Evaporative Cooling Technology Today

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Abstract

Water, because of its stability, heat transfer capabilities and seemingly inexhaustible supply, has been the prime sink used by nearly all industries for heat rejection. The Evaporative Cooling approach is basically a water saving technique where cooling water is continuously recirculated through the heat generating source and is cooled by evaporative heat rejection through the cooling tower. The cooling tower is the simplest and least expensive of all the evaporative cooling methods. The paper covers the nature and convenience of evaporative cooling as used in small, prefabricated cooling towers for HVAC applications and in large field erected units for industrial applications. Procedures for correct maintenance and cleaning in order to obtain maximum operating efficiency are addressed. The advantages and applications of wet dry hybrid units with particular reference to reducing water consumption are covered. The latest developments in heat exchange components are examined along with the relative merits of different forms and construction materials for the tower internals. The discussion that follows is about a wet-dry hybrid evaporative cooler, which in addition to the conventional tower has a coil that precools the hot water before it enters the wet section of the tower.

Keywords: *Cooling tower, Evaporative cooling, Wet-dry hybrid tower*.

INTRODUCTION

Basic characteristics of an evaporative cooling tower

An evaporative cooling tower is a machine of relatively simple conception and operation. The water to be cooled for a chiller, industrial process or refrigeration installation is pumped and distributed through spray nozzles over a fill pack or heat exchange surface through which passes an air current commonly generated by a fan. A small fraction of this water evaporates and the remainder is cooled thanks to the absorption of the latent heat of evaporation by the passing air, and falls under gravity into a basin (usually an integral part of the tower) from where it is pumped back to the heat load source.

To avoid water entrainment the tower is fitted with droplet separators. Typical water evaporation rate is 1.8 m^3/h for every 1.000.000 kcal/h of heat rejected. A water quantity equal to that lost by evaporation must be bled-off from the tower inlet pipe (from the heat load): both these quantities are compensated by the make-up. In a circuit connected to an evaporative cooling tower the rate of water evaporation varies in proportion to the heat to be rejected at every instant. Moreover it is reduced as the outside ambient temperature goes down in the low season because the effect of the sensible heat exchange between the water to be cooled and the air current becomes significant. The water leaving temperature from the tower is determined by the wet-bulb temperature of the intake air and the design value (for a reasonable selection) will in any case be at least 3°C above the design summer wet-bulb temperature. This is about 15°C below the outlet temperature obtainable from an air-cooled unit of reasonable size. [Cooling tower maintenance manuals, EEC Machinery Directive].

For the correct application of any cooling tower it is advisable to consider at least the following items:

- Layout (for correct airflow without recirculation).
- Piping (for correct distribution, avoiding hold-up problems and cavitation).
- Freeze protection.
- Noise Levels and, where applicable.
- Capacity control.

Ramifications of the standard cooling tower to suit the zone and application

The first aspect to be considered in terms of a modern modification of the traditional cooling tower is the wet-dry hybrid version execution. There are various options to examine: the most cost-effective solution for a particular installation depends substantially upon the importance of reducing water consumption.

It is generally considered that the dry section of the cooling tower is primarily for plume control. In that case the cooling tower has the basic format shown in Fig. 2.

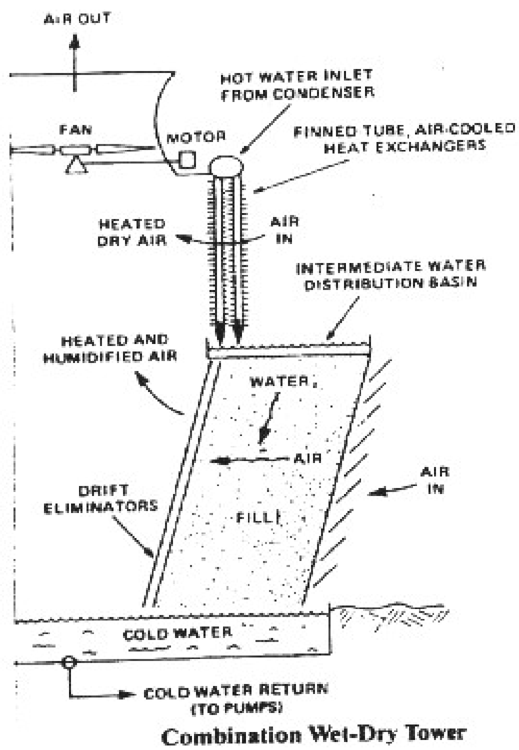


Figure 1: Operating principle of an evaporative cooling tower

It should be noted that the coils are mounted in a way which results in cross-flow heat exchange between the water descending inside the coil and the air flux: this is a poorer usage of the heat exchanger than complete counter-flow but is the standard set-up for ease of coil mounting. The cross-flow form of the tower wet/evaporative section is standard in the USA [ASHREA] whereas in Europe a counter-flow wet section which has the form of figure 1 is used.

The dry section serves to provide warm, dryer air to be mixed with the very humid warm air from the evaporative cooling tower lower section. This is to reduce or eliminate plume formation when the discharge air comes in contact with cooler ambient air above the fan stacks [this "plume" is due to the condensation of water previously in vapour form].

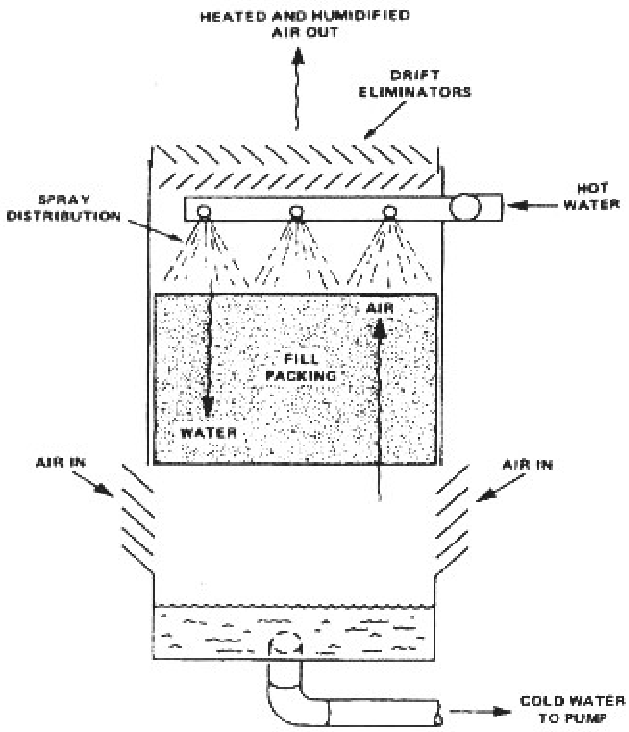


Figure 2: [ASHREA]

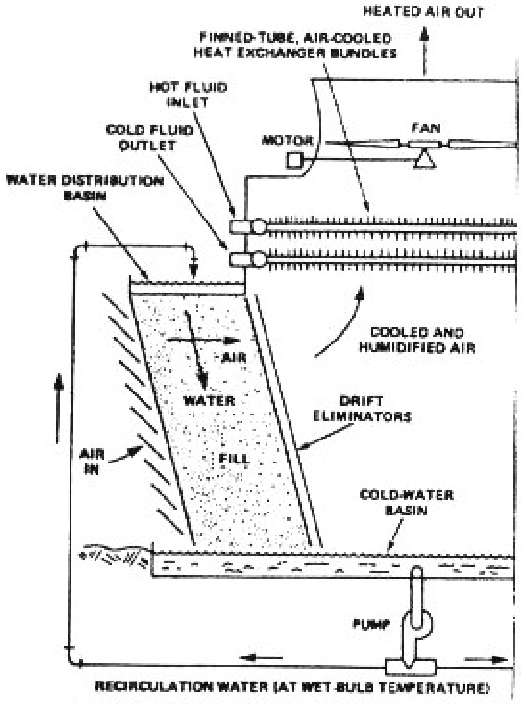
However in the context of industrial plant in hot climates where water consumption is a critical factor, it is instead appropriate to concentrate upon the quantity of pre-cooling of the entering warm water that can be achieved in the dry section, either at design conditions (summer dry bulb) or mid-season conditions. [Blackadder D.A. & Nedderman R.M. *A Handbook of Unit Operations*]. Subsequently the dry cooling should be maximised throughout the year. In the design stage the possibilities, according to the surrounding conditions and ambient temperatures should be carefully considered because "oversized" coils may be the appropriate option. I would not recommend the use of the open plastic fill-type heat exchangers for the dry section: they are an interesting idea for cooler climates where we need to reduce the cost of the heat exchanger support structure but the lower heat transfer by conduction through plastic plates and the lack of extended surface make them unsuitable for our objective of maximising dry cooling.

Here is a practical selection example

The end-user (a petro-chemical industry in Mexico) needs to cool 2725 m³/h of water from 47°C to 37°C with ambient air of 33°C/60% relative humidity (these conditions exist 20 days per annum): this corresponds to a design wet bulb temperature of 26°C. They indicate desirable design conditions of water cooled from 42°C to 32°C for ambient air at 28°C dry bulb with 65 % relative humidity (wet bulb = 23°C).

The final design was based upon obtaining a dry pre-cooling of the given water flow rate from 42°C to 39°C using 16 finned coils, each 9 m long by 2 m high for air available at 28°C. These coils go then in pairs on 4 double air-intake counter-flow film fill cooling cells which evaporatively cool the flow from the combined coil outlets from 39°C to 32°C at 23°C design entering air wet bulb. What is interesting is that these coils can cool the same flow from 42°C to 36,3°C for an entering air temperature of 15°C (corresponding to the customer's winter season). This of course requires airside regulation in as much as we need full airflow on the coils and considerably diminished evaporative cooling capacity for the lower "wet" section of the tower. [Foster R.E. Air Conditioning with Evaporative Technology; March 1999]

There is another interesting manner of approaching the question of maximising air-blast cooling capacity: the use of humidification panels, constructed from corrugated sheets of either resin-treated paper or fibre-treated PVC, over which water is distributed in excess and air is drawn in cross-flow format (to minimise airside pressure drop and risk of droplet entrainment). This system adiabatically cools and humidifies the inlet air which follows the line of constant wet bulb temperature (very nearly parallel with the lines of adiabatic saturation in the air-water system which has similar values of diffusivity and thermal diffusivity): in this manner the air supplied to the dry cooling coils [Fig. 3] can be reduced in temperature typically by 5 - 6°C, with a consequent reduction in cooling water temperatures within the closed and protected finned-coils. [Personal Correspondence; Comfort Air, Zwolle Netherlands].



Adiabatically Saturated Air-Cooled Heat Exchanger

Figure 3: [ASHREA handbook Ch.37]

As a natural extension from this examination of the best selection, usage and maintenance of evaporative cooling towers and having touched on evaporative cooling as a means of increase air-blast cooling capacity, there is a further development worthy of mention, being applicable as an economical HVAC system and particularly promising for hot countries with limited energy. In recent years, to provide some more economical and simpler "air-conditioning" for non-critical environments, a development has been made from standard adiabatic cooling, where some air cooled by the humidifying fill is cycled back to an air-air heat exchanger in order to pre-cool the outside air, before it enters the fill. This system basically permits us to cool a couple of degrees below the ambient air wet bulb temperature. Of course this type of system really provides "conditioned" air, which is too humid for normal "comfort", even if it is help for some spaces. A Dutch company has researched intensively and is now developing a commercial-scale-cooling unit derived from this technology, which brings further temperature reductions and a controlled humidity level. Although it is not possible to provide at this time the technical details (because of patents pending) it is possible to state that there will be commercial available a system suitable for "volume comfort cooling" in large commercial and industrial buildings and enclosed market areas. This system has the main advantages of:

- Significant reductions in energy consumption compared to normal "chiller-type" air conditioning.
- No refrigerant circuit and no compressor energy requirement.
- Relatively low cost and simple units for easy assembly even in areas with limited industrial facilities.
- Easy installation and service by ventilation personnel.

There will also be the possibility of application on mobile units without additional power.

The second important variable to consider in the design of the cooling tower is the fill-type. A whole section has been dedicated to "film" fills because of their greater heat exchange surface per unit volume. The starting point is to identify where the water is corrosive or scaling and/or dirty (charged with mud, algae etc.). It is necessary to have values of ppm solids, pH, calcium hardness and total alkalinity. From these values are derived the Langlier saturation index which tells us whether the water is corrosive or scaling. In the case of the former, our concern must be with the support structures - the situation can be exacerbated by problems such as stress-corrosion cracking of steel in the presence of chloride ions. Scaling problems mean that we should be selecting the tower with a more open fill structure, best with vertical channels, .to facilitate inspection and cleaning and reduce risk of blockage. [Personal correspondence; Tower components USA].

Heavy scaling and/or high dirt levels require an effective splash fill with an optimised plastic grid system: smaller spans, inter-grid support to distribute loading and the ability to fit closely to the tower structural pillars are the key features [Tower Components Inc.].

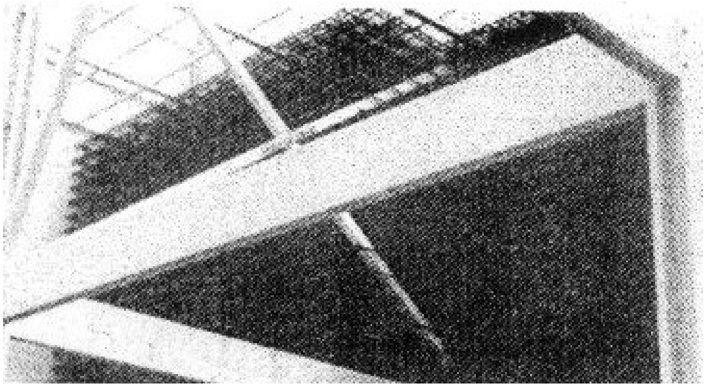


Figure 4: Splash Grids during Installation

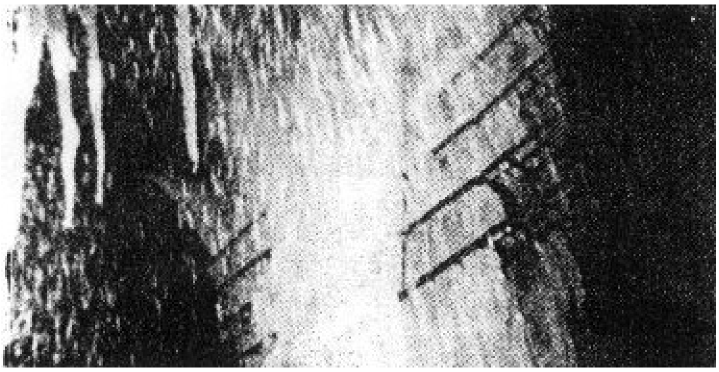


Figure 5: Cell with Splash Fill in Operation [Photos courtesy of Tower Components Inc.]

Using these more open or splash fills means selecting a larger unit with a greater initial investment: the saving comes in reduced maintenance and downtime.

Synthetic fill pack & the advantages of pvc

The use of plastic materials for cooling tower internals was born in the USA principally of the necessity to increase surface per unit volume and reduce both material and installation costs, providing also corrosion resistance.

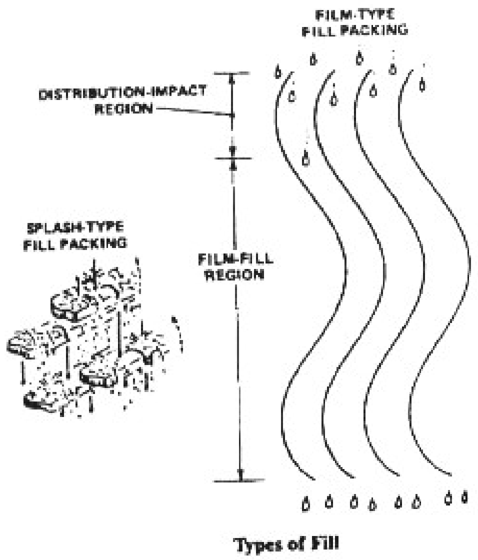


Figure 6: [ASHREA]

For example, in an evaporative cooling tower the employment of corrugated PVC sheets for all types of tower has enabled manufacturers to significantly reduce the cell dimensions thanks to a much greater specific exchange surface (for heat and mass transfer) per unit volume of cooling tower, compared to the old style fills made of wooden slats, grilles or indeed metal panels.

In very large refinery towers and in the hyperbolic, natural draught towers of electrical power stations it was common practice for many years to employ a heat exchange surface made from asbestos-cement panels.

Plastic packings have offered a cost effective alternative on a large scale all over both western and eastern Europe and allowed the end-users to dispose of that rather unhealthy asbestos material!

Typically a synthetic/plastic fill is composed of high quality corrugated PVC sheets: these are assembled with the direction of the corrugations inverted every other sheet and glued together to form modules, typically 1200 x 300 x 300 mm or 1200 x 600 x 600 mm [although larger units can require modules of 1800 mm or 2400 mm length].

PVC is nowadays generally considered by tower manufacturers to be the most suitable synthetic material for the majority of cooling tower applications - for 3 reasons:

- It is intrinsically self-extinguishing.
- It has an optimum resistance to cycles of thermal "shock" (hot water brought on to cold fill pack when starting-up an industrial installation in the Winter).
- Best fill sheet efficiency because the adhesion of the water to make a nice, thin layer (which exchanges heat and mass with the passing air) on a synthetic sheet is best on PVC. When a cooling tower is put into service the friction of the water flowing over the fill sheets changes its surface in such a way that the adhesion (and hence the thermal performance) is maximised in about 6 weeks. Other plastic materials require about 10 times as long. [EUROFILL Literature Fill Media & Droplet Eliminators].

Additionally it is worth mentioning that for big cooling tower projects PVC fill can be supplied in loose sheets for easy and quick site assembly: this minimises transport and storage volume and costs.

For some time during this past decade interest was shown in other plastic compounds considered possibly more "ecological" because potentially easier to recycle. Apart from the fact that used fill pack contains either biological matter, deposits or scale and must therefore be cleaned up before disposal, the PVC industry and more precisely the ECVM has invested in PVC recycling technology which will break down PVC waste into its constituent components. In the E.U. the first plants on PVC recycling are currently being brought on line.

The cooling tower is technologically simple equipment but once the right equipment supply for the application and surroundings has been effected there must also be a programmed and systematic approach to maintenance and servicing in order to ensure efficiency and avoid energy and water wastage.

Advised servicing for cooling towers

Type of servicing	Start-up	Shut-down	Annual
Inspection of the general condition of the unit	X		
Cleaning and removal of residues	X	X	
Cleaning and rinsing of pan	X	X	
Cleaning of filter	X	X	
Adjustment of water level	X		
Inspection of the heat exchange surface	X		X
Inspection of the drift eliminators	X		X
Inspection of the water distribution tubes	X		X
Check and adjustment of bleed-off	X		
Check make-up valve	X		
Check for noise or vibrations	X		
Voltage and absorbed current control	X		
Lubricate bearings (where applicable)	X	X	
Check for unobstructed fan rotation	X		
Check for direction of fan rotation	X		
Drain pan and piping		X	
Inspection of galvanised components (where applicable)		X	

"Trouble-Shooting" Guide To Tower Internals

Problem/Difficult	Causes	Remedies/Rectifying Action
A. Excessive absorbed current	1. Voltage reduction	Check the voltage
	2a. Incorrect angle of axial fan blades b. Loose belts on centrifugal fans (or speed-reducers	Adjust the blade angle Check belt tightness
	3. Overloading owing to excessive airflow-fill has minimum water loading per m^2 of tower section	Regulate the water flow by means of the valve
	4. Low ambient air temperature	The motor is cooled proportionately and hence delivers more than nameplate power
B. Drift/carry-over of water outside the unit	1. Uneven operation of spray nozzles	Adjust the nozzle orientation and eliminate any dirt
	2. Blockage of the fill pack	Eliminate any dirt in the top of the fill
	3. Defective or displaced droplet eliminators	Replace or realign the eliminators
	4. Excessive circulating water flow (possibly owing to too high pumping head)	Adjust the water flow-rate by means of the regulating valves. Check for absence of damage to the fill!
C. Loss of water from basins/ pans	1. Float-valve not at correct level	Adjust the make-up valve
	2. Lack of equalising connections	Equalise the basins of towers operating in parallel
D. Lack of cooling and hence increase in temperatures owing to increased temperature range	1. Water flow below the design valve	Regulated the flow by means of the valves
	2. Irregular airflow or lack of air	Check the direction of rotation of the fans and/or belt tension (broken belt possible)
	3a. Recycling of humid discharge air	Check the air descent velocity
	b. Intake of hot air from other sources	Install deflectors
	4a. Blocked spray nozzles (or even blocked spray tubes)	Clean the nozzles and/or the tubes
	b. Scaling of joints	Wash or replace the item
	5. Scaling of the fill pack	Clean or replace the material (washing with inhibited aqueous sulfamic acid is possible but long, complex and expensive)

Indications of Component Life

Although it is naturally difficult to provide precise indications of the lifetime of the modular internals [which do depend upon air and water quality and general treatment of the unit], the following indications are worth considering:

- If the circulating water is scaling then the film fill pack may require replacement after 3 years. For small factory assembled units this is an acceptable maintenance work necessity. For very large units it represents a problem and is why splash fill should be seriously considered in these cases.
- Metallic drill eliminators should be examined with a view to possible replacement after 3 - 4 years: the solution of longer duration is modular PVC panels [fitted into a suitably resistant frame if they are on the summit/discharge of a forced-draught unit].

Tower fill replacements using plastic fill blocks

A 12 - 13 mm wave form is the most common type in the factory-assembled small cooling towers with fill heights of 300 mm to 1200 mm. Very occasionally a greater spacing is employed in smaller units. A 20 mm spacing is the standard fill for big cooling cells and field-erected units (cross-sections greater than 3 - 4 m by 3 - 4 m) with fill height commonly 1200 - 1800 mm. In large cells one may observe very strong jets of water from the spray nozzles: this can be due to dirt blocking some of the nozzle discharges, missing nozzles, poor water distribution or even the type of nozzle used. In this sort of case it is advisable to place a top half-layer or full layer of fill made with sheets of increased thickness (typically 500 macron). Towers with dirty or clogging water use even bigger openings [a 27 mm or even 50 mm wave-form] but it is important that this type of fill is covered by a top half-layer of 20 mm wave fill which ensures that the water sprayed is completely distributed over the main fill surface and does not descend freely down part of an opening.

When repacking a tower it is important to:

- Check existing fill supports and hold-down channels for compatibility and positions compared to the new flu modules.
- Respect the original distance between the spray nozzles and the top of the fill. The "catch" here is that if we try to increase fill height (to obtain more thermal capacity) we. might reduce the space between the sprayers and the fill - water distribution can suffer and so tower performance decreases instead of increasing!
- Check temperature requirements: for high temperature applications (> 60°C) which represent 5 - 10 % of the installations a high temperature PVC is available (most commonly an ABS additive is employed to obtain the increased temperature limit).

Modular plastic drift eliminators

This type of eliminator is appreciated by maintenance contractors and end-users who have experienced the common corrosion problems associated with traditional metal-bladed eliminators in galvanised steel. The light-weight PVC eliminators are also better for towers with discharge ductwork, discharge hoods and air discharge sound attenuation because the panels are easier to remove, inspect and refit. [Johnson T. PowerGen Plastic Packings for Large Cooling Towers, - *The Chemical Engineer*, 1999].

Starting from preformed PVC sheets, these eliminators are prefabricated in handy blocks for ready insertion in the cooling tower and for easy removal for inspection of the water distribution. Thanks to their rectangular, modular form and to the ease of cutting, and exact coverage of the water distribution system can be made on site when renovating the tower.

Droplet eliminators

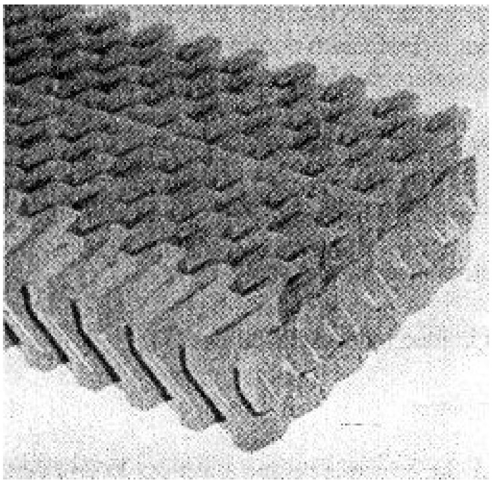


Figure 7: [Photo courtesy of Eurofill Srl]

Three model types can be identified:

- Panels comprising air passages with 2 changes in direction of airflow: these are used on axial fan, induced-draught towers. The panels are arranged in 2 series with the air direction changes oriented to bring the air towards the centre of the tower and the fan intake (for minimum pressure drop).
- Panels comprising air passages with 4 changes in direction of airflow (Fig. 7). These are more appropriate for forced-draught units where it is necessary to direct the hot, wet discharge air away from the air intake.
- Panels which employ a honeycomb structure of curved passages - these have a rather high-pressure drop.

In hot climates or regions of strong sunshine the UV resistance of plastic eliminators on the top of forced-draught units is normally a concern to the end-user. It is normal to employ a strong, dark pigmentation of the PVC used tot tower fill and eliminators in order to provide UV resistance (as suggested in Cooling Tower Institute guidelines). High temperature PVC is best coloured white, using Titanium Dioxide, which provides increased UV resistance and of course more heat is reflected instead of absorbed. [Waste not want not; *The Chemical Engineer* 1999].

Air inlet louvres

The PVC panel type of air inlet louvre is derived from a structure equivalent to half an eliminator panel, suitably reinforced, and is designed for induced-draught cooling towers on which it serves four purposes:

- Prevention of the suction of objects such as leaves from the surroundings into the tower.
- Elimination of water splash discharge from the pan.
- Smoothing of the entering airflow.
- Shading of the pan water and consequent discouragement of the possible growth of algae or other micro-organisms.

It represents a very efficient replacement from grilles and profile structures on small aria medium-sized towers and is quickly fitted using a simple support frame.

CONCLUSION

Summer heat can cause indoor conditions to become much hotter than desired. Evaporative cooling is one way to reduce temperatures inside buildings. As water evaporates, it absorbs energy from the surrounding environment. A well-maintained ventilation system with evaporative cooling can reduce incoming air temperature by 5 to 10°C. Cooler indoor temperatures can improve the environment for plants and animals, plus significantly improve working conditions for employees. Evaporative cooling systems lower air temperature using mists, sprays, or wetted pads. Introducing water into ventilation air increases relative humidity while lowering the air temperature.

For HVAC systems a new technology is presented which involves adiabatic humidification and cooling of air with supplementary heat exchange facilities to lower final air temperature and reduce relative humidity. This is the coolHeart system from Comfort Air which has resulted in refrigerant tree air coolers with very low energy consumption. The main advantages of the system are:

- Significant reductions in energy consumption compared to normal air conditioning.
- No refrigerant circuit and no compressor energy required.
- Low cost, simple units for easy assembly even in areas with limited industrial facilities.
- Easy installation and service by ventilation personnel.
- Possibility of application on mobile units without additional power.

Modifications of the standard cooling tower have been presented, the principle behind a wet-dry hybrid version has been shown and it is generally considered that the dry section of the cooling tower is primarily for plume control. The most cost-effective solution for a particular installation depends substantially upon the importance of reducing water consumption. In that case the cooling tower has the basic form shown in Fig. 2. The dry section provides warm, dryer air to be mixed with very humid warm air from the evaporative cooling tower lower section. This reduces or eliminates plume formation when the discharge air comes in contact with cooler ambient air above the fan. In the context of industrial plant in hot climates, where water consumption is a critical factor, it is appropriate to concentrate on the quantity of pre-cooling of the entering warm water that can be achieved in the dry section. Dry cooling should be maximised throughout the year. At the design stage the alternatives should be carefully considered, according to the prevailing ambient conditions and "oversized" coils may be the appropriate option. The authors do not recommend the use of open plastic fill-type heat exchangers for the dry section because of their lower heat transfer by conduction and lack of extended surface, which make them unsuitable for maximising dry cooling. These are an interesting idea for cooler climates where the need to reduce the cost of the heat exchanger support structure exists.

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