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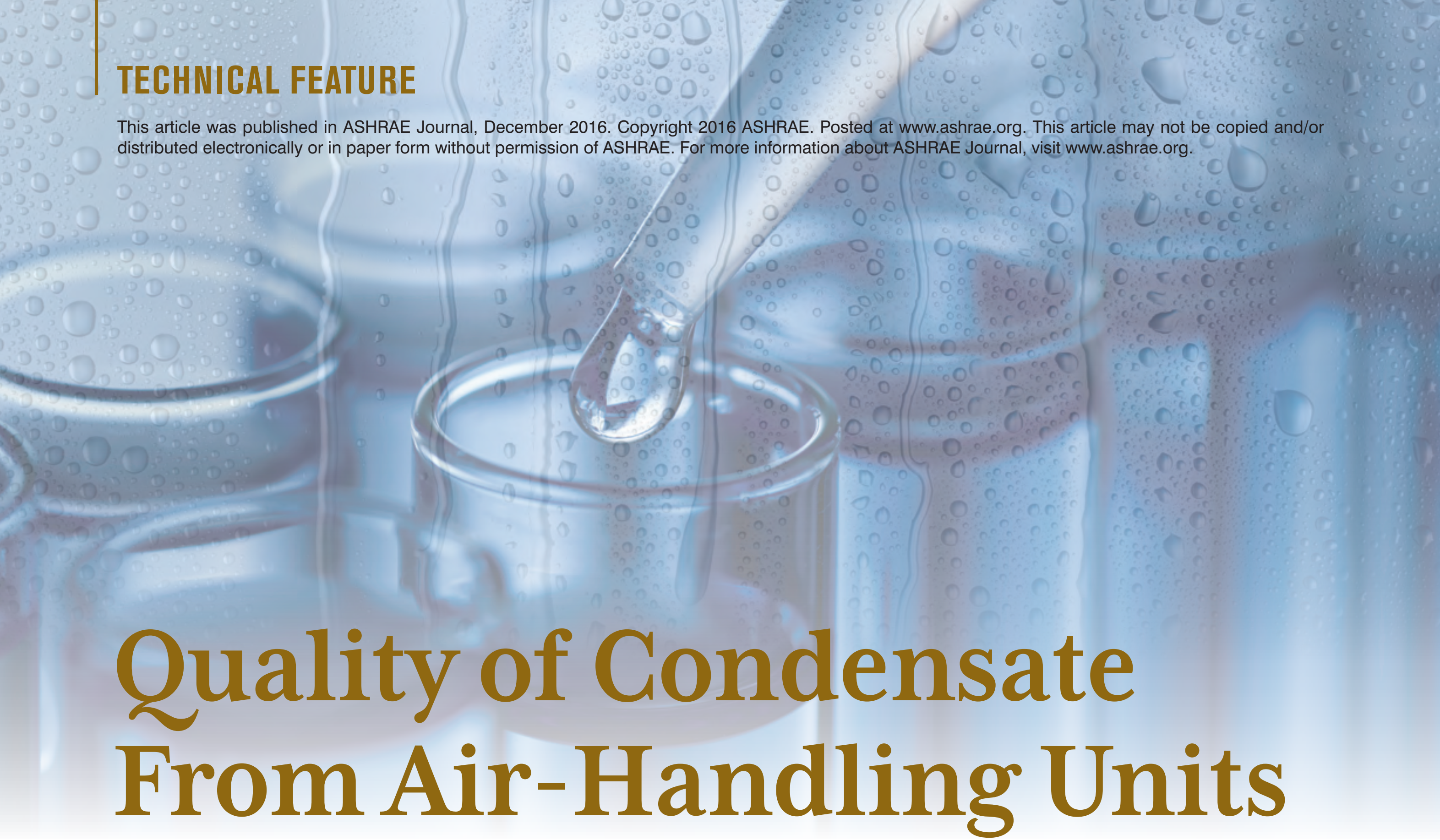

Quality of Condensate From Air-Handling Units

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Collecting condensate from large air-handling units (AHU) for on-site use is compelling, particularly in humid climates prone to drought. Identifying the optimal on-site use for the condensate requires knowledge of the quantity and quality of the condensate versus the quantity and quality required for potential on-site applications. This article provides evidence that condensate from properly maintained large AHUs is high-quality water, explains how system design and maintenance affect condensate quality, and highlights considerations for on-site applications of condensate.

The condensate addressed in this article refers strictly to condensate from the cooling coils of large AHUs such as those in commercial and institutional facilities, as opposed to condensate from steam systems, which is inherently different. Only large AHUs yield enough condensate to justify the expense of collecting and using condensate on site. This size threshold is reflected in the ASHRAE Standard 189.1 requirement to collect condensate for reuse from "air-conditioning units with capacity greater than 65,000 Btu/h (19 kW)… in regions where the ambient mean coincident wet-bulb temperature at 1% design cooling conditions is greater than or equal to 72°F (22°C)."[1]

Figure 1 illustrates the fundamental components inside an AHU. As relatively moist and humid air flows over the cooling coils located inside an AHU, the moisture in the air condenses on the cooling coils and drips into a drain pan located beneath the cooling coils. This water, hereafter referred to simply as condensate, is removed from the AHU through an exit port. The condensate can then be either disposed of properly or used on site.

Rough estimates of the expected quantity of condensate produced by an AHU can be calculated using rules of thumb.[2,3] More accurate estimates can be calculated using models based on climate data.[4,5] Although condensate derived from the air in most locations is expected to be high-quality water, fear of contamination often deters its use as an alternative on-site water source. Contaminants in water can be defined as a physical, chemical, biological, or radiological substance or matter.[6]

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The contaminants in the condensate formed on the cooling coils originate from one of two sources. The first source is the air passing through the AHU. Air filters installed at the outside and return air entrances to the AHU act to capture contaminants suspended in the air (*Figure 1*). Contaminants that are not captured by the air filters pass through to the cooling coils. This is the reason condensate from AHUs in facilities like hospitals, where return air could contain pathogens, requires special consideration or is even disqualified from consideration for reuse.

The second source of contamination is the surface of the cooling coils and drain pan. Since the formation of condensate on the cooling coils occurs in a process similar to distillation, the resulting condensate is slightly acidic and lacks total dissolved solids. As such, condensate tends to react with the metal surface of the cooling coils and drain pan to form metal ions, a chemical contaminant.

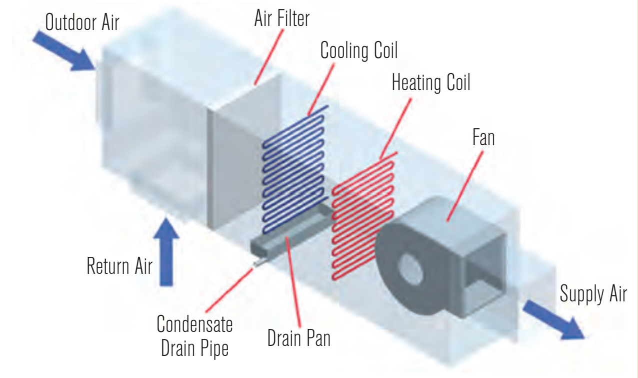
In addition, if the AHU is poorly maintained, microbial growth may accumulate on the cooling coils or the drain pan and be picked up by the condensate. If antimicrobial tablets are placed in the drain pan as part of a preventative maintenance program, the ingredients in the tablets can become a source of chemical contamination as well.

Once the condensate exits the drain pan in the AHU, it travels through plumbing to a sewer drain, an immediate application on site, or a storage tank for later use on site.

The plumbing and associated fixtures along the flow path, hereafter referred to as distribution plumbing, can be an additional source of contamination. Biofilms containing microbes build up on the inside wall of water distribution pipes over time in virtually all water supply systems, including drinking water. Most of these microbes are harmless to humans. However, action is required when pathogenic microbes are detected.[7]

Contamination by distribution plumbing materials is also a consideration.[6] For example, condensate collection systems with long runs of copper pipe can result in condensate with a higher concentration of copper compared to similar systems using polyvinyl chloride (PVC) or cross-linked polyethylene (PEX) pipe.

FIGURE 1 Schematic of a typical draw-through commercial air-handling unit (AHU).



Water Quality Requirements

The required level of water quality depends on the intended application. Some examples of on-site condensate use are cooling tower makeup water, irrigation, car washing, toilet flushing, and process water. Water that has a higher likelihood of body contact, inhalation, or ingestion must be of higher quality than water that will not come in contact with humans. For example, subsurface irrigation does not require as high a quality of water as toilet flushing. The requirement for high-quality water is typically to prevent illness from pathogenic microbes and toxins.

The concept of only treating water to the purification level necessary for the intended application keeps treatment costs to a minimum. This concept is referred to as "fit for purpose."[8] When water treatment is necessary, it is commonly achieved through one or more of the following techniques: screening, sedimentation, ozonation, filtration, adsorption, UV exposure, chlorination, pasteurization, advanced oxidation, reverse osmosis, and addition of anticorrosive additives.

Unlike drinking water, which must follow federal regulations, water collected for on-site non-potable applications is governed by state and local jurisdictions per applicable codes. These codes govern the materials, design, construction, and installation of systems to promote human health and facilitate system operation and maintenance. For example, among the many requirements of the International Plumbing Code is the requirement to transport non-potable water in clearly marked purple pipe and protect any potable water supply connected to a non-potable water system against backflow.[9]

TABLE 1 Chemical contaminants in condensate samples in parts per million (ppm or mg/L).

	CHEMICAL CONTAMINANT	ALUMINUM (Al)	CALCIUM (Ca)	COPPER (Cu)	IRON (Fe)	LEAD (Pb)	MAGNESIUM (Mg)	NICKEL (Ni)	POTASSIUM (K)	SODIUM (Na)	ZINC (Zn)
CONDENSATE SAMPLES	Practical Quantitation Limit (PQL)	0.050	1.00	0.010	0.050	0.010	0.050	0.010	1.00	1.0	0.010
	Number of Samples in Which Contaminant Detected	3	0	13	2	0	1	1	0	1	15
	Values/Range of Detected Contaminant	0.053 0.078 0.547	—	0.016 to 1.34	0.130 0.956	—	0.059	0.171	—	11.3	0.018 to 0.267
	Average of Detected Contaminant	0.226	—	0.23	0.543	—	0.059	0.171	—	11.3	0.18
	Drinking Water Primary Maximum Contamination Level (PMCL)[10]	—	—	1.3	—	0.015	—	—	—	—	—
	Drinking Water Secondary Maximum Contamination Level (SMCL)[10]	0.2	—	1.0	0.3	—	—	—	—	—	5
	SAWS Drinking Water Quality[11]	<0.02	56.2 to 99.0	<0.002 to 0.379	<0.01 to 0.091	<0.001 to 0.0163	8.99 to 18.20	0.0011 to 0.0062	1.10 to 6.53	8.08 to 23.4	<0.005 to 0.0328

Ensuring that a reclaimed water system satisfies applicable codes and produces water quality adequate for the intended use is the joint responsibility of the designer and installer. Maintaining this quality is the responsibility of the building owner through effective operation and maintenance of the system.

Experimental Approach and Analysis for the Study of Condensate Quality

Since the expected potential contaminants in condensate are chemical and microbial, the evaluation of condensate water quality will be based on the concentration of these constituents along with physical properties, which may impact condensate use on site. Samples of condensate were collected from AHUs in a diverse set of commercial buildings in terms of age, size, function, and configuration of the condensate flow path. To focus strictly on the quality of untreated condensate from the AHU and distribution plumbing, this study measures contaminants encountered upstream of any storage tanks in the system. Untreated stagnant water in storage tanks is expected to foster microbial growth and may contain other sources of water such as rainwater or makeup water from a municipal supply.

Although preliminary results from over 50 water samples tested in a laboratory at Trinity University support the results published here, only test results from 19 water samples tested in labs certified by the National Environmental Laboratory Accreditation Program (NELAP) are included in this paper. (These labs are the San Antonio Testing Laboratory in San Antonio and the U.S. EPA Office of Research and Development in Cincinnati.)

The results of the chemical analysis, physical measurements, and microbial analysis were evaluated for range and trends. Individual building characteristics were explored to determine causes of irregularities in the data.

Since condensate is high-quality water, the most practical thresholds for comparison are the National Primary Drinking Water Regulations[10] (includes the National Secondary Drinking Water Regulation). The primary regulations are enforceable for drinking water, while the secondary regulations are "non-enforceable guidelines regarding contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water."[10] In addition, since water quality only needs to be "fit for purpose" and condensate is rarely used on site for drinking water, the test results are also compared to other water requirements and data, where appropriate.

Chemical Analysis, Results, and Considerations

Table 1 shows the results from 19 condensate samples compared to National Primary Drinking Water Regulations of chemical contaminants and municipal water quality in San Antonio where the condensate samples were collected.[10,11] Only those regulated chemical contaminants that are potentially present in condensate were tested. For example, no source exists for arsenic, barium, or chromium to contaminate the condensate unless the AHU is located at a site, such as an industrial

site, for which these contaminants are found suspended in the air at the intake of the AHU. So these regulated contaminants are not included in *Table 1*.

The likely metal contaminants found in condensate are traces of the aluminum, copper, iron, nickel, and zinc from the metal components inside the AHU. Older systems could also include traces of lead from lead solder on the cooling coils or copper pipes. The practical quantitation limit (PQL) listed in *Table 1* is the lowest measurable value for each contaminant tested using certified test equipment. For chemical contaminants detected in three or fewer of the 19 water samples, the individual measured values are shown in *Table 1*. Otherwise the range of measured values is provided.

The most common chemical contaminants were zinc (Zn) in 79% and copper (Cu) in 68% of the samples, followed by aluminum (Al) in 16% and iron (Fe) in 10% of the samples. Only one condensate water sample measured at or above the National Primary Drinking Water Regulations' primary maximum contaminant level (PMCL) for chemical contaminants. This sample was collected from a location were the condensate had traveled over 150 ft (45 m) in a copper tube after exiting the AHU. The sample contained 1.34 ppm copper, slightly over the 1.3 ppm PMCL. This was the only sample that would not qualify as drinking water quality due to elemental chemical contaminant levels.

Samples were collected from locations where the condensate had traveled anywhere from 3 ft to 150 ft (1 ft to 45 m) in copper tubing (14 samples), PVC pipe (two samples), or galvanized pipe (three samples) after exiting the AHU. Although the sample with the highest copper content was from the longest single run of copper pipe (150 ft [45 m]), and the samples with the highest copper contents tended to come from the longer lengths of copper pipe, there is not a perfect correlation between length of copper pipe and the amount of copper in the condensate.

For example, the condensate samples with the next highest concentrations of copper after 1.34 ppm were 0.792 ppm and 0.302 ppm, taken from a 30 ft (9 m) and 60 ft (18 m) long copper pipe, respectively. In addition, one sample from a copper pipe over 100 ft (30 m) contained less than 0.010 ppm of copper, while a sample from a PVC pipe contained 0.034 ppm.

The data indicates that length of copper tubing through which condensate travels is a significant factor in the resulting copper content in the condensate, but not the only factor. Other likely factors include the metal composition of the cooling coil inside the AHU and properties influencing the interaction between a metal surface and condensate, such as the thickness and composition of any biofilms formed on the metal surface and flow rate of the condensate.

Aluminum, copper, and iron were the only elements that occurred at values above the National Secondary Drinking Water Regulation's secondary maximum contaminant level (SMCL), in one sample each. Since PMCLs do not exist for aluminum or iron, the samples with elevated aluminum and iron would qualify as drinking water quality in terms of elemental chemical contaminant levels. However, since these samples exceed the SMCLs, the water might cause cosmetic effects or not be aesthetically pleasing.

The presence of aluminum and copper in the condensate can be explained by the fact that these metals are the primary materials comprising cooling coils. In addition, iron and nickel (Ni) can be found in the galvanized steel drain pan and some pipes in the flow path downstream of the cooling coils. Nickel was found in one condensate water sample. No lead (Pb) was detected in any condensate samples.

The other elements tested were calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na). Calcium and magnesium contribute to water hardness. Potassium and sodium levels influence alkalinity. They are also the main cations (i.e., positively charged ions) present in freshwater, from which drinking water is derived. Condensate values for calcium, magnesium, potassium and sodium are below levels commonly found in drinking water, as shown in *Table 1.*

Physical Measurements and Results

Results of physical measurements are shown in *Table 2*. Temperatures of the condensate at the time of collection ranged from 55°F to 81°F (13°C to 27°C). The samples collected just downstream of the AHU exhibited the lower temperatures, while the samples collected at a discharge point far downstream of the AHU and located outside were higher.

The total dissolved solids (TDS) measured 2 ppm to 33 ppm, well below the SMCL of 500 ppm. In addition, the TDS range measured is below typical municipal drinking water levels as illustrated by comparison with local municipal (San Antonio Water System) drinking water quality. Low TDS is a benefit for on-site applications such as cooling tower makeup water and process water where mineral deposits caused by TDS are undesirable.

The data revealed that the three samples with pH values below 6.00 (5.94, 5.67, and 5.16) were the only three samples with measurable aluminum contamination of 0.053, 0.078, and 0.547, respectively. Aluminum contamination is attributed to aluminum used in cooling coils in some AHUs. The pH values excluding those from the three samples with high aluminum content ranged from 6.0 to 6.9, still slightly acidic, which can lead to corrosion and negative aesthetic characteristics. Additives can be used as needed to increase the pH for the selected on-site application. As a point of reference, the expected range for drinking water per the National Secondary Drinking Water Regulations is pH of 6.5 to 8.5.[10]

TABLE 2 Physical properties of condensate samples.

	PHYSICAL PROPERTY	TEMPERATURE (°F)	PH	TOTAL DISSOLVED SOLIDS (TDS) (PPM)
CONDENSATE SAMPLES	Uncertainty in Measurement	±1° F	±0.05 pH Units	±2 ppm
	Range for Samples	55 to 81	5.16 to 6.92	2 to 33
	Average for Samples	63	6.3	10
Drinking Water Primary Maximum Contamination Level (PMCL)[10]		—	—	—
Drinking Water Secondary Maximum Contamination Level (SMCL)[10]		—	6.5 to 8.5	500
SAWS Drinking Water Quality[11]		—	7.4 to 7.9	272 to 340

Microbiologic Analysis and Results

The microbial tests sought to determine the presence of indicator microorganisms commonly used to assess water quality for public health purposes. *Table 3* shows the results from microbial analysis of the 19 condensate samples.

Heterotrophic plate count (HPC) measures a range of bacteria that are naturally present in the environment and require organic carbon for growth. HPC itself has no health effects, but is commonly used to evaluate how well a water system is maintained; the lower the concentration of bacteria, the better maintained the water system.[10] EPA's surface water rules require systems using surface or groundwater influenced by surface water to contain no more than 500 bacterial colonies per ml.[10] The maximum HPC detected in the condensate flow was 28.7, well below the 500 limit.

Total coliforms (TC) are a group of related bacteria that are, with a few exceptions, not harmful to humans. Total coliforms can, however, be a useful indicator of the presence of other pathogens in water.[10] So like HPC, the lower the concentration of TC, the better maintained the water system. TC is commonly evaluated in combination with *E. coli* to identify water contaminated by fecal matter from mammals. Unlike groundwater and rainwater, which are collected from surfaces exposed to wildlife, condensate formed on the coils inside the AHU is not exposed to a likely source of *E. coli*. *E. coli* was not detected in any of the condensate samples, including those with high TC levels too numerous to count (TNTC).

Legionella is found naturally in water and multiplies in warm and non-treated water. If water containing *Legionella* becomes airborne in the form of an aerosol and is inhaled, it can cause Legionnaire's disease, a potentially fatal illness involving pneumonia.[12] The Occupational Safety and Health Administration (OSHA) has set action levels for common building systems that may form aerosol from water. The first action level for cooling towers, domestic water, and humidifiers is 100, 10, and 1 colony-forming unit (CFU) of *Legionella* per ml, respectively, prompting cleaning and/or biocide treatment.[13] EPA has established a maximum contaminant level goal (MCLG) of zero *Legionella* organisms for drinking water. An MCLG is a nonenforceable guideline based solely on an evaluation of possible health risks, taking into consideration a margin for public safety.[10] All water samples tested negative for *Legionella* species by media culture. One condensate water sample did test positive for a *Legionella*-like organism at concentrations above 300 CFU/mL. This sample was collected from a location approximately 100 ft (30 m) downstream of the AHU at a water temperature of 81°F (27°C).

Aeromonas are known to be present in most water environments. *Aeromonas* are typically found at levels below 10 CFU/100 mL in drinking water and may reach levels of 3 log 10 CFU/mL to 5 log 10 CFU/mL in groundwater during summer.[14] So, the 4 CFU/100 mL to 6 CFU/100 mL level found in 24% of the condensate samples is comparable to those found in drinking water. *Aeromonas*

TABLE 3 Microbes present in condensate samples.

MICROBIAL CONTAMINANTS		*E.COLI* (CFU/100ML)	HETEROTROPHIC PLATE COUNT (HPC) (MPN/ML)[a]	TOTAL COLIFORMS (TC) (CFU/100 ML)	*LEGIONELLA*[b] (CFU/100 ML)	*AEROMONAS*[b] (CFU/100 ML)	*ENTEROCOCCI*[b] (MPN/100 ML)	PROKARYOTIC CELLS[b] (CFU/100 ML)	EUKARYOTIC CELLS[b] (CFU/100 ML)
CONDENSATE SAMPLES	Practical Quantitation Limit (PQL)	1.00	1.00	1.00	1.0	1.00	1.00	1.00	1.00
	Number of Samples Microbes Detected	0 of 19	16 of 19	13 of 19	0 of 17	4 of 17	0 of 17	17 of 17	8 of 17
	Range of Detected Microbes	—	2.8 to 28.7	8 to TNTC[c]	—	4 to 6	—	—	—
	Average of Detected Microbes	—	15.4	129[d]	—	4.5	—	—	—
Drinking Water Primary Maximum Contamination Level (PMCL)[10]		1.00[d]	<500	Present in < 5% Samples[d]	—[e]	—	—	—	—

[a] MPN/mL = most probable number per mL

[b] Two of the 19 samples did not arrive to the EPA test lab within the requisite time after collection. Therefore, only 17 versus 19 condensate samples were analyzed for these contaminants.

[c] TNTC = too numerous to count

[d] If *E.coli* is detected and a repeat sample is positive for TC, then PMCL violation. All samples testing positive for TC must also be checked for *E.coli,* and if two consecutive samples are TC positive with one also being *E.coli* positive, then PMCL violation.

[e] No PMCL for *Legionella*, but EPA established maximum contaminant level goal (MCLG) of zero *Legionella* for drinking water.

were not detected in the remaining 76% of the condensate samples. *Enterococci* were not detected in the condensate samples. Though not regulated by the EPA's primary standards, the EPA criteria for recreational water where full-body immersion and ingestion are likely indicates levels should be below 30 CFU/100 mL to 35 CFU/100 mL in fresh and marine water.[15]

The presence of prokaryotic cells indicates low organic carbon content in the water sample, while the presence of eukaryotic cells indicates high organic carbon content. Dissolved organic carbon acts as a nutrient to accelerate the growth of bacteria such as *Legionella*. Therefore, eukaryotic cells can be used as an indicator for the potential of amplified *Legionella*.

The higher temperature condensate samples contained higher numbers of eukaryotic cells. Since the water exiting the AHU is relatively cold, the temperature rise and potential for increase in eukaryotic cell growth is expected in the distribution plumbing more than in the AHU itself.

In addition, analysis of samples collected while agitating the inside surface of the pipe with a cotton swab to disturb the built up biofilm (results not displayed in this paper) confirmed the presence of elevated eukaryotic cells and related bacteria in the biofilm compared to the condensate water alone. Microbial growth and amplification of microbial growth in biofilms is a concern in all water distribution systems, regardless of the water source.[7]

Based on the indicator microorganisms considered, the 19 condensate samples collected for this study did not exhibit any pathogenic microbes at levels of concern for human contact. However, potential exists for hazardous conditions to develop. So, care must be taken to properly design, maintain, and monitor condensate collection systems for the chosen application to protect human health.

On-Site Uses for Condensate from AHUs

Routing condensate directly to a cooling tower for use as makeup water is typically the optimal application of reclaimed condensate for the following reasons:

- Condensate production only occurs when the cooling tower is active and requires makeup water to support its evaporative cooling process.
- Condensate recovery ranges from 5% to 15% of the required volume of cooling tower makeup water for typical commercial buildings.[2] So, there is no need for a storage tank to store condensate.
- Cooling tower water is already treated, so no additional treatment is required.
- The cool condensate enhances the evaporative cooling process of the cooling tower.
- The addition of makeup water with low total dissolved solids helps dilute the accumulated dissolved

solids that result from evaporation, extending the time between blowdown events.

- Routing condensate to a cooling tower only requires pipes if the AHU is at a higher elevation than the cooling tower (i.e., gravity-driven flow). Even if a small reservoir and pump are needed to elevate the condensate, the cost is still relatively low and the payback period is relatively short.

Additional information on condensate collection systems, including payback period calculations, can be found in the "San Antonio Condensate Collection and Use Manual for Commercial Buildings."[16] A more general discussion of the economics of condensate collection across the United States is provided by Lawrence, Perry and Alsen.[5]

Other potential applications include irrigation, car washing, toilet flushing, and process water, to name a few. However, these applications involve more complex systems and can be much more costly if additional water treatment and monitoring is required. Reasons to choose one of these other applications instead of routing condensate to a cooling tower are: a cooling tower may not exist on site, the distance between the AHU and cooling tower is too long or arduous to justify the cost of installation (especially in retrofit cases), or another application offers preferred benefits.

For example, condensate may be used to wash cars to take advantage of the lack of total dissolved solids in condensate, which avoids mineral deposits on the cars. For another example, the owner of an existing building could choose to use condensate as makeup water for a prominent fountain, which may otherwise be prohibited by local regulations from operating during times of drought restrictions. For new construction or renovations, Standard 189.1-2014 requires ornamental water features be supplied by alternative on-site water or municipally reclaimed water.[1]

Design and Maintenance Considerations for On-Site Condensate Use

Fundamental to obtaining high-quality condensate is proper design and maintenance of the AHU to minimize microbial growth. This includes a properly designed and maintained air seal, commonly called a trap, to ensure positive flow of condensate out of the drain pan. Water stagnating in the drain pan or in the downstream flow path can incur microbial growth, thus antimicrobial tablets can be used as preventative maintenance. Preventative maintenance also includes scheduled cleaning of the cooling coils.

Even with a perfectly designed and maintained AHU, microbes (some potentially pathogenic) can accumulate in the water distribution system, so care must be taken to properly maintain the distribution system and possibly treat the water as necessary to make the water "fit for purpose." Guidance on monitoring and maintaining water distribution systems includes practices such as flushing the pipes and chemical disinfection. ASHRAE Standard 188-2015 addresses risk management for building systems with respect to *Legionella* and provides a good overview of best practices to mitigate human exposure to potentially pathogenic waterborne microbes in building water systems.[17]

In terms of materials used in the condensate flow path, using nonmetallic pipe, such as PVC or PEX, reduces metal contaminants in the flow path. A meter to measure the quantity of condensate produced is a valuable monitoring tool to help alert personnel if the condensate flow is not as expected. Finally, a means to divert cleaning solvents from the condensate collection flow path during cleaning is a recommended design feature of the condensate system. Additional information on design and implementation of condensate collection systems can be found in the "San Antonio Condensate Collection and Use Manual."[16]

Conclusions

The condensate samples taken from AHUs of diverse buildings in terms of age, size, function, and configuration of the condensate flow path showed condensate to be relatively high-quality water that has the potential to become contaminated as it travels through the distribution plumbing. In all cases, elemental chemical contamination was minimal and predictable based on material composition of the cooling coils, drain pan, and distribution plumbing. Microbial contamination reflected via eukaryotic cell growth was shown to increase with increased temperature in distribution plumbing along the condensate flow path. Metal contaminants can be minimized through system design, while microbial contaminants can be minimized through design and maintenance of the AHU and water distribution system. Water treatment is required for some applications to make the condensate "fit for purpose" for the intended use on site. In all cases condensate collection systems must adhere to codes imposed by the governing jurisdiction.

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