becomes cooler and less buoyant and creates a downward flow in the tower. At the bottom of the tower, an outlet allows the cooler air into the interior. Similar to mechanical evaporative coolers, towers can be an attractive low-energy solution for hot and dry climate as they only require a water pump to raise water to the top of the tower.[14] Energy savings from using a passive direct evaporating cooling strategy depends on the climate and heat load. For arid climates with a great wet-bulb depression, cooling towers can provide enough cooling during summer design conditions to be net zero. For example, a 371 m2 (4,000 ft2) retail store in Tucson, Arizona with a sensible heat gain of 29.3 kJ/h (100,000 Btu/h) can be cooled entirely by two passive cooling towers providing 11890 m3/h (7,000 cfm) each.[15] For the Zion National Park visitors' center, which uses two passive cooling towers, the cooling energy intensity was 14.5 MJ/m2 (1.28 kBtu/ft;), which was 77% less than a typical building in the western United States that uses 62.5 MJ/m2 (5.5 kBtu/ft2).[16] A study of field performance results in Kuwait revealed that power requirements for an evaporative cooler are approximately 75% less than the power requirements for a conventional packaged unit air-conditioner.[17] Indirect evaporative cooling The process of indirect evaporative cooling Indirect evaporative cooling (closed circuit) is a cooling process that uses direct evaporative cooling in addition to some heat exchanger to transfer the cool energy to the supply air. The cooled moist air from the direct evaporative cooling process never comes in direct contact with the conditioned supply air. The moist air stream is released outside or used to cool other external devices such as solar cells which are more efficient if kept cool. This is done to avoid excess humidity in enclosed spaces, which is not appropriate for residential systems. Maisotsenko cycle One indirect cooler manufacturer uses the Maisotsenko cycle (M-Cycle), named after inventor and Professor Dr. Valeriy Maisotsenko, employs an iterative (multi-step) heat exchanger made of a thin recyclable membrane that can reduce the temperature of product air to below the wet-bulb temperature, and can approach the dew point.[18] Testing by the US Department of Energy found that a hybrid M-Cycle combined with a standard compression refrigeration system significantly improved efficiency by between 150-400% but was only capable of doing so in the dry western half of the US, and did not recommend being used in the much more humid eastern half of the US. The evaluation found that the system water consumption of 2-3 gallons per cooling ton(12,000 BTUs) was roughly equal in efficiency to the water consumption of new high efficiency power plants. This means the higher efficiency can be utilized to reduce load on the grid without requiring any additional water, and may actually reduce water usage if the source of the power does not have a high efficiency cooling system.[19] An M-Cycle based system built by Coolerado is currently being used to cool the Data Center for NASA's National Snow and Ice Data Center (NSIDC). The facility is air cooled below 70 degrees Fahrenheit and uses the Coolerado system above that temperature. This is possible because the air handler for the system uses fresh outside air, which allows it to automatically use cool outside ambient air when conditions allow. This avoids running the refrigeration system when unnecessary. It is powered by a solar panel array which also serves as secondary power in case of main power loss.[20] The system has very high efficiency but, like other evaporative cooling systems, is constrained by the ambient humidity levels, which has limited its adoption for residential use. It may be used as supplementary cooling during times of extreme heat without placing significant additional burden on electrical infrastructure. If a location has excess water supplies or excess desalination capacity it can be used to reduce excessive electrical demand by utilizing water in affordable M-Cycle units. Due to high costs of conventional air conditioning units and extreme limitations of many electrical utility systems, M-Cycle units may be the only appropriate cooling systems suitable for impoverished areas during times of extremely high temperature and high electrical demand. In developed areas, they may serve as supplemental backup systems in case of electrical overload, and can be used to boost efficiency of existing conventional systems. The M-Cycle is not limited to cooling systems and can be applied to various technologies from Stirling engines to Atmospheric water generators. For cooling applications it can be used in both cross flow and counterflow configurations. Counterflow was found to obtain lower temperatures more suitable for home cooling, but cross flow was found to have a higher coefficient of performance (COP), and is therefore better for large industrial installations. Unlike traditional refrigeration techniques, the COP of small systems remains high, as they do not require lift pumps or other equipment required for cooling towers. A 1.5 ton/4.4kw cooling system requires just 200 watts for operation of the fan, giving a COP of 26.4 and an EER rating of 90. This does not take into account the energy required to purify or deliver the water, and is strictly the power required to run the device once water is supplied. Though desalination of water also presents a cost, the latent heat of vaporization of water is nearly 100 times higher than the energy required to purify the water itself. Furthermore, the device has a maximum efficiency of 55%, so its actual COP is much lower than this calculated value. However, regardless of these losses, the effective COP is still significantly higher than a conventional cooling system, even if water must first be purified by desalination. In areas where water is not available in any form, it can be used with a desiccant to recover water using available heat sources, such as solar thermal energy.[21][22] Theoretical designs In the newer but yet-to-be-commercialized "cold-SNAP" design from Harvard's Wyss Institute, a 3D-printed ceramic conducts heat but is half-coated with a hydrophobic material that serves as a moisture barrier.[23] While no moisture is added to the incoming air the relative humidity (RH) does rise a little according to the Temperature-RH formula. Still, the relatively dry air resulting from indirect evaporative cooling allows inhabitants' perspiration to evaporate more easily, increasing the relative effectiveness of this technique. Indirect Cooling is an effective strategy for hot-humid climates that cannot afford to increase the moisture content of the supply air due to indoor air quality and human thermal comfort concerns. Passive indirect evaporative cooling strategies are rare because this strategy involves an architectural element to act as a heat exchanger (for example a roof). This element can be sprayed with water and cooled through the evaporation of the water on this element. These strategies are rare due to the high use of water, which also introduces the risk of water intrusion and compromising building structure. Hybrid designs Two-stage evaporative cooling, or indirect-direct In the first stage of a two-stage cooler, warm air is pre-cooled indirectly without adding humidity (by passing inside a heat exchanger that is cooled by evaporation on the outside). In the direct stage, the pre-cooled air passes through a water-soaked pad and picks up humidity as it cools. Since the air supply is pre-cooled in the first stage, less humidity is transferred in the direct stage, to reach the desired cooling temperatures. The result, according to manufacturers, is cooler air with a RH between 50-70%, depending on the climate, compared to a traditional system that produces about 70–80% relative humidity in the conditioned air. Evaporative + conventional backup In another hybrid design, direct or indirect cooling has been combined with vapor-compression or absorption air conditioning to increase the overall efficiency and/or to reduce the temperature below the wet-bulb limit. Materials Traditionally, evaporative cooler pads consist of excelsior (aspen wood fiber) inside a containment net, but more modern materials, such as some plastics and melamine paper, are entering use as cooler-pad media. Modern rigid media, commonly 8" or 12" thick, adds more moisture, and thus cools air more than typically much thinner aspen media.[24] Another material which is sometimes used is corrugated cardboard.[25][26] Design considerations Water use In arid and semi-arid climates, the scarcity of water makes water consumption a concern in cooling system design. From the installed water meters, 420938 L (111,200 gal) of water were consumed during 2002 for the two passive cooling towers at the Zion National Park visitors' center.[27] However, such concerns are addressed by experts who note that electricity generation usually requires a large amount of water, and evaporative coolers use far less electricity, and thus comparable water overall, and cost less overall, compared to chillers.[28] Shading Allowing direct solar exposure to the media pads increases the evaporation rate. Sunlight may, however, degrade some media, in addition to heating up other elements of the evaporative cooling design. Therefore, shading is advisable in most applications. Mechanical systems Apart from fans used in mechanical evaporative cooling, pumps are the only other piece of mechanical equipment required for the evaporative cooling process in both mechanical and passive applications. Pumps can be used for either recirculating the water to the wet media pad or providing water at very high pressure to a mister system for a passive cooling tower. Pump specifications will vary depending on evaporation rates and media pad area. The Zion National Park visitors' center uses a 250 W (1/3 HP) pump.[29] Exhaust Exhaust ducts and/or open windows must be used at all times to allow air to continually escape the air-conditioned area. Otherwise, pressure develops and the fan or blower in the system is unable to push much air through the media and into the air-conditioned area. The evaporative system cannot function without exhausting the continuous supply of air from the air-conditioned area to the outside. By optimizing the placement of the cooled-air inlet, along with the layout of the house passages, related doors, and room windows, the system can be used most effectively to direct the cooled air to the required areas. A well-designed layout can effectively scavenge and expel the hot air from desired areas without the need for an above-ceiling ducted venting system. Continuous airflow is essential, so the exhaust windows or vents must not restrict the volume and passage of air being introduced by the evaporative cooling machine. One must also be mindful of the outside wind direction, as, for example, a strong hot southerly wind will slow or restrict the exhausted air from a south-facing window. It is always best to have the downwind windows open, while the upwind windows are closed. Different types of installations Typical installations Typically, residential and industrial evaporative coolers use direct evaporation, and can be described as an enclosed metal or plastic box with vented sides. Air is moved by a centrifugal fan or blower (usually driven by an electric motor with pulleys known as "sheaves" in HVAC terminology, or a direct-driven axial fan), and a water pump is used to wet the evaporative cooling pads. The cooling units can be mounted on the roof (down draft, or downflow) or exterior walls or windows (side draft, or horizontal flow) of buildings. To cool, the fan draws ambient air through vents on the unit's sides and through the damp pads. Heat in the air evaporates water from the pads which are constantly re-dampened to continue the cooling process. Then cooled, moist air is delivered into the building via a vent in the roof or wall. Because the cooling air originates outside the building, one or more large vents must exist to allow air to move from inside to outside. Air should only be allowed to pass once through the system, or the cooling effect will decrease. This is due to the air reaching the saturation point. Often 15 or so air changes per hour (ACHs) occur in spaces served by evaporative coolers, a relatively high rate of air exchange. Evaporative (wet) cooling towers Main article: Cooling tower Large hyperboloid cooling towers made of structural steel for a power plant in Kharkiv (Ukraine) Cooling towers are structures for cooling water or other heat transfer media to near-ambient wet-bulb temperature. Wet cooling towers operate on the evaporative cooling principle, but are optimized to cool the water rather than the air. Cooling towers can often be found on large buildings or on industrial sites. They transfer heat to the environment from chillers, industrial processes, or the Rankine power cycle, for example. Misting systems Mist spraying system with water pump beneath Misting systems work by forcing water via a high pressure pump and tubing through a brass and stainless steel mist nozzle that has an orifice of about 5 micrometres, thereby producing a micro-fine mist. The water droplets that create the mist are so small that they instantly flash-evaporate. Flash evaporation can reduce the surrounding air temperature by as much as 35 °F (20 °C) in just seconds.[30] For patio systems, it is ideal to mount the mist line approximately 8 to 10 feet (2.4 to 3.0 m) above the ground for optimum cooling. Misting is used for applications such as flowerbeds, pets, livestock, kennels, insect control, odor control, zoos, veterinary clinics, cooling of produce, and greenhouses. Misting fans A misting fan is similar to a humidifier. A fan blows a fine mist of water into the air. If the air is not too humid, the water evaporates, absorbing heat from the air, allowing the misting fan to also work as an air cooler. A misting fan may be used outdoors, especially in a dry climate. It may also be used indoors. Small portable battery-powered misting fans, consisting of an electric fan and a hand-operated water spray pump, are sold as novelty items. Their effectiveness in everyday use is unclear.[citation needed] Performance Understanding evaporative cooling performance requires an understanding of psychrometrics. Evaporative cooling performance is variable due to changes in external temperature and humidity level. A residential cooler should be able to decrease the temperature of air to within 3 to 4 °C (5 to 7 °F) of the wet bulb temperature. It is simple to predict cooler performance from standard weather report information. Because weather reports usually contain the dewpoint and relative humidity, but not the wet-bulb temperature, a psychrometric chart or a simple computer program must be used to compute the wet bulb temperature. Once the wet bulb temperature and the dry bulb temperature are identified, the cooling performance or leaving air temperature of the cooler may be determined. For direct evaporative cooling, the direct saturation efficiency, ϵ {\displaystyle \epsilon } , measures in what extent the temperature of the air leaving the direct evaporative cooler is close to the wet-bulb temperature of the entering air. The direct saturation efficiency can be determined as follows:[31] ϵ = T e , d b − T l , d b T e , d b − T e , w b {\displaystyle \epsilon ={\frac {T_{e,db}-T_{l,db}}{T_{e,db}-T_{e,wb}}}} Where: ϵ {\displaystyle \epsilon } = direct evaporative cooling saturation efficiency (%) T e , d b {\displaystyle T_{e,db}} = entering air dry-bulb temperature (°C) T l , d b {\displaystyle T_{l,db}} = leaving air dry-bulb temperature (°C) T e , w b {\displaystyle T_{e,wb}} = entering air wet-bulb temperature (°C) Evaporative media efficiency usually runs between 80% to 90%. Most efficient systems can lower the dry air temperature to 95% of the wet-bulb temperature, the least efficient systems only achieve 50%.[31] The evaporation efficiency drops very little over time. Typical aspen pads used in residential evaporative coolers offer around 85% efficiency while CELdek[further explanation needed] type of evaporative media offer efficiencies of >90% depending on air velocity. The CELdek media is more often used in large commercial and industrial installations. As an example, in Las Vegas, with a typical summer design day of 42 °C (108 °F) dry bulb and 19 °C (66 °F) wet bulb temperature or about 8% relative humidity, the leaving air temperature of a residential cooler with 85% efficiency would be: T l , d b {\displaystyle T_{l,db}} = 42 °C – [(42 °C – 19 °C) × 85%] = 22.45 °C or 72.41 °F However, either of two methods can be used to estimate performance: Use a psychrometric chart to calculate wet bulb temperature, and then add 5–7 °F as described above. Use a rule of thumb which estimates that the wet bulb temperature is approximately equal to the ambient temperature, minus one third of the difference between the ambient temperature and the dew point. As before, add 5–7 °F as described above. Some examples clarify this relationship: At 32 °C (90 °F) and 15% relative humidity, air may be cooled to nearly 16 °C (61 °F). The dew point for these conditions is 2 °C (36 °F). At 32 °C and 50% relative humidity, air may be cooled to about 24 °C (75 °F). The dew point for these conditions is 20 °C (68 °F). At 40 °C (104 °F) and 15% relative humidity, air may be cooled to nearly 21 °C (70 °F). The dew point for these conditions is 8 °C (46 °F). (Cooling examples extracted from the June 25, 2000 University of Idaho publication, "Homewise"). Because evaporative coolers perform best in dry conditions, they are widely used and most effective in arid, desert regions such as the southwestern USA, northern Mexico, and Rajasthan. The same equation indicates why evaporative coolers are of limited use in highly humid environments: for example, a hot August day in Tokyo may be 30 °C (86 °F) with 85% relative humidity, 1,005 hPa pressure. This gives a dew point of 27.2 °C (81.0 °F) and a wet-bulb temperature of 27.88 °C (82.18 °F). According to the formula above, at 85% efficiency air may be cooled only down to 28.2 °C (82.8 °F) which makes it quite impractical. Comparison to other types of air conditioning This section possibly contains original research. Please improve it by verifying the claims made and adding inline citations. Statements consisting only of original research should be removed. (August 2009) (Learn how and when to remove this template message) A misting fan Comparison of evaporative cooling to refrigeration-based air conditioning: Advantages Less expensive to install and operate Estimated cost for professional installation is about half or less that of central refrigerated air conditioning.[32] Estimated cost of operation is 1/8 that of refrigerated air conditioning.[33] No power spike when turned on due to lack of a compressor Power consumption is limited to the fan and water pump, which have a relatively low current draw at start-up. The working fluid is water. No special refrigerants, such as ammonia or CFCs, are used that could be toxic, expensive to replace, contribute to ozone depletion and/or be subject to stringent licensing and environmental regulations. Can be operated on home power inverter during power cuts. This is particularly useful in areas that experience frequent power outages.[34] Newly launched Air coolers can be operated though remote control.[35] Ease of installation and maintenance Equipment can be installed by mechanically-inclined users at drastically lower cost than refrigeration equipment which requires specialized skills and professional installation. The only two mechanical parts in most basic evaporative coolers are the fan motor and the water pump, both of which can be repaired or replaced at low cost and often by a mechanically inclined user, eliminating costly service calls to HVAC contractors. Ventilation air The frequent and high volumetric flow rate of air traveling through the building reduces the "age-of-air" in the building dramatically. Evaporative cooling increases humidity. In dry climates, this may improve comfort and decrease static electricity problems. The pad itself acts as a rather effective air filter when properly maintained; it is capable of removing a variety of contaminants in air, including urban ozone caused by pollution,[citation needed] regardless of very dry weather. Refrigeration-based cooling systems lose this ability whenever there is not enough humidity in the air to keep the evaporator wet while providing a frequent trickle of condensation that washes out dissolved impurities removed from the air. Disadvantages Performance Most evaporative coolers are unable to lower the air temperature as much as refrigerated air conditioning can. High dewpoint (humidity) conditions decrease the cooling capability of the evaporative cooler. No dehumidification. Traditional air conditioners remove moisture from the air, except in very dry locations where recirculation can lead to a buildup of humidity. Evaporative cooling adds moisture, and in humid climates, dryness may improve thermal comfort at higher temperatures. Comfort The air supplied by the evaporative cooler is generally 80–90% relative humidity and can cause interior humidity levels as high as 65%; very humid air reduces the evaporation rate of moisture from the skin, nose, lungs, and eyes. High humidity in air accelerates corrosion, particularly in the presence of dust. This can considerably reduce the life of electronics and other equipment. High humidity in air may cause condensation of water. This can be a problem for some situations (e.g., electrical equipment, computers, paper, books, old wood). Odors and other outdoor contaminants may be blown into the building unless sufficient filtering is in place. Water use Evaporative coolers require a constant supply of water. Water high in mineral content (hard water) will leave mineral deposits on the pads and interior of the cooler. Depending on the type and concentration of minerals, possible safety hazards during the replacement and waste removal of the pads could be present. Bleed-off and refill (purge pump) systems can reduce but not eliminate this problem. Installation of an inline water filter (refrigerator drinking water/ice maker type) will drastically reduce the mineral deposits. Maintenance frequency Any mechanical components that can rust or corrode need regular cleaning or replacement due to the environment of high moisture and potentially heavy mineral deposits in areas with hard water. Evaporative media must be replaced on a regular basis to maintain cooling performance. Wood wool pads are inexpensive but require replacement every few months. Higher-efficiency rigid media is much more expensive but will last for a number of years proportional to the water hardness; in areas with very hard water, rigid media may only last for two years before mineral scale build-up unacceptably degrades performance. In areas with cold winters, evaporative coolers must be drained and winterized to protect the water line and cooler from freeze damage and then de-winterized prior to the cooling season. Health hazards An evaporative cooler is a common place for mosquito breeding. Numerous authorities consider an improperly maintained cooler to be a threat to public health.[36] Mold and bacteria may be dispersed into interior air from improperly maintained or defective systems, causing sick building syndrome and adverse effects for asthma and allergy sufferers. Wood wool of dry cooler pads can catch fire even from small sparks. See also Architectural engineering Botijo (Spanish evaporative water cooler) Building engineering Car cooler Coolgardie safe Cooling tower Dehumidifier Humidifier HVAC Pot-in-pot refrigerator Yakhchāl Legionella Legionnaire's Disease References

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