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AIR WASHERS - A new look at a vintage technolgy

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Last year (2002) marked the 100th anniversary of the first modern day air-conditioning system designed by Willis Carrier.[1] It consisted of a cooling coil arrangement in which supply air was cooled and dehumidified by indirect heat exchange with cold water pumped through tubing. Carrier surmised that an alternative design using direct contact between the air and chilled water might improve performance. In his early air-conditioning systems, he observed that, although the air came in contact with water on the cooling coil surface, dehumidification occurred.

Carrier's explanation of this phenomenon was that "... *in other words we had the apparent paradox of reducing the moisture in air by bringing it into contact with moisture. Of course the explanation was simple. The temperature of water was below the dew point or condensation temperature of the entering air. Why should we not, then, spray the cold water into the airstream, thus increasing the surface contact and reducing the resistance to air-flow...*"[2]

From this observation and other experiments, Carrier discerned that the phenomenon of cooling and dehumidification of a moist airstream could be accomplished by using chilled water in direct contact with an airstream. Based on that premise, Carrier designed a spraytype air conditioner (air washer) that was manufactured by the Buffalo Forge Company, shown in **Figure 1**, Carrier subsequently used air washers extensively for cooling and dehumidification in many industrial applications.[3] Over time, this air conditioning approach became less popular.

Current air-conditioning technologies rely on chilled water (or refrigerant- based) cooling coils to indirectly cool and dehumidify supply air.

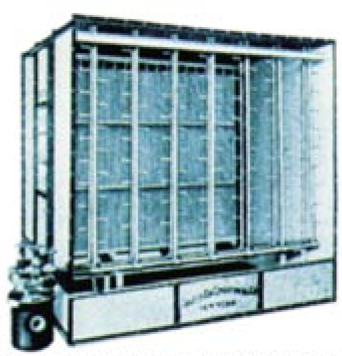

Figure 1 : Carrier-designed air washer.

" In addition to conditioning a supply airstream, air washers are capable of cleaning the supply airstream with low air-side pressure drop and minimum maintenance."

The operating cost of these "indirect" systems is affected adversely by the high air-side pressure drop and cooling losses due to finite approach temperatures* and fouling that occurs on the air- and water-sides.

** The approach temperature is the difference in temperature between the coldest fluid entering the coil and the leaving air dry bulb temperature.*

With a renewed interest in energy conservation and enhanced indoor air quality, it may make sense to revisit direct-contact spray coolers due to their enhanced effectiveness and ability to control both the temperature and humidity of a supply airstream. The early implementations of spray coolers lost favor because they tended to be bulky and expensive, but this need not be the case. Operating at higher air velocities, optimum air and water relative velocities, and use of packing material all increase the conductance of spray coolers, helping them to be more compact and efficient. In addition to their ability for conditioning a supply airstream, air washers are capable of cleaning the supply airstream with low air-side pressure drop and minimum maintenance.

In a typical air washer, water droplets are brought into direct contact with the air resulting in the exchange of heat and mass (moisture) from the air to the water droplets. If the supply water temperature is below the entering air dew-point temperature, moisture from the air will condense onto the water droplets; thereby, dehumidifying the supply airstream.

Figure 2 illustrates the major components in an air washer air-handling unit. Chilled water is sprayed directly into a prefiltered warm moist supply airstream. The chilled water absorbs heat from the air and condenses moisture from the air when the supply water temperature is below the entering air dew-point temperature. The water spray nozzles can be arranged in co-flow or counter-flow with the airstream. Also, an extended media fill material can be used to increase the surface area of water in contact with the supply airstream. A downstream mist eliminator may be needed depending on the face velocity of air through the unit as well as the characteristics of the water spray droplets.

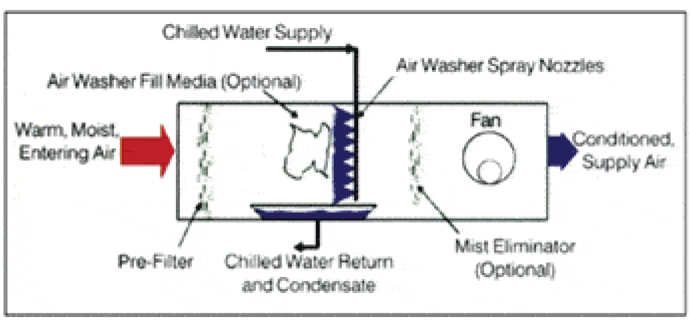

Figure 2 : Air washer air-handling unit.

In contrast to the air washer, **Figure 3** shows the major components in a traditional central station air-handling unit using a plate-finned chilled water cooling coil. In this arrangement, the water is supplied to a multi-row cooling coil and does not come into direct contact with the supply airstream. The chilled water cools the coil surface which, in turn, cools and dehumidifies the supply airstream. Moisture from the supply air condenses onto the coil surface and drains by gravity to a pan located beneath the coil. Pre- and final filters are needed for particulate control. Although prefilters are generally located upstream of coils, designers may locate the final filters either upstream or downstream of the cooling coil.

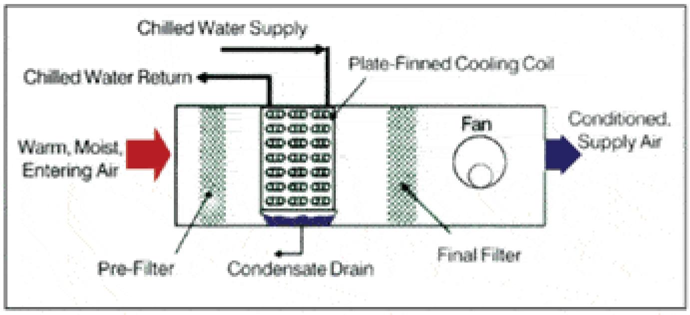

Figure 3 : Typical central station air-handling unit.

Water sprays in an air washer configuration have the ability to filter air with an efficiency of 95% for particles larger than 5 microns.[5] Although many microorganisms are much smaller (ca. 1 micron), most microorganisms tend to agglomerate to form "macro particles" with aggregate sizes greater than their mono-disperse sizes.[6] These microorganisms can be effectively scrubbed from a contaminant-laden airstream by an air washer.

With the intent of transporting microorganisms from the airstream to the water, the question is whether or not the air washer sump could be a potential contaminant source. Although we were not able to find specific studies that investigated the risk of microbial growth, and amplification on the water-side of an air washer system, several sources note the importance of water treatment in air-washer systems to control biological growth.[7,8,9]

Many strategies can prevent the amplification of microorganisms in the supply water system. One strategy relies on the use of traditional chemical biocides such as chlorine. An alternate strategy is to use dissolved ozone. Ozone is a powerful biocide capable of destroying bacteria and viruses as well as oxidizing many organic and inorganic compounds. Ozone also serves as a descaling agent.[10] Owing to its high oxidation potential, ozone offers the opportunity to purify the airstream indirectly by spraying ozone-sanitized fresh water into the airstream rather than introducing gaseous ozone directly into the air. Concentrations of dissolved ozone in the liquid phase can be controlled to yield efficacious microorganism control while keeping the ozone concentration in the supply airstream below threshold limits (TLV for ozone is 0. 1 ppm).

Cooling Air: Direct vs. Indirect Contact

Despite their advantage of being able to cool, dehumidify and filter supply air, air washers also need to be economically competitive with conventional platefinned chilled water cooling coils. To investigate the economic feasibility of air washers, a comparison was made between a chilled-water-cooling- coil system and a direct-contact air wash cooling system. The power consumption, capital costs, and operating weight of both a cooling coil and a direct-contact air wash cooling system were considered. The overall conductance between air and water was fixed for both the chilledwater- cooling-coil and the spray cooler systems. The conditions are summarized in **Table 1**. A schematic and operating conditions for a direct-contact spray cooler is shown in **Figure 4** and similar information for an indirect chilled water coil system is shown in **Figures 5 and 6**.

Table 1 : Inlet and exit conditions necessary for comparison.

	Inlet	Exit
Dry Bulb	80°F (26.67°C)	55°F (12.78°C)
Wet Bulb	67°F (19.44°C)	54°F (12.22°C)
Inlet Air Volume Flow Rate	20,000 cfm (9,439 L/s)	
Water Temperature	43.21°F (6.23°C)	50.74°F (10.41°C)
Water Volume Flow Rate	200 gpm (12.6 L/s)	
Cooling Load	62.92 tons (221 kWT)	
Velocity (Cooling Coil Air Handler)	500 ft/min (2.54 m/s)	
Velocity (Direct-Contact Air-Handler)	571 ft/min(2.90 m/s)	

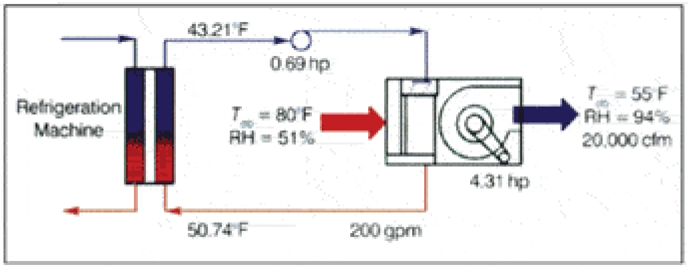

Figure 4 : Chilled water direct contact air handler.

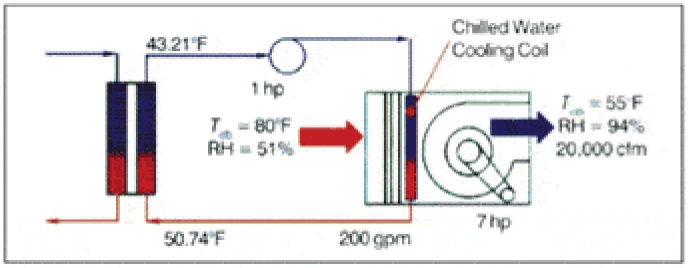

Figure 5 : Chilled water cooling coil air handler.

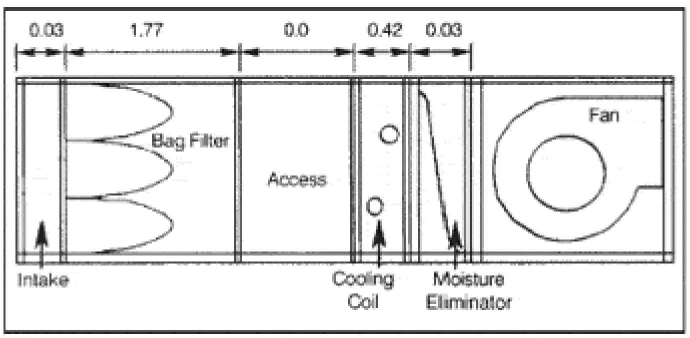

Figure 6 : Chilled water cooling coil air handler components and pressure drop (in w.g.) across each component.

The results of the comparative study are presented in **Figure 9** and **Table 2**. **Figure 9a** shows that the direct contact air cooler uses less power than the indirect system to operate the fan and pump. The fan power is lower than in a comparable indirect system because of the lower air-side pressure drop. The pump power is small for both systems. **Figure 9b** shows that the first cost of the direct contact spray cooler can be lower than that for the chilled water cooling coil.

Table 2 : Results of the comparison study.

	Spray Cooling Air Handler	Chilled Water Cooling Coil Air Handler
Air-Side Pressure Drop	0.82 in. H_2O (204 Pa)	2.26 in. H_2O (560 Pa)
Water-Side Pressure Drop	5 psi (34 kPa)	9.35 (64 kPa)
Fan Power (@ 60% Efficiency)	4.31 hp (3.21 kW)	11.88 hp (8.86 kW)

Pump Power (@ 85% Efficiency)	0.69 hp (0.51 kW)	1.28 hp (0.95 kW)
Total Power	1.43 hp (1.07 kW)	8.22 hp (6.13 kW)
Dimensions (L×W×H)	84.25 in. (2.1 m) × 66.25 in. (1.68 m) × 32.25 in. (0.81 m)	118.75 in. (3 m) × 62 in. (1.57 m) × 199.5 in. (5.07 m)
Rigging Weight	445 lbs (202 kg)	5,141 lbs (2332 kg)
Installed Weight	1,155 lbs (524 kg)	5,322 lbs (2414 kg)
Capital Cost	$ 4,000	$ 25,000

Developing Direct Contact Spray Coolers

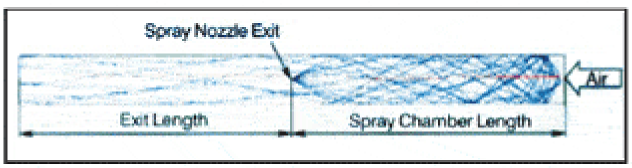

Figure 7 : Spray Chamber.

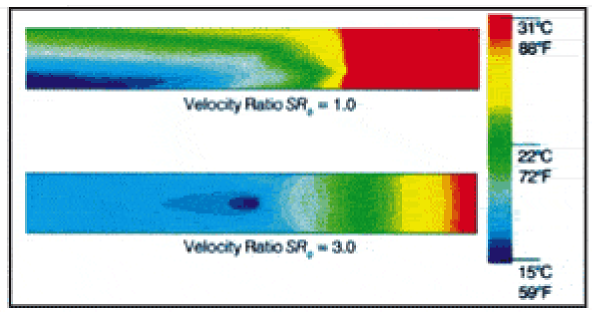

Figure 8 : Temperature contours for the spray cooler.

During the past 10 years, research work at the University of Wisconsin-Madison has been conducted on developing spray coolers. Reindl[11] studied the heat and mass transfer to chilled water sprays for cooling inlet air to stationary combution turbines. Numerical models were developed for three directcontact spray configurations : parallel flow, crossflow and counterflow. On comparing the effectiveness of the three configurations, it was observed that the crossflow configuration had the higher effectiveness.

Klockow[12] experimentally studied the process of sanitizing the airstream by ozonating the sprayed water. The concentration of ozone in the leaving airstream was higher than the permissible limits. This leads to the conclusion that more research work is needed in this field to control the ozone concentration.

El-Morsi [13] studied the effect of gravity, initial speed ratio,[†] and average droplet diameter on the performance of a spray cooler in a counterflow configuration. The work was done using a CFD code that was validated experimentally. **Figure 7** shows the spray cooler and the water droplets as they are sprayed inside the spray cooler. The air enters the spray cooler from the left hand side and water is sprayed from the spray nozzle in the middle of the spray cooler. The figure also shows that as the water droplets reach the walls they reflect back and continue penetrating through the spray chamber. Once their velocity reaches zero, the droplets begin to move backwards, and subsequently accelerate in the opposite direction, as they get carried by air.

The results of the numerical simulations showed that the gravitational force causes the air temperature profiles to be skewed towards the bottom, resulting in a non-uniform temperature distribution along the vertical direction. However, this non-uniformity decreases as the initial speed-ratio decreases, as shown in **Figure 8**. Generally, the effectiveness tends to increase as the spray cooler initial speed ratio increases until the maximum effectiveness is reached at an optimum speed ratio. The trend is then reversed beyond this point. Finally, increasing the droplet diameter decreases the effectiveness. This information can be used to optimize the design of direct contact spray cooler.

† The ratio of the magnitude of the initial spray horizontal velocity component to that of the initial velocity of air.

Conclusions

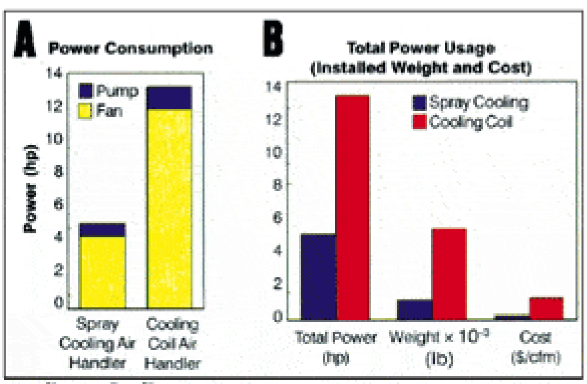

Figure 9 : Direct contact vs. chilled water air handlers.

Air washers were used extensively in early airconditioning systems and are used today in industrial applications such as textile mills, fiber processing, tobacco processing, carpet manufacturing, and malting operations. Air washers are available in sizes from 500 cfm to 300,000 cfm (236 L/s to 141,570 L/s). A significant advantage of air washers is their ability to control the temperature and humidity of a supply airstream without the thermal penalty of an additional heat exchange. In addition, air washers can be effective at providing airside filtration. The challenge of air washers lies in the maintenance of an open hydronic system that includes water treatment (biocide, scale, corrosion, etc.) and waterside filtration to remove particulates scrubbed from the airstream. Would an air washer work in your next project?

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