The facts about evaporative cooling

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Whitepaper

Introduction

Evaporative cooling, also known as adiabatic cooling, is an effective means of cooling, where the air is cooled as the result of the evaporation of water. The energy required for the evaporation is taken out of the air and so the air cools down. We see this phenomenon frequently in nature, and it is also easy to find examples of how man has exploited the principle since ancient times. Because evaporative cooling is very energy efficient, uses no refrigerant and also enables a comfortable working environment, this technique has again come into in the spotlight in recent years.

Evaporative cooling: direct or indirect cooling

We can distinguish between two methods of evaporative cooling: indirect evaporative cooling and direct evaporative cooling. In both instances the air is cooled by the evaporation of water. The rule of thumb is that the evaporation of 1 litre of water provides 0.7 kW cooling. Evaporative cooling works more efficiently at higher outdoor temperatures. Above 30°C the air can be cooled by 10°C or more adiabatically, which is a very efficient means of cooling. Very hot operating conditions lead to even better results. The only limitation is the additional moisture content in the air.

1. Indirect evaporative cooling

In indirect evaporative systems, the directly cooled air is not routed into the space. Instead, the "coolth" is transferred to another airflow via a heat exchanger. In general this air flow comes in from the outside. This more complex method is chosen in those instances either where the final relative humidity of a space is critical, or where it is important to have very dry air and also not to increase the humidity.

Indirect evaporative cooling systems can make use of humidified process air to cool the supply air. So they work with multiple airflows. Outside air is directed through a heat exchanger to cool a room inside, while in another part process air is moistened and again (sometimes simultaneously) passed through the heat exchanger before being discharged outside. The heat exchanger is generally situated on the roof or within an air handling unit. Thus the moist air passes the "coolth" to the heat exchanger, which then cools the incoming cold air without it getting moist. This transfer is accompanied by some small losses and also having a double flow uses up some energy.

An indirect evaporative cooling system operates largely using outside air. However, there it is not possible to recirculate 100% of the air because the process means that the secondary air, which is part of the primary air, is discharged to the outside. In some indirect evaporative systems, it is desirable to treat or to de-scale the water in order to prevent the heat exchanger from getting quickly scaled up. The greatest advantage of indirect evaporative cooling is that a temperature near to the dew point of the air can be reached without the air to be cooled becoming moister.

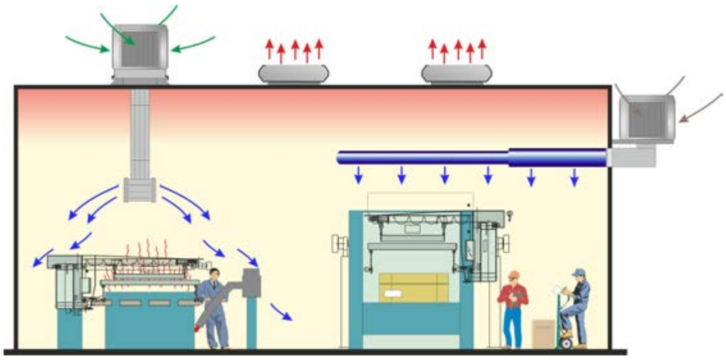
2. Direct evaporative cooling

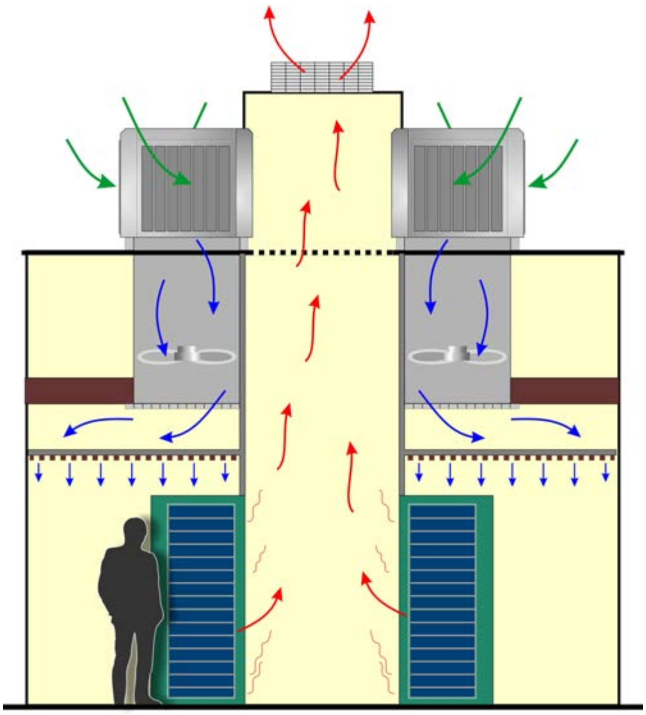
In comparison to the indirect evaporative cooling, direct evaporative cooling systems are a lot less complex. The air for cooling (which is generally outside air) is sucked through a water saturated barrier. This barrier is made of a material which may contain a lot of water such as cellulose, wood or paper. A circulation pump keeps the medium very moist. Part of the water in the supply air evaporates off the medium. The air flow therefore becomes moister, and the temperature of the air drops significantly. The resistance of the cooling medium is generally very low, from less than 20 Pa down to almost zero, so the fan has to overcome hardly any resistance. Because all the air is cooled and there is only one airflow, a direct evaporative cooling system has a minimal energy consumption (less than 1 kW to cool 10,000 m^3 / h).

One potential disadvantage is that the supply air now becomes more moist in both absolute and relative terms. But because all the cool air warms up in the internal space, the relative humidity there drops quickly. Because the air supplied consists of 100% outside air, air quality is good. Since adiabatically cooled air is introduced to the space, it is necessary to provide a suitable discharge of air. The hot air is generally best removed at high level by means of natural ventilators. Where this is not possible, exhaust fans may be used.

Applications

Evaporative cooling is ideal for controlling the internal temperature; it is economical, leads to comfortable conditions, and it is especially suited to big or tall spaces. Typical examples include the metal industry, food industry, plastics industry and warehouses. It is also well suited where certain types of fresh fruits and vegetables have to be preserved: in this instance the temperature needs to be held close to zero and the humidity close to 100%, and the contribution of additional moisture is an added advantage. So, where it is desirable to increase the humidity in the space, direct evaporative cooling can be especially useful. In some industrial sectors this is especially beneficial in the winter and spring, when it can be unusually dry.





Evaporative cooling in data centres

Evaporative cooling can play a special role in keeping data centres cool, since it can dramatically reduce energy consumption. Data centres are generally large consumers of energy. This is because of two reasons.

Whilst the necessarily installed equipment consumes a lot of power, it is also necessary to maintain a set temperature and humidity (especially in the winter months) in the space in order for the equipment to operate effectively and without faults, which also adds to the installed loads.

New insights into the allowable limits of temperature and humidity offer new opportunities. Not so long ago, the major computer manufacturers altered their environmental requirements. The permissible operating temperature must now be between 18°C and 25 °C, with a permitted increase to 27°C for short periods, and the relative humidity is now increased to 80 % (ASHRAE 2011 Class A2). These new guidelines allow the use of evaporative cooling in data centres in many parts of the world, including the UK, with considerable energy savings.

Often in data centres a primary form of evaporative cooling is already commonplace, with water spraying through nozzles into the air flow. Where there is this arrangement, it is necessary to treat the water using humidification, for example by reverse osmosis.

Short payback

Evaporative cooling is not only an effective solution for new data centres, it can also result in huge savings for existing data centres. The costs of large energy guzzling cooling systems which were installed in order to meet the previously stringent requirements are obvious from the energy bills.

Evaporative cooling makes use of the cooling effect of water to reduce the temperature in the data centre and uses only a little electricity to power the fans. The higher the outdoor temperature, the more efficient the operation of the system, and the more effectively we can address the issue of the heat load generated by the servers. During the colder winter months, warm air can be recirculated into the supply air so that the temperature is maintained in the space at the desired level. And there is the advantage specifically for data centres that in the winter months excessively low humidity is prevented.

Energy calculation relating to a 200 kW data centre

EER average	44,3
EER maximum	50,0
EER minimum	36,7

Climate conditions Tempera.	Absolute humidity	Relative humidity	Hours per year	adiabatic efficiency	enthalpy	wet bulb absolute humidity	supply air absolute humidity	**supply air temperat.**	Temperat. drop ΔT	Supply air density	**vol. flow total**	vol. flow ambient air	vol. flow recircul. air	power fan	power total	**Electrical total**	**Water total**	**Water total**	**EER**	EER x h
				adiabatic efficiency 88 %							mass flow = constant 9,26 kg/s	T exhaust = constant 39,0 °C	Q = constant 200 kW	power fan @ 40000 m³/h: 2x EBM A3G990 M3G150-NA 3,98 kW	power 2xCSTR pump + controls 0,18 kW	**39930**	Bleed rate 30 %	**161**		
[°C]	[g/kg]	[%]	[h]	[%]	[kJ/kg]	[g/kg]	[g/kg]	**[°C]**	[K]	[kg/m³]	**[m³/h]**			[kW]	[kW]	**[kWh]**	**[Liter/h]**	**[m3]**	**[kW$_{tot}$/ kW$_{el}$]**	[kW$_{tot}$/ kW$_{el}$ x h]
33	10,4	33	4	88%	60,0	15,4	14,8	**22,2**	10,8	1,18	**39.446**	36.071	3.375	3,82	4,00	**16**	265	1,06	**50,0**	200
32	10,7	36	2	88%	59,7	15,3	14,7	**22,0**	10,0	1,18	**39.472**	35.647	3.825	3,82	4,00	**8**	246	0,49	**49,9**	100
31	10,1	36	15	88%	57,2	14,6	14,1	**21,2**	9,8	1,19	**39.591**	33.997	5.594	3,86	4,04	**61**	242	3,62	**49,5**	743
30	9,2	35	15	88%	53,8	13,7	13,1	**20,2**	9,8	1,19	**39.747**	32.058	7.689	3,91	4,09	**61**	243	3,65	**49,0**	734
29	10	40	36	88%	54,8	14,0	13,5	**20,4**	8,6	1,19	**39.718**	32.349	7.370	3,90	4,08	**147**	214	7,72	**49,1**	1766
28	10,1	43	37	88%	54,1	13,8	13,3	**20,1**	7,9	1,19	**39.767**	31.746	8.021	3,91	4,09	**151**	198	7,34	**48,9**	1809
27	11,1	50	65	88%	55,6	14,2	13,8	**20,4**	6,6	1,19	**39.717**	32.275	7.442	3,90	4,08	**265**	166	10,79	**49,1**	3189
26	11,1	53	57	88%	54,6	13,9	13,6	**20,0**	6,0	1,19	**39.776**	31.563	8.212	3,91	4,09	**233**	151	8,63	**48,9**	2785
25	11,1	56	73	88%	53,5	13,6	13,3	**19,6**	5,4	1,20	**39.836**	30.866	8.970	3,93	4,11	**300**	137	9,99	**48,6**	3551
24	10,4	56	106	88%	50,7	12,9	12,6	**18,7**	5,3	1,20	**39.976**	29.405	10.570	3,97	4,15	**440**	135	14,31	**48,2**	5105
23	9,4	54	130	88%	47,1	11,9	11,6	**17,5**	5,5	1,20	**40.156**	27.707	12.449	4,03	4,21	**547**	140	18,19	**47,5**	6181
22	9,9	60	154	88%	47,4	12,0	11,7	**17,5**	4,5	1,20	**40.160**	27.641	12.519	4,03	4,21	**648**	116	17,83	**47,5**	7319
21	10,5	68	188	88%	47,9	12,1	11,9	**17,5**	3,5	1,20	**40.151**	27.686	12.465	4,03	4,21	**791**	90	16,83	**47,6**	8941
20	10,3	71	248	88%	46,3	11,7	11,6	**16,9**	3,1	1,21	**40.240**	26.903	13.337	4,05	4,23	**1.050**	79	19,61	**47,3**	11720
19	10	73	297	88%	44,6	11,3	11,1	**16,3**	2,7	1,21	**40.342**	26.060	14.282	4,08	4,26	**1.266**	71	20,97	**46,9**	13934
18	9,8	76	378	cooling off				**18,0**	0,0	1,20	**40.132**	28.364	11.769	4,02	4,20	**1.587**	0	0,00	**47,6**	18001
17	9,5	79	364	cooling off				**17,0**	0,0	1,21	**40.278**	26.977	13.301	4,06	4,24	**1.545**	0	0,00	**47,1**	17155
16	8,9	79	381	cooling off				**16,0**	0,0	1,21	**40.432**	25.706	14.726	4,11	4,29	**1.635**	0	0,00	**46,6**	17761
15	8,6	81	456	cooling off				**15,0**	0,0	1,22	**40.579**	24.545	16.034	4,16	4,34	**1.977**	0	0,00	**46,1**	21036
14	8,2	83	493	cooling off				**14,0**	0,0	1,22	**40.730**	23.476	17.255	4,20	4,38	**2.160**	0	0,00	**45,6**	22501
13	7,7	83	470	cooling off				**13,0**	0,0	1,23	**40.885**	22.488	18.397	4,25	4,43	**2.082**	0	0,00	**45,1**	21219
12	7,1	82	403	cooling off				**12,0**	0,0	1,23	**41.043**	21.571	19.472	4,30	4,48	**1.805**	0	0,00	**44,6**	17993
11	6,7	82	392	cooling off				**11,0**	0,0	1,24	**41.197**	20.723	20.474	4,35	4,53	**1.775**	0	0,00	**44,2**	17314
10	6,2	82	370	cooling off				**10,0**	0,0	1,24	**41.355**	19.932	21.423	4,40	4,58	**1.694**	0	0,00	**43,7**	16163
9	5,8	82	408	cooling off				**9,0**	0,0	1,25	**41.512**	19.195	22.317	4,45	4,63	**1.888**	0	0,00	**43,2**	17630
8	5,6	84	396	cooling off				**8,0**	0,0	1,25	**41.664**	18.508	23.157	4,50	4,68	**1.852**	0	0,00	**42,8**	16931
7	5,3	85	363	cooling off				**7,0**	0,0	1,25	**41.821**	17.862	23.958	4,55	4,73	**1.716**	0	0,00	**42,3**	15354
6	5	87	340	cooling off				**6,0**	0,0	1,26	**41.978**	17.256	24.722	4,60	4,78	**1.625**	0	0,00	**41,8**	14226
5	4,6	86	297	cooling off				**5,0**	0,0	1,26	**42.139**	16.685	25.455	4,65	4,83	**1.435**	0	0,00	**41,4**	12290
4	4,2	84	311	cooling off				**4,0**	0,0	1,27	**42.301**	16.146	26.156	4,71	4,89	**1.520**	0	0,00	**40,9**	12727
3	4	86	334	cooling off				**3,0**	0,0	1,27	**42.460**	15.639	26.821	4,76	4,94	**1.650**	0	0,00	**40,5**	13522
2	3,7	85	310	cooling off				**2,0**	0,0	1,28	**42.622**	15.158	27.464	4,81	4,99	**1.548**	0	0,00	**40,0**	12412
1	3,4	85	328	cooling off				**1,0**	0,0	1,28	**42.785**	14.703	28.082	4,87	5,05	**1.657**	0	0,00	**39,6**	12989
0	3,2	84	213	cooling off				**0,0**	0,0	1,29	**42.947**	14.272	28.675	4,93	5,11	**1.088**	0	0,00	**39,2**	8343
-1	3	86	124	cooling off				**-1,0**	0,0	1,29	**43.110**	13.863	29.247	4,98	5,16	**640**	0	0,00	**38,7**	4804
-2	2,7	83	69	cooling off				**-2,0**	0,0	1,30	**43.277**	13.472	29.804	5,04	5,22	**360**	0	0,00	**38,3**	2643
-3	2,5	84	84	cooling off				**-3,0**	0,0	1,30	**43.442**	13.101	30.341	5,10	5,28	**443**	0	0,00	**37,9**	3183
-4	2,2	79	45	cooling off				**-4,0**	0,0	1,31	**43.611**	12.747	30.864	5,16	5,34	**240**	0	0,00	**37,5**	1686
-5	2,3	88	3	cooling off				**-5,0**	0,0	1,31	**43.771**	12.412	31.360	5,22	5,40	**16**	0	0,00	**37,1**	111
-6	2,3	94	1	cooling off				**-6,0**	0,0	1,32	**43.935**	12.091	31.844	5,27	5,45	**5**	0	0,00	**36,7**	37

The catch

There is a snag, however, when such systems are used in data centres. Since the direct evaporative system (as with any indirect system) operates on bringing in external air, a backup system is necessary. If there is a fire, the building may become smoke-logged because the air supply is no longer provided and the system fails. No data centre can afford that situation arising. Therefore, many data centres choose to provide back up facilities in the form of a chiller and an emergency generator. However the additional costs for this back up system may, again, be easily recouped by the low energy and operating costs of evaporative cooling. Another option for backup is to use PCM instead of mechanical cooling.

Rumours, rumours…

Evaporative cooling is not new. All over the world it is used while remaining well within the ASHRAE standards. In the UK, however, the technology is still relatively rarely used, since the following kinds of counter-arguments are doing the rounds.

Arguments used against evaporative cooling

1. "Evaporative cooling does not work in the UK's climate".
Our experience of installed systems teaches us that the opposite is true. The mathematical model has been developed based on a meteorological standard, and it is possible to make a projection based on the results in the application of evaporative cooling of a building. The result is affected by the weather. In wet weather the effectiveness is lower. In contrast, the hotter it is outside, the greater the cooling effect (10K T or more in a heat wave). This contrasts starkly with a compressor refrigeration system in which the performance decreases with increasing outside temperatures.

2. "Working in a humid environment is uncomfortable".
Here, too, in practice the increase in humidity is not noticed by people. Also, measurements and tests to the ISO 7730 standard, which establishes the standard for comfort in the workplace, show that comfort levels are maintained.

3. "The effect is small".
The effect is indeed lower than for mechanical cooling at normal ambient conditions. In general, however, in these circumstances the need for cooling is also less.

4. "The water usage is very high".
The water usage is about 20 to 30 litres per unit per hour. The UK has the advantage that there is no water shortage. Water costs about £2 per litre (purchasing + sewerage costs, etc.). The water costs are much lower than the power consumption and therefore have less impact on the total operating costs.

5. "It is so simple, it cannot work".
Over the centuries nature has shown us the way and offered us solutions that enable us to make savings. So the elephant shows us an effective example of evaporative cooling. It sucks up to 8 litres of water through its trunk and sprays it right where it wants to. In addition to the direct cooling that it brings, there is an additional cooling effect. Due to the evaporation of the water on the skin, the temperature drops too. Simple? Yes. But it also shows that with the use of the right tools, however simple, it is possible to balance energy use and temperature.

The benefits

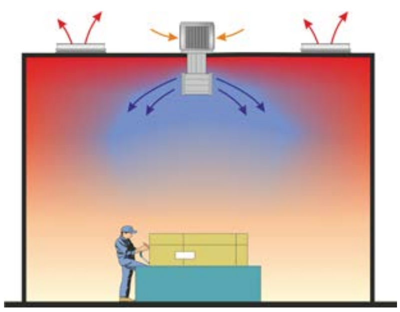
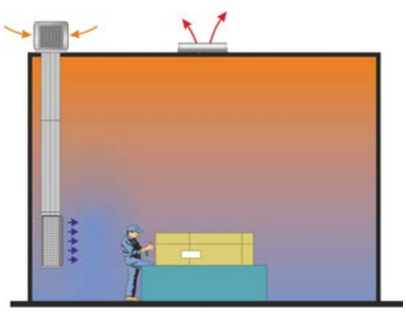
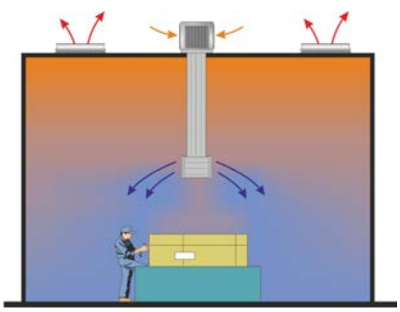
1. Sustainable
The system is energy efficient: for 10,000 m^3 cooled air, only 1 kW of electrical power is needed. If part of a natural ventilation design, evaporative cooling enables lower air volumes to be used to still achieve the same result.

2. No refrigerants
Instead of refrigerant, ordinary tap water is used.

3. Clean air
There is always cooled, fresh (clean) air. This provides a pleasant indoor climate.

4. Simplicity
It is a relatively simple technology and since it is highly reliable it is easy to maintain.

5 . Lower running costs than A/C.
Typical running costs are four to seven times lower than classic A/C solutions – and for data centres even lower.

The risks

Knowing that legionella is transmitted through inhalation of aerosol droplets containing the bacteria, there are two main risk areas that water based systems need to address:

Waterborne: legionella bacteria multiply at temperatures above 250°C and 500°C, so water temperature is a key factor in controlling the growth of the bacteria in the system. Minimising the quantity of legionella bacteria in the system's water is the first step in controlling the risk of infection.

Airborne: risk of breathing in legionella bacteria if the cooling system atomises water bearing the bacteria.

Does this mean that evaporative cooling is not safe?
No, but it does mean that if you are considering such a system for your factory or warehouse it is important that you understand how it manages these risks and make sure it has the right certification.

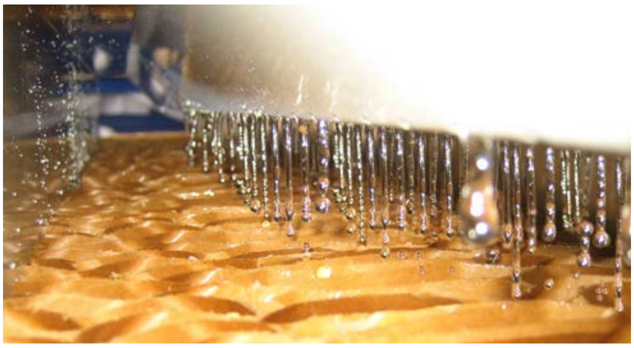
What makes an evaporative cooling system safe

Waterborne risks: water quality is critical: the system must ensure it is maintained and monitored. The system should be designed to maintain the water temperature below 200°C and include safety mechanisms that kick in if it rises above 250°C. Regular maintenance is also critical and a system designed to make inspections easy is preferable.

For example, our Colt CoolStream system uses only drinking water, exchanges the water regularly, monitors its temperature and foresees a drying cycle that kills all legionella bacteria once a day. In addition, there is an additional safety feature that ensures that in cases of an error the unit bleeds off all water and dries itself, and in case of a power outage the water empties automatically by a failsafe drain valve.

Airborne risks: the system should be designed in a way that prevents the release of water aerosols during the cooling process. This can be done in three ways with direct evaporative cooling:

a: Designing the system so that it produces macro droplets bigger than 5 micrometres (μm). This solution, however, is very risky, as micro droplets will also be created, increasing the risk of breathing in the bacteria. It also requires frequent maintenance and automatic disinfection systems.



b: Preventing the formation of droplets using a modern rigid wet medium, which is the most common solution. In this case, however, it is worth looking at the type of fan used: axial fans ensure a very smooth and even air distribution over the face of the wet medium, offering more effective protection. The large centrifugal units used by many units, on the other hand, tend to provide a more uneven distribution. Look out for systems using Aspen wood pads as desorption media, as they allow the passage of droplets even at low air velocities below 1.7 m/s. These are sometimes found in older or simpler, low-end units.

c: Accepting the formation of micro droplets, protecting from contamination by ensuring complete disinfection of the water. This solution can be expensive to install and operate.

Going back to our example, the way we have addressed this in our CoolStream system is by controlling the maximum speed of the air as it goes through the wet desorption medium, so that it is too slow to carry water droplets. The axial fans are controlled to keep the air speed below 1.7 m/s, well below the 2.0 m/s minimum speed where water droplets can be caught in the air stream, leaving a safety margin.

How do I know an evaporative cooling system is safe?

The first thing to do is to check which hygiene tests the system has successfully completed and that it has achieved a hygiene certification issued by a standards organisation recognised by the Health and Safety Executive (HSE). You can find detailed guidance and practical advice in the HSE L8 Approved Code of Practice.

What is a safe system?

Whoever wants to know if a system is safe can first check the hygiene tests that the system has successfully and the related certification. For example, having a VDI 6022 certificate provides assurance that not only Legionella, but also E. coli and other hygiene aspects of such a system have been addressed satisfactorily. VDI certificates issued by the German Association of Engineers are internationally recognized as the worldwide standard.

About Colt

Colt is an international company in business for over 80 years which specialises in the design, supply, installation and maintenance of systems that provide healthy and safe living and working conditions.
Colt makes careful use of natural resources and develops energy efficient solutions. It focuses on innovative, energy saving techniques.