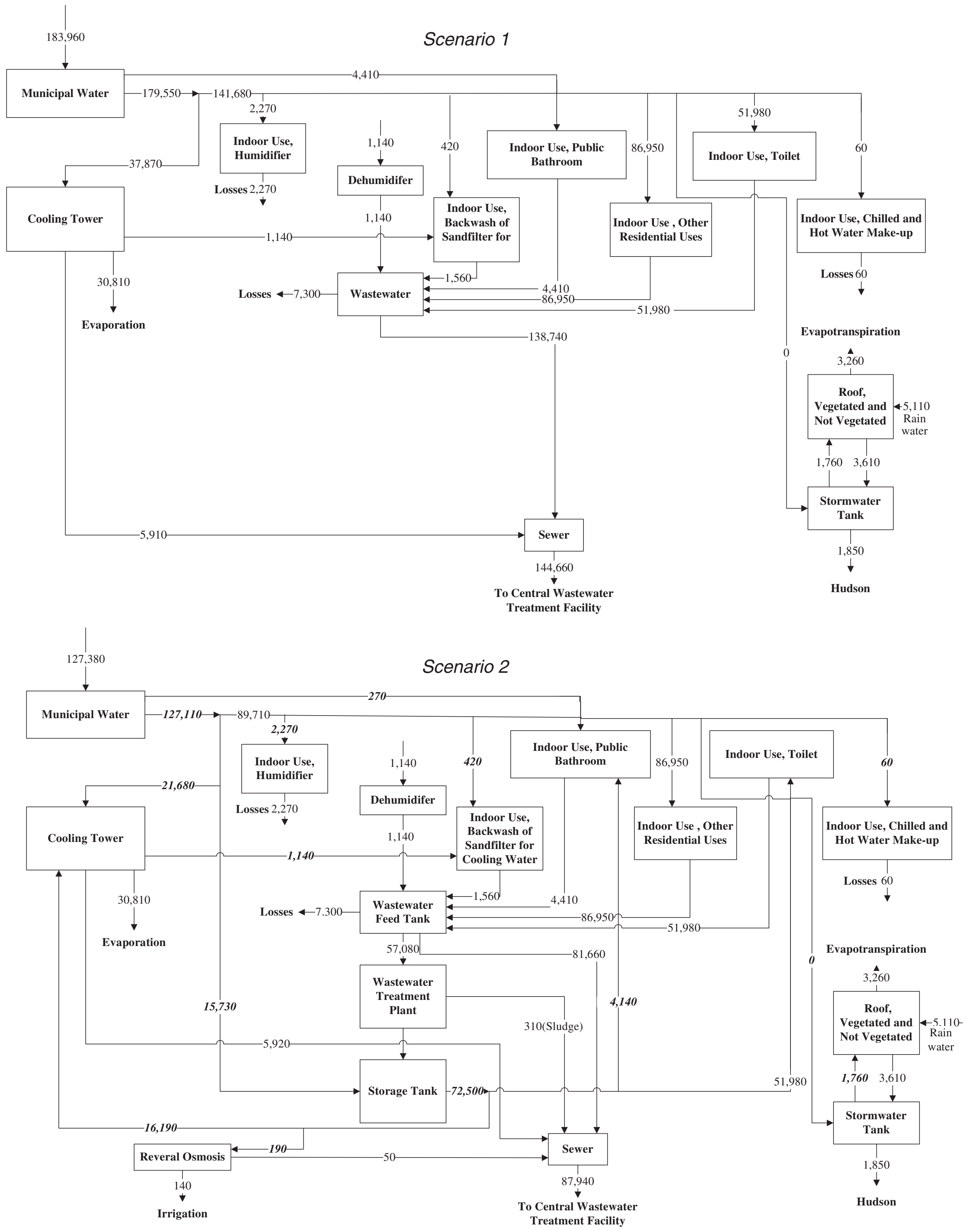

FIGURE 2. Detailed Water Mass Balance for Solaire Scenarios for the Time Period From October 1, 2004, Until September 30, 2005 (l/d, Scenario 1: conventional building with the same low-flow/water conserving fixtures as the Solaire but no water reuse, Scenario 2: Solaire building).

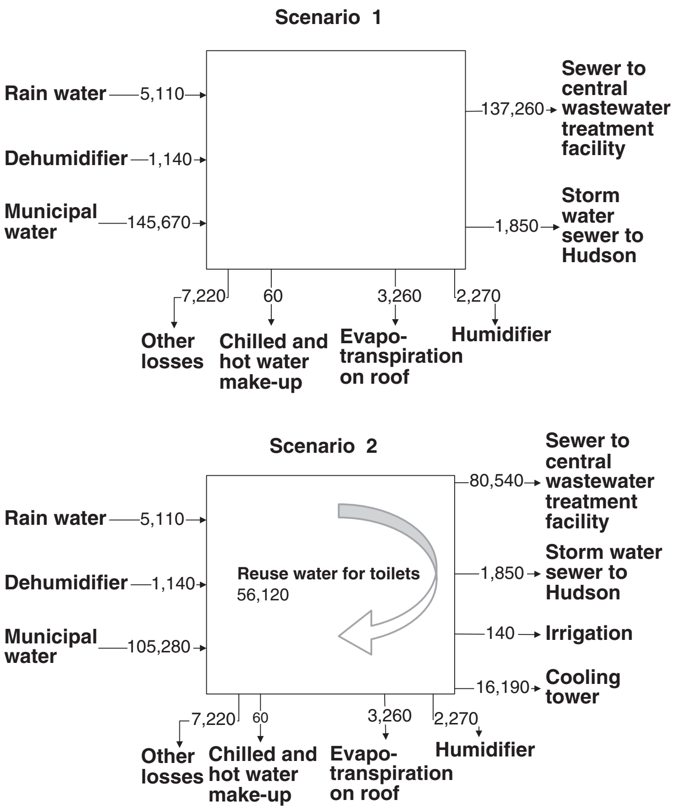

FIGURE 3. Summary Water Mass Balance for Solaire Scenarios (Excluding the Cooling Tower and the Public Bathroom) for the Time Period From October 1, 2004, Until September 30, 2005 (l/d, Scenario 1: conventional building, Scenario 2: Solaire building).

consumption by several hundred thousand liters per day (43-66%). In terms of loop-closing, Scenario 2, which generates potable water, is the most desirable option, where 1,324,100 l/d (350,000 gal/d) of water are reused. Reverse osmosis brines that are formed as residues from the water treatment process represent a difficult to handle waste stream and they are responsible for most of outputs. The rest goes to the sludge treatment process in Scenario 2. The amount of brines as outputs could be reduced in Scenario 2 if part of the wastewater is processed to nonpotable instead of potable water. In other scenarios (3 and 4), most of the output water goes to receiving bodies of water or other uses inside the building (cooling water) or outside the building (e.g., irrigation, flushing water for toilets in other buildings).

Although the amount is minimal, compost and residue flow (3,800 l/d) is separated in Scenario 3, and compost and residues flow (3,400 l/d) and urine flow (21,600 l/d) are separated in Scenario 4.

Less flushing water is used with urine separation resulting in lower use of reuse water in Scenario 4 (558,800 l/d) compared to Scenario 3 (856,800 l/d). The urine flow is a very small flow but is expected to contain 70% of the nitrogen and 63% of the phosphorus (Baccini and Brunner, 1991; Brunner and Rechberger, 2003). This flow also contains many micropollutants, especially pharmaceuticals and hormones, that are excreted by humans (NOVAQUATIS, 2005). Therefore, urine separation is an option that should be further investigated.

As discussed, complete closing of the wastewater/water loop within the building is not possible with the selected technologies. The high-rise building can also not be seen in isolation and the context needs to be taken into account. For example, other end users are needed when nonpotable water is produced, and residuals need to be handled off-site.

Daily Indoor Water Use in the Solaire

The 577 occupants in the Solaire building consumed on average 246 l/(d cap) (65 gcd) water from October 1, 2004 until September 30, 2005. Municipal water and reuse water were included in the water use, but cooling water and water used in the public bathroom were not considered. If the 45 nannies/housekeepers – even though they are not living in the building – are added as full day occupants, the average daily per capita indoor water consumption decreases to 227 l/(d cap) (60 gcd).

Without evaluating an actual conventional building similar to the Solaire, the water consumption in a conventional building is difficult to predict. After a toilet rebate program in the mid-90s replaced about one third of New York's toilets with low-volume toilets (6 l/flush, same volume as in the Solaire), a mean daily water use of 318 l/(d cap) (84 gpcd) was determined for multi-story buildings in New York City (Westat 1997). Considering only buildings built after 1947 an average daily indoor water use of 272 l/(d cap) (72 gpcd) was found. The same study also showed an increase in water consumption with increase in population density (higher buildings) and household income.

A field study of 1,188 single-family homes at 12 study sites across the United States (U.S.) and Canada (Mayer *et al.*, 1999) determined a mean per capita indoor water use of 262 l/(d cap) (69.3 gpcd) for indoors without major water conservation [range of study site means: 216 l/(d cap) (57.1 gpcd) in Seattle, Washington to 316 l/(d cap) (83.5 gpcd) in Eugene, Oregon]. This is not a national average, but this mean per capita water use is accepted for comparison purposes all over the United States. There is no similar study for multi-story buildings, but it is assumed that the mean per capita water use in multi-story buildings is similar or smaller (Vickers, 2001). If low-

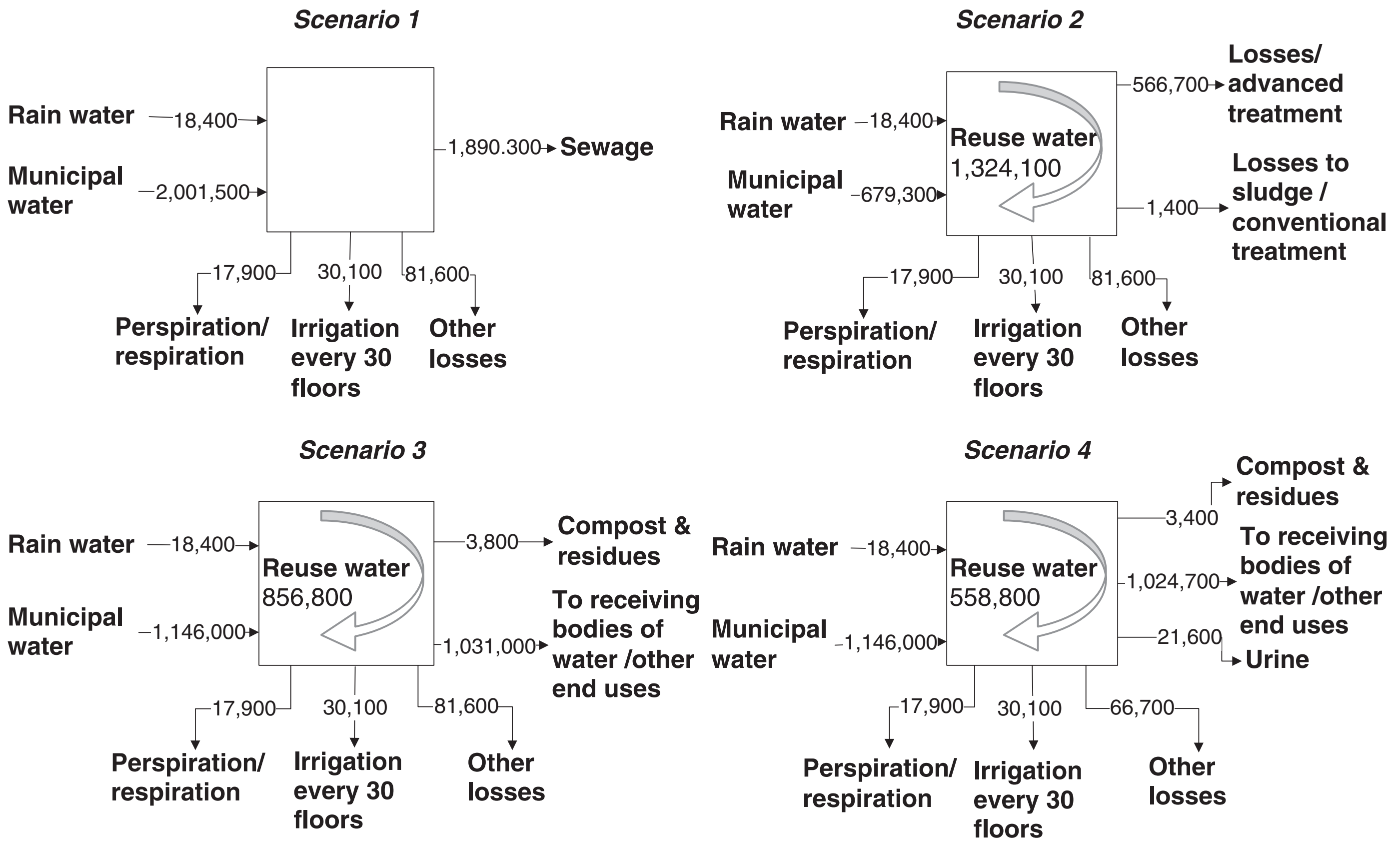

FIGURE 4. Water Mass Balances for 2020 Tower Scenarios [l/d, Scenario 1: conventional building; Scenario 2: 2020 Tower with treatment of wastewater to potable water; Scenario 3: 2020 Tower with treatment of source-separated streams to nonpotable water; and Scenario 4: 2020 Tower with treatment of source-separated streams to nonpotable water and separation of concentrated nutrients (urine)].

flow fixtures and appliances are implemented, the mean per capita indoor water use can be reduced to about 170 l/(d cap) (45 gpcd) for single-family homes [44.7 gpcd (USEPA, 1998); 45.2 gpcd (Vickers, 2001)]. The Solaire uses low-flow/water conserving fixtures and appliances, but the consumption considerably exceeded 170 l/(d cap) (45 gpcd). The toilet flushing water use in the Solaire was 90 l/(d cap) (23.8 gpcd), which is more than twice as much as expected {39.3 l/d [10.4 gpcd (USEPA, 1998)]; 31.0 l/d [8.2 gpcd (Vickers, 2001)]}. Some of this might be attributed to toilet leaks that were reported.

Socioeconomic factors and individual behavior may also explain the elevated water use in the building. Mayer *et al.* (1999) found similarities across 12 study sites between the amount of water used by the same fixtures and appliances, but emphasized the importance of individual behavior on mean daily water use. For example, water use increased with the size of the house (more affluent) and renters showered and flushed the toilets more often. If more occupants are working outside the building, there is less toilet and faucet use but an increase of water use for clothes washing and showers and baths. Dishwasher use and clothes washing are slightly responsive to household income. Households with teens and children use more water compared to households with only adults and clothes washing also increases with the number of teens in the household.

To better understand the water use in the Solaire, submetering and determination of individual water end uses would be beneficial. This should be complimented by an analysis of water consumption data (billing records) for newer New York City multi-story buildings.

CONCLUSIONS

The water balance analysis of the Solaire showed that efforts to close the loop reduce the amount of municipal water entering the building; however, as expected, make up municipal water is still needed in all scenarios. This remains true in the hypothetical

2020 Tower under an expanded range of scenarios. Therefore, water conservation (i.e., modification of human behavior) and water efficiency improvements (i.e., equipment, appliances and fixtures) are important major factors in reducing the municipal water needed in all scenarios.

This study also demonstrated the value of a case study. A case study cannot be generalized, but it can give an in-depth understanding of the study question, in this case water use and water conservation. An expansion of the current case study and also expansion into other resources, such as energy is needed (e.g., life-cycle assessment). For an in-depth understanding, human factors need to be included as well. Case studies in less affluent neighborhoods might prove to be very useful as well.

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