GREEN WATER TECHNOLOGIES AND RESOURCE MANAGEMENT FOR WATER SYSTEM HEAT-TRANSFER APPLICATIONS IN THE BUILT ENVIRONMENT

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INTRODUCTION

In recent years it has become self-evident to many of us that we need to protect and restore our changing environment. By "environment" we are generally referring to our surroundings—our biophysical environment, which in earlier times meant the four classical elements, earth, fire, water, and wind, and later came to include the quintessence *or the* aether*—air or space. Today we tend to refer more to the nitrogen, carbon, and hydrologic cycles. Also, today we consider our environment to additionally mean the exchange of mass energy or other properties that affect our life cycle and that of other organisms. But in our everyday world there is another environment—the built environment—which encompasses the design, construction, management, and use of buildings, neighborhoods, cities, parks, and systems that provide our individual and global surroundings, and the setting for all sustainable human activity. As all built environments depend upon energy, water, and other natural resources from the earth's biophysical environment for their very existence, it might be hoped that our biophysical and built environments (see Figure 1) can coexist in some form of commensal symbiosis, whereby we humans and our built environment benefit while the biophysical environment is unaffected. However, unless significant global positive change comes soon, it is looking increasingly like a parasitic relationship, where humans collectively benefit at the expense of the natural world.*

From construction to daily operation, our buildings and the built environment are the source of most global carbon dioxide (CO_2) emissions and, in recent years, in recognition and response to the unsustainable climate and resources position we find ourselves in, we have seen the founding of various national and international "green" (i.e., the promotion of conservation and sustainability) organizations and programs. Green organizations include natural resources defense groups and building trade bodies that have developed and promote sustainable building assessment rules, incentives, and design tools. Specifically, some green organizations include the Building Research Establishment (BRE)[2] in the U.K., the Green Building Council (USGBC),[3] and the Green Building Initiative (GBI)—the U.S. licensor of Green Globes[4]—both in the U.S. All these organizations have proposed best engineering, conservation, and sustainability practices for the built environment. Best practices include green water management programs for water-based heat-transfer systems that in turn have been developed over the years by trade bodies such as the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), the Federation of European Heating and Air Conditioning Association (REHVA),[5] the International Association of Plumbing and Mechanical Officials (IAPMO), and Building Owners and Managers Association (BOMA) International.

With regard to internationally used green building guides and design/operational tools, the BRE has developed an assessment method to measure and rate the environmental performance of any type of new or existing building—the Environmental Assessment Method for Buildings around the World (BREEAM).[6] In the U.S. the USGBC has developed their Leadership in Energy and Environmental Design program (LEED),[7] which additionally recognizes environmental leadership in the building industry, and the GBI has its Green Globes assessment protocol and rating system.[8] Also, ASHRAE

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FIGURE 1. The Built Environment.

has its Green Guide,[9] IAPMO its Green Plumbing and Mechanical Supplement,[10] and BOMA Canada its Building Environmental Standards (BESt).[11]

Many countries around the world have developed their own standards for green building or energy efficiency for buildings (and are members of the World Green Building Council, which sets the standard for high quality local councils and stimulates knowledge sharing.) The Dutch Green Building Council (DGBC),[12] for example, chose to use the English BREEAM methodology as the basis for their sustainability label. The Canadian Green Building Council (CaGBC)[13] has a LEED program very similar to that in the U.S., also with a LEED Accredited Professional (LEED AP) designation for those people who can demonstrate their understanding of environmentally sustainable building design, construction, and operation. In Australia the Green Building Council of Australia (GBCA) has its National Australian Built Environment Rating System (NABERS),[14] which rates a building on the basis of its measured operational impacts, including energy, water, waste, and indoor environment. New Zealand tends to work closely with Australia on many issues, regulations, and codes of practice; thus the New Zealand Green Building Council (NZGBC)[15] has Green Star rating tools and accredited professional training similar to those in Australia.

The various standards, measurements, and rating systems tend to provide slightly different environmental impact assessment paths for old and new properties, and for residential, commercial, and institutional (e.g., healthcare) buildings. Also, there are credits or stars potentially available in various categories, which although differing from system to system, tend to cover areas such as management, health and well-being, energy, transport, water, materials, waste, land use and ecology, and pollution.

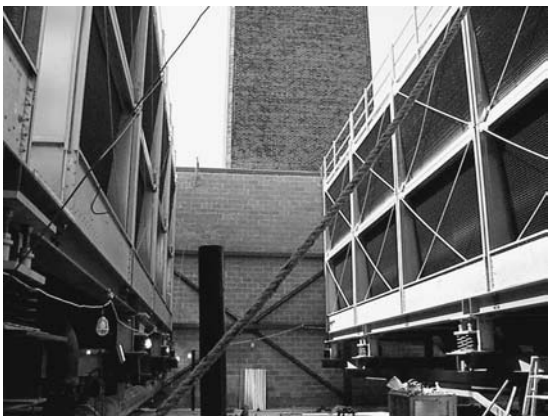
All green initiatives, guides, and management tools require some measure of water conservation and efficiency in rated buildings. For example, water conservation features may require consumption targets within buildings to be less than perhaps 30 to 35 gal/ft^2/yr, or that cooling towers be equipped with high-efficiency drift eliminators to achieve drift reduction down to only 0.002 percent of the circulated water volume for counter-flow towers and 0.005 percent for cross-flow towers. The New South Wales (NSW) Department of Planning recommends using water from rainwater tanks in the pool and spa (with appropriate pH modification and use of chlorine disinfectant), and supports the use of rainwater tanks for all non-potable uses. And through its BASIX[16] web-based planning tool, designed to assess the water and energy efficiency of new residential developments, has found, through a performance monitoring study, that average measured water savings exceed 40%.

In its report "Monitoring Energy and Water in Existing Buildings,"[17] the GBCA recommends using building management control system software to monitor water and energy consumption as a precursor to implementing resource minimization. The Water Efficiency (WE) section of the LEED Reference Guide for Green Buildings and Maintenance (Version 3)[7] requires a minimum of 20 percent reduction in internal building water use for LEED certified buildings. It also suggests strategies to make such buildings more water efficient, such as low-flow plumbing fixtures coupled with sensors and automatic controls, reusing non-potable wastewater (graywater) and capturing rainwater.

GREEN WATER TECHNOLOGIES FOR BOTH WATER AND ENERGY CONSERVATION

The LEED system is one of only a few green building rating systems that specifically consider cooling water management in buildings. LEED offers credits for conservation in areas such as cooling water

FIGURES 2 AND 3. Exterior and interior of large HVAC cooling tower.



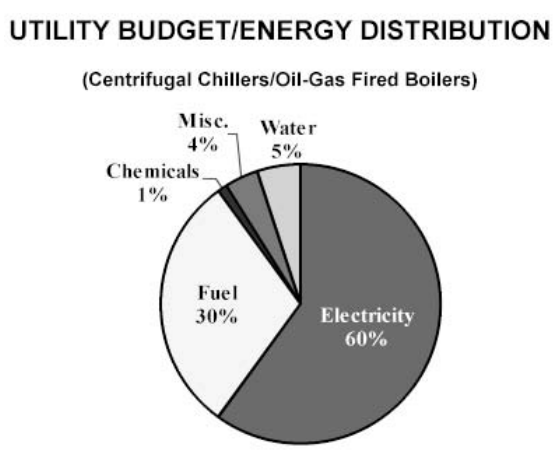
management for building heating, ventilation, and air conditioning and refrigeration systems (HVAC & R). The intent of LEED WE by cooling tower water management is to reduce potable water consumption through effective chemical management and/or use of non-potable makeup water; and credits are applicable in both conservation areas. A cooling tower is a prime example of a water-based heat-transfer system employed in commercial and institutional built environments (see Figures 2 and 3); but there are other examples, such as evaporative condensers, low-pressure steam boiler heating systems, steam humidifiers, and cold, chilled, and pressurized hot water loops. All these additional water systems offer opportunities for water and (especially) energy conservation through judicious water management, the application of green water technologies, and high operational efficiency. Even greater water and energy conservation target opportunities exist with very large building heat-transfer applications, such as district hot water heating, city building steam supply/distribution schemes, and university campus chilled water distribution from a central facility. Unfortunately, these types of systems are not well targeted under LEED.

Nevertheless, it should be noted that, with or without the impetus promoted by LEED and other initiatives, water treatment professionals have always been "green"—no matter the market sectors within which they might work, be they municipal potable and wastewater, ultrapure water, food and beverage, power or general industry, residential, commercial and institutional buildings, transport, and others. Objectives for the water treatment industry have not always been clearly stated, but effectively have always been:

- To reduce and conserve use of water and non-renewable energy sources.
- To prevent the contamination and misuse of water and other natural resources.

The pie chart below (Figure 4) demonstrates why water treaters have always been green. It shows that the cost of water and water treatment are only minor components compared to the energy costs of

FIGURE 4. Utilities pie chart.



a typical building utility budget. Small improvements in maintaining clean waterside heat-transfer surfaces provide large gains in heat-transfer efficiency and energy cost reduction, and property managers have always been eager to reduce and control energy costs.

Before being green became the new universal norm, water treaters had employed green water technology strategies for many years. Examples include:

- An emphasis on ensuring clean water-side surfaces, free of scales, corrosion, and foulants, to maximize heat transfer efficiencies and save energy resources.
- The promotion of high cycles of concentration (COC) for recirculating cooling water in cooling systems, to save water/chemicals/energy.
- The use of high-pressure (HP) boiler blowdown as a non-potable makeup water source to cooling towers.
- The recovery of condensate from whey (COW water) in dairies for use as boiler makeup water.
- In food plants, the recovery of evaporated water from tomato paste for general reuse applications.
- The triple rinsing and recycling of chemical pails and drums for reuse—saving material costs, and to reduce pollution.
- The water treatment industry has cut down on the use of zinc, phosphate, and (especially) molybdenum in recent years.
- The industry regularly uses chlorine dioxide and peracetic acid biocides to shorten pesticide chemistry life cycles.
- Water treatment companies often provide contract chemical-fill services so that drums of chemicals need not be left on site, thus minimizing health, safety, and spillage risks.
- Water treaters use "free cooling" strategies via strainer cycle protocols in spring and fall, to save energy in HVAC & R systems.

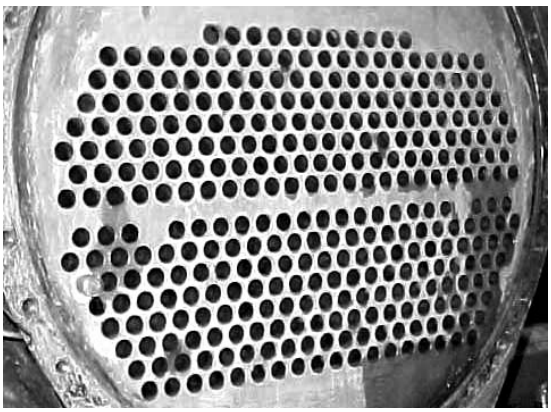
However, in this new era of environmental concern there remains much to achieve in the built environment, especially with regard to designing and providing comprehensive water-in to water-out technologies and total facility water/energy resource utilization management and sustainability. Even more, we need to promote the principles of water reduction/recovery/reuse and savings in associated energy sources (such as electrical driven pumps).

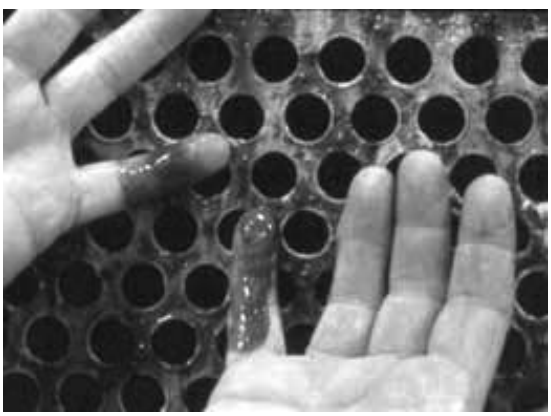
- Reduce—especially use of potable and fresh water
- Recover—especially process/waste streams for other applications
- Recycle—again and again, aiming for minimum energy input and (where cost-effective) zero liquid discharge

The LEED Green Building Guide—Operation and Maintenance—proposes WE credits for cooling tower management whereby operators are required to use at least 50% non-potable water and/or provide "chemical management." This latter program requires the development and implementation of a plan that addresses chemical treatment, bleed-off, biological control, staff training, and the use of a conductivity meter and controlled bleed rates to maintain proper cycles of concentration at all times.[7]

Our view is that whereas the intent of LEED in providing WE credits for both water conservation actions is sound, in practice a combined non-potable and chemical management approach is not always achievable, as the source and quality of any non-potable water stream proposed for cooling tower makeup will determine the requirements and costs of downstream chemical management. (i.e., the concentration and types of contaminants present in any non-potable water source will place limitations on possible cooling water COC and thus limit the potential for maximum water/energy savings, without incurring significant additional costs for physical pretreatments and/or chemical treatments.) Typically, lower-grade non-potable waters contain higher dissolved and/or suspended contaminants that require additional physical/chemical treatments to optimize the risk/rewards balance between water/energy savings and capital and maintenance costs. Each project must be considered on its individual merits due to differing water sources and qualities, potential treatment options, regional differences in energy and water costs, capital cost and maintenance limitations, and the desired environmental outcomes. Figures 5 and 6 reflect clean and fouled chiller heat-exchangers. The higher energy costs of heat transfer in a fouled chiller can be envisaged!

FIGURES 5 AND 6. Clean chiller heat-exchanger and fouled chiller heat-exchanger.

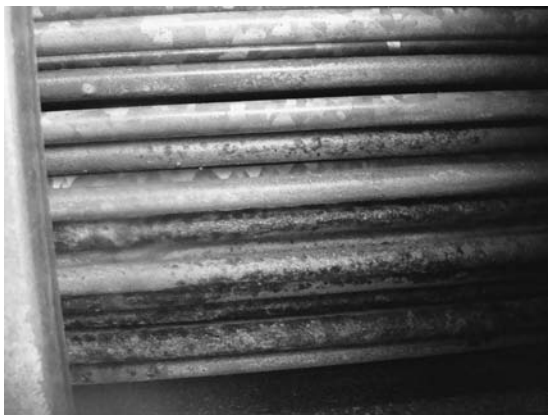




Thus, while we wholeheartedly agree with the intent of the LEED Guide, we would suggest that with respect to cooling tower water management it does not go far enough and that some of its emphasis is misplaced. We argue that:

1. Chemical management of cooling towers requires the development of a water management plan that addresses more than simply chemical treatment, bleed-off, biological control, etc. The section is, in our view, poorly written and incomplete. Given that energy is always the most costly and potentially environmentally damaging resource. The primary intent of a water management plan for cooling towers should be to focus on devising ways to minimize energy costs by maximizing heat-transfer efficiency, via producing and maintaining scrupulously clean water-side heat-transfer surfaces. If this objective can be achieved while simultaneously saving water through the use of non-potable makeup and high COC, then maximum green credits should accrue.
2. We acknowledge the importance of LEED (and similar green building programs) in the area of water efficiency, but suggest the program needs to consider not just WE credits but also water system energy efficiency (WSEE) credits. Also, WE and WSEE credits should be available for all types of building heat-transfer water systems—not simply cooling towers. Additionally required is a comprehensive approach to water and energy savings in building heat-transfer systems, in order to identify and coordinate total conservation opportunities and carbon footprint reduction.
3. Expanding on the theme of a coordinated approach to identifying energy savings from each and every type of building heat-transfer water system, in many cases it will be appropriate to employ analytical techniques such as pinch technology to calculate feasible thermodynamic energy targets (or minimum energy consumption) and achieve them by optimizing heat recovery systems, energy supply methods, and facility operating conditions.[18] In large buildings minimum water utility consumption should be targeted, leading to process network design/retrofit and a resultant water cascade table identifying water recycle and reuse paths. Such an approach will inevitably mean tight control of pretreatment equipment and chemistries, effective bleed-off and biological control, and in many cases the use of pumped feed systems and automatic monitoring and control equipment linked to in-house building energy management systems. Also required is the active involvement and commitment of in-house or outsourced building staff to the program—not simply training. Above all, in any water and energy resource management plan, a water treatment professional is required to interpret results and advise on and coordinate the overall program, if problems such as those shown in Figures 7 and 8 are to be avoided.

FIGURES 7 AND 8. Corroded condenser tubes and biofouled return water system.



4. "Chemical management" is an inappropriate term and an inadequate focus. All green water management plans should place primary emphasis on installing pre-treatment equipment technologies wherever possible and appropriate to take as much of the water treatment duty away from chemistries.

GREEN WATER PRETREATMENT TECHNOLOGIES

We know from experience that water treatment programs work best when pretreatment equipment takes the strain and chemistries are used in a polishing role. Suitable pre-treatment technologies[18] include:

- Side-stream or full-stream filtration: To reduce suspended solids and prevent fouling of heat-exchange surfaces and other areas within the cooling system. Multimedia filtration is generally the best choice, with particulate removal effectiveness, typically down to 10 microns. However, the filter bed can provide a platform for microbial growth so close control is necessary. Nevertheless, filtration is a boon for all cooling systems in helping to ensure clean waterside surfaces and can be recommended without reservation.
- Ion-exchange or lime-soda softening: To reduce hardness levels and increase COC. Usually partial softening is much better than full softening. Typically, an approximate 80/20 ratio provides cooling system makeup water with an acceptable Langelier Saturation Index (LSI). We note that some water management programs utilize full softening combined with natural or introduced silicate (or similar) corrosion-inhibiting chemical treatments.[20] Where ion-exchange softening is employed (in most cases), typically sodium chloride is the regenerate of choice; however, potassium chloride is a more environmentally acceptable regenerant.
- Dealkalization: By acid or ion-exchange, to reduce alkalinities and permit higher calcium concentrations without risk of carbonate scaling. Both methods permit higher COC. All developing countries tend to use sulfuric acid as it is cheaper.
- Electro-chemical devices for calcium removal, permitting high COC: Essentially these are side-stream electrolysis programs derived from electro-plating technology that drives calcium to a cathode, from where it has to be periodically removed as hydroxide sludge. Corrosion can be a problem with this technology so effective monitoring and control is vital.[21, 22] This green technology should not be confused with non-chemical or magnetic devices (NCDs).
- Cooling tower basin dirt sweepers: As with filters a further aid to producing clean recirculating cooling water, leading to higher COC without risks of heat-exchange surface fouling.

- Cottonwood air intake screens: A useful device for cooling towers and evaporative condensers to protect against their air-scrubbing effects in dust-laden atmospheric environments, such as when existing towers are located close to new building construction projects.

GREEN CHEMISTRIES

We note that no matter the type or design of water treatment plan and the use of pretreatment equipments, some water treatment chemistries will always be required, irrespective of the protestations of suppliers of so-called magnetic or non-chemical devices and the naysayers who believe all chemicals are toxic. However, chemicals should be regarded as "polishing" tools, to be used only at low concentrations and no more than necessary. With the technologies now available in the marketplace, organic chemistries generally can be substituted for up to 100% of inorganic chemistries (such as nitrites, borates, silicates, phosphates, zinc, caustic, and others) in every type of heat-transfer application. Feed rates and concentration requirements for organics are typically lower and operating efficiencies higher.

Modern organic chemistry formulations are primarily drawn from combinations of various common-or-garden phosphonates and polymers, together with limited concentrations of specialist chemistries. These formulation blends tend to permit operation at higher stress levels and higher cycles of concentration without undue risk of failure.[23] Thus, even though costs for organic chemistries (on a per-pound basis) tend to be higher than for inorganic-based programs, performance is generally better, leading to improved water conservation and, overall, a more cost effective program with an improved ROI.

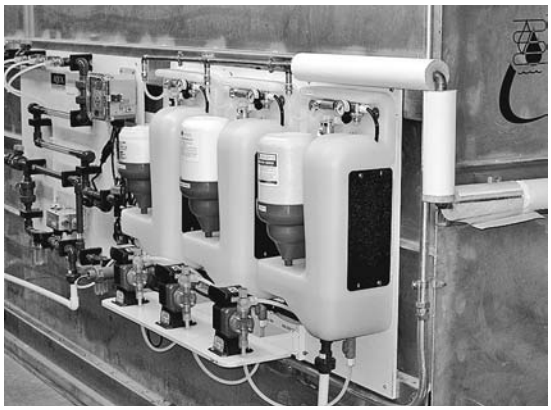
Some water treatment chemistries are derived from food chemicals, or are also used as indirect or direct food additives, or placed on generally-regarded-as-safe lists (GRAS). These chemistries are often promoted as being green and can include various molecules like ascorbates, sorbates, polysuccinates, and polyaspartates. However, these green chemistries are not suitable for every type of water system application, and the most effective molecules may often contain components such as phosphorus or nitrogen (e.g., phosphonosuccinate oligomer and iminodisuccinic acid), which, unfortunately, tend to anger the anti-phosphate/nitrogen lobbies.

Several effective non-P and/or non-N containing molecules are in common use for water treatment management; these include polymaleic acid (PMA), polyacrylic acid (PAA), and sulfonated styrene-maleic anhydride copolymer (SS/MA). But it is an inescapable fact that for maximum molecular effectiveness, i.e., green water management, a water treatment chemical formulation will most likely also require one or more phosphorus or nitrogen-containing chemistries, such as: tolyltriazole (TTA), 2-phosphonobutane-1,2,4-tricarboxylic acid (PBTC), phosphinocarboxylic acid (PCA), hydroxyphosphonoacetic acid (HPA), or polyaminophosphonic acid (PAP).[23] Thus, managing water systems with green methodology inevitably means that some (limited) phosphorous and/or nitrogen is added to the water as part of the chemical molecule treatment program. Figures 9 and 10 reflect safe and effective solid chemistry feed and control for smaller HVAC cooling systems and liquid chemistry feed and control for larger HVAC systems.

To those who suggest that being green means eliminating the use of all chemicals in water treatment schemes, we suggest that this idea is generally not possible or practical for several reasons, including the following:

1. The alternatives often proposed are often some form of NCD, such as permanent or electromagnetic, AC induction, or electrostatic physical water treatments. If these equipments do actually work (and this is still a contentious issue), they tend to adequately perform only under very limited and very controlled conditions, and only with certain types of water (generally low-to-medium hardness waters). They are not suitable for cooling systems employing recycled waters such as grey water as makeup. NCDs look an appealing—if capital expensive—green option and are often favored by new construction specifiers, but there remains too much marketing hype with these product offerings and not enough peer-reviewed performance data made available from the industry. In addition to scale control, water savings, and little or no

FIGURES 9 AND 10. Solid and liquid chemical inhibitor and biocide feed, monitoring, and control.



operator oversight, additional claims made often include corrosion control fouling control, and planktonic and biofilm sessile microbiological control. Most of these claims are spurious, as documented in a considerable body of literature. From an example of this literature,[24] the following generalizations can be drawn:

- The performance of these devices under both controlled laboratory conditions and field conditions has been unpredictable.
- In applications with positive results, basic mechanical and chemical information on the systems has been lacking, compromising the credibility of these results. In addition, the experimental designs have been questionable.
- Some manufacturers have made extravagant claims leading to a discrediting of the industry.

Note 1: The author has personally conducted controlled field trials and observed similar trials conducted by independent engineering consultants on a variety of non-chemical devices. These trials were all in hard water areas where cooling towers tend to operate at low COC, (i.e., high water consumption) and the risk of scaling on heat-transfer surfaces and resultant high energy costs are a significant ongoing problem. No successful result has ever been observed by the author where non-chemical devices have been used to treat hard water.

Note 2: A "pulse-powered chemical-free water treatment" device is proposed by ASHRAE (Green Tip #14).[25] The tip provides both pros and cons, but in the author's view, the pros are too general, whereas the cons are specific: "The equipment does not work effectively on very soft or distilled water, or with high chlorides or silica, and energy is still required."

2. Green Chemistry/sustainable chemistry initiatives do not seek to eliminate chemicals (there are more than 50 million named chemistry molecules available today); rather, they support the research and development of safer chemicals and safer chemical processes, and propose pollution prevention via source reduction (i.e., chemical transformations not harmful to the environment). The concept of green chemistry is also based on 12 principles developed some years ago by Anastas (then of the USEPA), such as maximizing atom efficiency, i.e., as per current water technology practice where we typically use formulations based on synergistic blends of phosphonate/polymer chemistries obtained from different chemistry manufacturers, to provide effective control over scale, ferrous corrosion, and fouling problems.[26]

Note 3: The recently published ASHRAE Green Guide discusses water treatment for cooling tower systems and focuses only on chemical water treatment.[5] However, the chemical discussion notes provided are somewhat out of date, not particularly green, and tend to reflect protocols for chemical

water treatment in large industrial cooling towers in developing countries rather than for building HVAC & R systems in fully developed countries.

3. Some promotions advocating the elimination of toxic chemicals are simply disingenuous. An example drawn from a recent marketing flyer[27] proclaims, "To be Green, both the USGBC LEED and USEPA Green Chemistry programs require that use of toxic chemicals be minimized or eliminated." The flyer goes on to promote its product as "the only effective microorganism control technology that eliminates use of all toxic chemicals," and "the equipment is a safe, cost effective means for making aqueous electrolytic bromine from the bromide ions found within the cooling water to control microorganisms in cooling tower systems." However, it should be noted that whilst we fully accept the technology works effectively, the equipment generates and uses hypobromous acid, which is regulated as a pesticide chemical (i.e., a toxin) under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA).

ZERO LIQUID DISCHARGE AND ZERO BLOWDOWN TECHNOLOGIES

Finally, we need to look at the potential for zero liquid discharge (ZLD) and zero blowdown technology (ZBT) as an ultimate objective in cooling water savings. There are various "green packages" of pretreatment equipment and chemical water treatment available in the marketplace that are appropriate for building HVACR cooling systems and aim for ZLD or employ ZBT. Many of these combination systems are promoted as new green technologies, yet for the most part such technologies have been available in one form or another for several years—when being green was not fashionable. Most, if not all, of the technologies on the market do work reasonably effectively, although they are not foolproof. Thus, because every cooling system, and the water it uses, provides a unique challenge, some initial field operating problems are to be expected, although a skilled water treater will identify and solve them.

Some ZLD/ZBT technologies are also appropriate for using non-potable recycled water as makeup. For commercial/institutional buildings the basic approach is typically as follows:

1. A cation ion-exchange water softener is employed to fully soften the recirculating cooling water, via a side-stream. The softener may be of a traditional design with tank space for resin bed expansion during backwashing, or a fully packed or high-efficiency softener design (HES).[28, 29]
2. The replacement of calcium by sodium (or increasingly by potassium, which is more expensive but more environmentally acceptable) permits COC to typically rise from 3 to 5x up to 12 to 16x, or possibly 25x or more—depending upon water losses due to drift, leaks, and/or filter and softener backwash demands. As calcium carbonate cannot now form scale on heat-transfer surfaces, a significant rise in COC is possible, which results in considerable water savings. In practice, however, the average COC over a 12-month period seldom exceeds 12 to 15x. And it should be remembered that the law of diminishing returns applies, so when COC exceeds 5 to 6x, the additional water savings possible with higher COC becomes progressively less and less, yet the risk of some other, often unforeseen, problem developing increases rapidly (such as supersaturation and fouling by other mineral salts in the recirculating water).
3. A filter of some design is always required (usually on a side-stream) to remove the accumulations of suspended solids that arise in the (zero bleed) recirculating water, as a result of the air-scrubbing action inherent in all cooling towers and evaporative condensers.
4. The highly concentrated recirculating water is decidedly corrosive to system metallurgies due to the lack of calcium present in the water (as calcium salts provide some anodic protection to system metals), and made even more corrosive due to the rise in alkali metal concentrations from ion-exchange, i.e., the exchange of calcium ions for aggressive sodium or potassium ions. This means that a supplemental chemical corrosion inhibiting treatment is always required. Some green packages simply use the higher levels of natural silicate in the water to provide basic protection—but these seldom work well as the silicate is not usually present in the polymeric form required to act as a corrosion inhibitor. Therefore, additional or complete replacement

chemistry is required. Also, depending upon the package supplied, the corrosion inhibitor component formulation may be based on inorganics such as polysilicates, poly/ortho phosphates, zinc and/or molybdenum, or organics such as TTA, HPA, PAP, or PBTC.

5. Additionally, an organic polymer chemistry component is required to stabilize the zinc, silicate, or phosphate chemistries (where used) and to control the precipitation of other saturated or supersaturated salts or troublesome minerals (such as iron or manganese) present in the recirculating cooling water. The polymers are usually various co- or ter-polymers, such as acrylic acid, 2-acrylamido-methylpropane sulfonic acid copolymer (AA/AMPS) or (where iron is a problem) acrylic acid, 2-acrylamido-methylpropane sulfonic acid, tertiary-butylacrylamide terpolymer (AA/SA terpolymer).
6. Where recycled water is used as a makeup source, additional contaminants such as ammonia, phosphate, or biologically supportive organics may be present, which give rise to additional water management complications. Such water may require tertiary treatments such as nitrification or aeration plus the use of additional chemical treatments. NCDs simply will not work under these conditions. Where, for example, ammonia is present, it will attack copper in the cooling system and so TTA chemistry plus pH modification (generally lowering the pH) will be required. If considerable sodium is present we can expect white rust corrosion of galvanized zinc cooling tower components. Silicates will not work effectively here but we may be able to use any phosphate present in the water as the basis of a tertiary inhibitor chemistry program. Again, this will typically require pH modification plus the use of other passivators such as a glucoheptonate.
7. For some heat-transfer schemes where very difficult waters are employed and ZLD is required, membrane equipment technologies, such as reverse osmosis (RO) and ultra filtration (UF) may be specified, but these schemes generate their own downstream problems (RO always generates a small "concentrate" discharge water stream that must be further treated if ZLD is to be achieved.), so a concentrator or crystallizer may also be required. These types of schemes are usually beyond the scope of normal building HVAC & R green programs, but ZBT may be appropriate.

GREEN WATER TECHNOLOGIES TOOLS AND RULES

It can be seen that to be green, to employ genuinely green water technologies, and practice effective water/energy resource management and conservation for heat-transfer applications in the built environment, is not simple; but to provide an effective sustainable water treatment solution is immensely rewarding to the mind and soul of the water treater. There remains, however, much to do as most buildings still use potable city water as their only source of cooling system makeup. Also, specifications for new construction building HVAC & R cooling systems today still typically tend to follow a standard but "tired" water management formula, based on limited pretreatment equipment, inefficient monitoring, limited servicing protocols, and chemistries that are not as green as they could be, and all at the lowest possible price. Unfortunately, there is no clear definition as to what constitutes a green water treatment chemical, and it is unlikely there ever will be as the reality is that chemicals are simply tools to be used by an experienced water treater in the same ways as he/she uses filters, RO, softeners, etc., as part of the armory employed to develop comprehensive and effective water treatment programs.

There are some companies out there who will certify products or services for "greenness" or "environmental preference"—at a price! One or two provide on-line, rapid self-certification processes, but these certification schemes are not worth the paper they are written on.[30] Others claim to be industry leaders in environmental compliance solutions but typically, these firms have no genuine mandate, qualification, or legal authority to act as certifiers. They tend to reserve the right to reject any water treatment product if it contains a chemistry that they have designated as a "prohibited ingredient," but the fact is they have no knowledge of how the product is to be applied in the field, its in-use concentration in water, or any removal and disposal mechanisms.[31] Nevertheless, there are some commonsense rules for using green chemistry and other green water technologies

for heat-transfer applications in the built environment. Examples of these rules include the following:

- No Cr, Hg, or organometallics should be permitted in discharged cooling water.
- Only limited discharges can be permitted for Cl_2, absorbable organohalogens, trihalomethanes (THMs), zinc, or phosphate.
- Biocides and algaecide pesticides will be needed. After any pesticide shock treatment, conduct a luminescent bacteria/algae test and bleed only if the luminescent bacteria toxicity result does not exceed $G_L = 12$.

Note: The luminescent bacteria test is a basic test for ecotoxicological testing of chemicals, waste water, and eluates from soil and sediment. Luminescent bacteria such as *Photobacterium phosphoreum* may be used, G_L = lowest ineffective dilution factor (LID), i.e., the dilution at which the inhibition of a luminescence effect in the test is slightly below 20%.

- Energy conservation is critical! A calcium deposit of 0.5 mm reduces heat transfer by 20%—and so raises energy consumption for any given output.
- Phosphonates are biologically poorly degradable; avoid high feed rates.
- Polycarboxylates degrade poorly. Low molecular weight favors degradation.
- Compared to Zn, the aquatic toxicity of molybdates is substantially lower, but high concentration can be toxic to plants and grazing animals, so care is needed.

SUMMARY

In summary, the various green building best practices programs developed in recent years by organizations such as the BRE, USGBC, GBI, and others have done much to protect and restore our changing biophysical environment against the negative effects of our global built environment. Good progress has been made to promote water and energy conservation in our buildings. Nevertheless, more needs to be done to focus on minimizing heat-transfer water system energy costs by promoting clean waterside surfaces and maximizing heat transfer rates in all types of facility water systems. This focus will lead to minimum water system energy consumption and provide opportunities for tax deductions (in the U.S. at least).

Note 4: Tax Deductions are available for energy-efficient improvements to commercial buildings under U.S. Internal Revenue Code, Section 179D.[32]

Linking this water system energy saving objective to the established intent of saving water in buildings and widening the scope for reuse of non-potable water has a positive compounding effect for conservation and sustainability in the built environment.

However, for any green building heat-transfer application, it is unlikely any single strategy or simple "install-and-forget-about-it" water treatment option can provide both maximum water and energy savings. Also, there is no clear definition as to what constitutes a green water treatment chemical. Thus, it can be deduced that for any green building project, the answer to providing very clean waterside surfaces, controlling associated pretreatment, chemistry, and maintenance costs, and maximizing water and energy efficiencies to produce an acceptable ROI requires a close working partnership between the specifier and water treater.

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