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ABSTRACT

Evaporative air cooling is an effective and environmentally benign method of cooling. Scientific evidence demonstrating that chlorofluorocarbon refrigerants (CFCs) are contributing to the destruction of the stratospheric ozone layer have prompted legislative action aimed at reducing the production and use of certain CFCs. Enacted legislation, by necessitating the introduction and use of alternative refrigerants, will increase the cost of installing, operating, and maintaining mechanical refrigeration systems. Conversion to alternative refrigerants will reduce the efficiency and capacity of existing systems. This paper describes how evaporative cooling methods can offset or eliminate the need for ozone-depleting refrigerants used in new and existing refrigerative systems.

INTRODUCTION

Evaporative air cooling is an effective and environmentally benign method of cooling. Evaporative cooling can help alleviate global climatic change in two ways: decreased electrical consumption compared to vapor compression refrigeration systems (hence decreased power plant emissions and greenhouse gases); and prevention of CFC usage since evaporative coolers use no CFCs.

The 1987 Montreal Protocol on Substances that Deplete the Ozone Layer requires participating countries to effect a 50% reduction in production of restricted CFCs by 1998. These reductions will cause shortages due to insufficient production capabilities and, in conjunction with excise taxes imposed by the United States government, considerably higher prices for CFCs. Current worldwide trends to control production of fully halogenated CFCs will provide increased opportunities for evaporative cooling.

The role that evaporative cooling can provide in reducing fully halogenated CFC use in this country is important since the largest component of CFC usage in the United States is for air conditioning and refrigeration, which accounted for 33% of total U.S. CFC consumption in 1988 (Lukosius, 1989). This paper describes some methods that evaporative cooling can be used to offset CFC use for cooling in the residential, commercial, and industrial sectors.

EVAPORATIVE AIR COOLING AND CFCs

Evaporative air cooling is the cooling effect provided by the adiabatic evaporation of water. Air is drawn through porous wetted pads or a spray, and its sensible heat energy evaporates some water, reducing the air's dry-bulb temperature. The temperature of the nearly saturated moist air approaches the ambient air's wet-bulb temperature. The air temperature is reduced by 60 to 95% of the wet-bulb depression (ambient dry-bulb temperature less wet-bulb temperature). Two methods of evaporative cooling exist. One method is direct cooling, in which water evaporates directly into the airstream, thus reducing the air temperature and humidifying it. The second method is indirect cooling, in which the primary air is cooled sensibly with a heat exchanger, while the secondary air carries away the heat energy from the primary air as generated vapor. Two basic techniques are used for indirect cooling: one form uses a heat exchanger in which water is used to evaporatively cool the secondary airstream with the system supply air passing through the exchanger; the second technique typically uses a finned tube heat exchanger in which the circulating water is evaporatively cooled remotely using a cooling tower or other direct process. Thermal storage tanks are sometimes used to take advantage of low nocturnal wet-bulb temperatures to produce colder water. Direct and indirect processes can be combined (indirect/direct). Compared to refrigerated systems, increased air flowrates are required for evaporative comfort cooling to compensate for the higher supply air temperatures.

Direct evaporative cooling can provide comfort over approximately 40% of the United States land area, from southern California to central Texas, and Arizona through Montana. Indirect/direct evaporative cooling can provide comfort in an additional 40% of the country for central and eastern areas outside of the lower Mississippi Valley and humid coastal plains. Relief cooling for greenhouses and industrial sites can be provided throughout the United States (Watt, 1986).

Evaporative cooling consumes significantly less energy than vapor compression refrigeration. The only power consuming components of an evaporative cooler are fans and small water pumps; refrigerated air conditioners and heat pumps are more complex, having more fans and a compressor. The energy savings realized by use of a direct evaporative cooler instead of vapor compression air conditioning systems are shown in Table 1.

TABLE 1
DIRECT EVAPORATIVE COOLER ENERGY SAVINGS COMPARED TO A REFRIGERATED AIR CONDITIONER OR AN ELECTRIC HEAT PUMP

City	Evap Cooling Energy Savings Compared to Air Conditioner	Heat Pump
Burbank	69%	70%
Phoenix	74%	72%
El Paso	68%	69%
Denver	69%	70%
Spokane	70%	71%

Source: Gordian Associates, 1977.

Energy savings of evaporative coolers vary with humidity levels and temperatures. Direct systems in low humidity zones typically realize an energy savings of 60 to 80% over refrigerated systems. Indirect/direct and three-stage indirect-indirect/direct systems realize a 40 to 50% energy savings in moderate humidity zones. Indirect systems with refrigerative second stages can provide adequate comfort cooling in high humidity zones with a savings of 20 to 25% (Watt, 1987).

With the enacted and proposed CFC regulations, the impact on the refrigeration industry will be greatest in the commercial sector. The compressor and heat transfer surfaces currently in use have been designed and optimized for CFC-11 and 12. The use of CFC substitutes will require compromises in energy consumption, capacity, and other design parameters. For example, using HCFC-123 in a unit designed for CFC-11 will result in a performance degradation of approximately 16% (Rothery, 1990). If the cooling system in a building loses cooling capacity, insufficient cooling may result during peak cooling hours, depending on how the building is designed.

Evaporative cooling will contribute towards reductions of fully halogenated CFCs in the commercial and industrial sectors, which now use virulent ozone depleting CFCs in their cooling systems. Evaporative cooling is useful in many commercial and industrial applications, such as spot cooling, commercial greenhouses, loading docks, factories, lobbies, large kitchens, poultry houses, laundries, and other similar situations. Comfort cooling can be provided throughout the country with staged and hybrid (evaporative and refrigerative systems combined) evaporative cooling systems.

DIRECT EVAPORATIVE COOLING

The most widespread use of direct evaporative air coolers in the United States is for cooling in residences. While it is known that at least 3.2 million residential evaporative coolers (representing about 4% of total households) are in use (DOE/EIA, 1984), 3.5 million residential systems is a more reasonable estimate and used in the analysis below (Kaly, 1989). Most of these coolers are located in the Southwest and are almost without exception direct evaporative coolers.

Extrapolating the results obtained by a study done in 1977 (Gordian Associates, Inc.), residential direct evaporative coolers in the Western United States today annually displace the energy equivalent of at least 10.5 million barrels of fuel oil per year in comparison to refrigerated cooling systems.

Refrigerated residential air conditioning in the United States almost exclusively uses HCFC-22 (R-22) as a refrigerant. In 1986, 104 million pounds of R-22 were used for air conditioning (Cox, 1989), with about 30 million residential refrigerated air conditioners in use (DOE/EIA, 1984). Conservatively, existing residential evaporative coolers have obviated the use of at least 21 million pounds of R-22 directly, based on 6 pounds refrigerant used per residential refrigerated system (typical systems will use from 6 to 12 pounds), and have obviated far more due to displaced recharging of refrigerated systems. R-22 has from 1/20 to 1/7 the ozone depletion effect of R-12 (estimates vary). R-22's current total contribution to overall ozone destruction is probably less than one percent (Shea, 1988). Therefore, the potential of residential evaporative cooling for ameliorating ozone depletion is very small, and will remain so, even if a very large part of the U.S. residential market used evaporative coolers instead of refrigerated air conditioning. R-22 is not regulated by the Montreal Protocol as it is not yet considered a significant part of the ozone depletion problem by the Protocol or the EPA. However, several bills pending in Congress have been introduced to regulate R-22, and if such legislation is enacted, then there will be additional opportunities for evaporative coolers to provide comfort residential cooling in the country.

INDIRECT/DIRECT EVAPORATIVE COOLING

Depending on climate conditions, many buildings can replace their refrigerated air conditioning systems with indirect/direct evaporative cooling systems. Many buildings in the Southwest use refrigerated air conditioning, which can be replaced with indirect/direct evaporative air conditioning systems to provide comfort cooling. One problem for retrofit situations is that existing building ducts may be inadequately sized for the increased airflow delivery required by indirect/direct evaporative coolers.

Performance of an indirect/direct evaporative cooler is shown for ASHRAE 1% summer design conditions (dry-bulb/mean coincident wet-bulb) for Denver, Albuquerque, Las Vegas, and El Paso in Table 2. The psychrometric process is shown in Figure A. The cooler is assumed to have a 65% indirect and an 85% direct effectiveness and is representative of normal commercial equipment (even greater effectiveness is achievable). An indirect cooler provides sensible cooling of the outside air, followed by an evaporative cooling effect from the direct cooler. In the Denver case, the representative indirect/direct evaporative cooler can deliver 54°F supply air for ASHRAE 1% design conditions. These deliverable air temperatures can cool a building sufficiently to provide comfort for the occupants without refrigeration. Thus, buildings located in the West can satisfactorily obtain comfort cooling without refrigerated systems by using indirect/direct evaporative cooling.

TABLE 2
INDIRECT EVAPORATIVE COOLING AND PRECOOLING

Site	ASHRAE 1% [a] Design Condition	Ind/Dir [b] Supply Air	% Capacity Added [c] Precooler1	Precooler2
Denver	93/59	54/51	14%	47%
Albuquerque	96/61	56/53	14%	43%
Las Vegas	108/66	61/57	15%	37%
El Paso	100/64	59/56	13%	37%
Los Angeles	93/70	67/65	7%	22%
Chicago	94/75	73/72	5%	11%
New York City	92/74	72/71	5%	13%
Dallas	102/75	72/70	7%	14%

[a] All temperatures are in degrees Fahrenheit, Dry-bulb/Mean Coincident Wet-bulb. Source: ASHRAE, 1989.

[b] All cases assume an overall performance factor of 65% for the indirect process and a saturation effectiveness of 85% for the direct process.

[c] The overall performance factor of Precooler 1 was 65%; the overall saturation effectiveness of Precooler 2 was 85%, and the heat exchanger effectiveness of B was 80%. 20% outside air was mixed with return air. Return air was 78/66°F and supply air was 55/52.5°F.

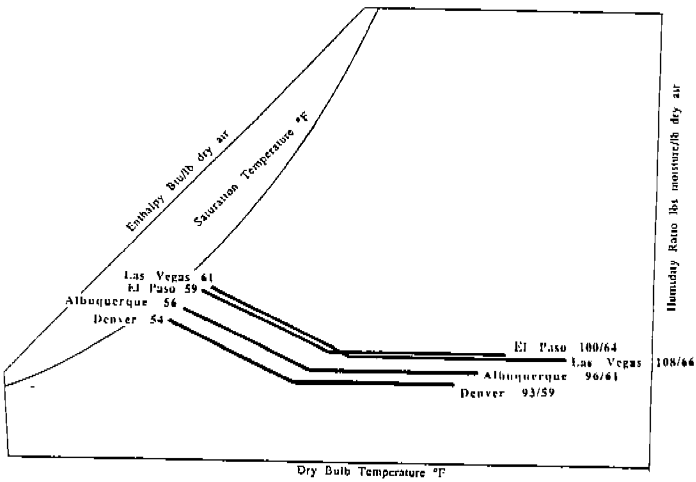


FIGURE A
INDIRECT/DIRECT EVAPORATIVE COOLING PROCESS

EVAPORATIVE PRECOOLING

Evaporative cooling can be used throughout the United States as a supplemental precooler to increase capacity for some of the estimated 4.1 million commercial buildings with refrigerated systems. Indirect coolers without a direct stage can precool all summer make-up air. Direct evaporative precoolers can be used on air-cooled condenser coils. Evaporative precoolers will be an important application in the near future as fully halogenated CFCs are phased out. Since the alternative HCFCs and HFCs are less efficient refrigerants than the fully halogenated CFCs, additional capacity may be needed if these refrigerants are to be used in marginally sized existing equipment. An evaporative precooler can be used to offset the reduced equipment performance.

In addition to reduced performance with substitute refrigerants, cooling systems will be faced with increased system loads. The new ASHRAE Standard 62-1989 reflects concerns over indoor air quality and essentially quadruples ventilating flowrates per person. Many cooling systems already have surplus capacity and may not be adversely affected. However, for those buildings that cannot tolerate a decrease in capacity, either the load must be reduced or the cooling capacity increased.

One way to increase capacity would be to place additional chilling equipment in buildings. A less expensive method would be to use indirect or direct evaporative precoolers on a building. A retrofit for an evaporative precooler can be relatively easy to place. As noted earlier, for drier parts of the United States, indirect/direct evaporative coolers can provide all of the comfort cooling needed in a commercial building.

Two cases for indirect evaporative precoolers are shown in Figure B. Case 1 places the evaporative precooler in the ventilation airstream, and Case 2 places the precooler after the mixed airstream, thereby requiring a larger heat exchanger due to the higher air volumes. Case 2 might not be an economically attractive alternative due to this considerably larger heat exchanger. For both cases, a return air temperature of 78° and 66°F (78/66) dry and wet-bulb temperatures was assumed. The supply air was provided to the building at 55/52.5. The overall effectiveness of the indirect precooler and heat exchange process (performance factor) in Case 1 was assumed to be 65%. In Case 2, the effectiveness of the direct stage of the precooler was assumed as 85%, and 80% effectiveness for the heat exchanger.

ASHRAE 1% summer design conditions for New York City, Los Angeles, Dallas, and Chicago are shown in Table 2, along with the percentage capacity added to the system for the two evaporative precooler cases. Note that even though these areas have a relatively high wet-bulb temperature, 5 to 7 percent capacity was added to the system for Case 1, and even more for Case 2. Thus, indirect evaporative precoolers can add significant capacity to a building's cooling system to help compensate for the decreased performance of substitute refrigerants and to accommodate increased system loads due to increased ventilation.

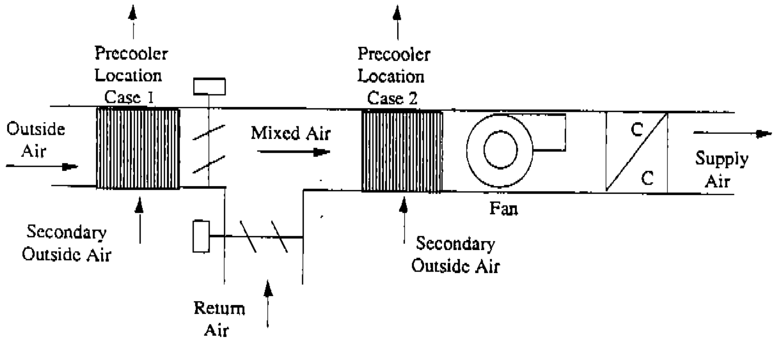


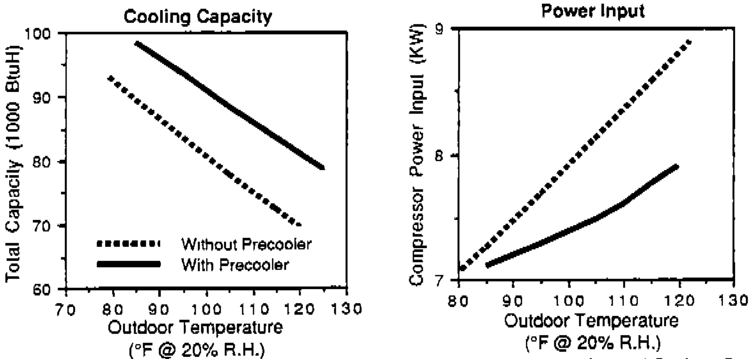
FIGURE B
INDIRECT EVAPORATIVE PRECOOLERS: CASES 1 & 2

The performance of refrigeration systems can also be enhanced by evaporatively precooling air used to cool condenser coils. The retrofit is easy and both power savings and increased capacity for the cooling system are realized. An added advantage is that the direct precooler will reduce summer head pressures and thus extend compressor life.

In a direct evaporative precooling process, panels of wetted medium are used mounted on condenser faces to precool all condenser air. Precooler panels should be sized at sufficiently low face velocities to prevent carryover of water and subsequent scaling of the condensing coils.

A direct precooler added to a 40 ton rooftop air conditioner operating at 95°F and 40% relative humidity, reduced head pressure by 12.6%, reduced power draw by 6%, increased the EER (Energy Efficiency Ratio) by 12.6% and the capacity by 6.6% (Research Products Corp). Figure C shows the difference in power input and cooling capacity with and without a precooler for a 7-1/2 ton air conditioner using R-22.

Energy savings from the installation of direct precoolers on air-cooled condensers are substantial. In the West, energy savings of over 20% are possible, while in the East, savings from 5 to 10% can be expected (Figure D). Simple payback in the West typically is in two years or less. For instance, installation and capital cost of a direct precooler over the condensing coil of a York 30 ton unit would cost approximately $2,670, with an estimated first year energy savings of about $2,850 in Phoenix (Energy Saver Mfg. Co.).



Source: Research Products Corp.

FIGURE C
POWER SAVINGS AND INCREASED COOLING CAPACITY FOR A 7 1/2 TON R-22 AIR CONDITIONER

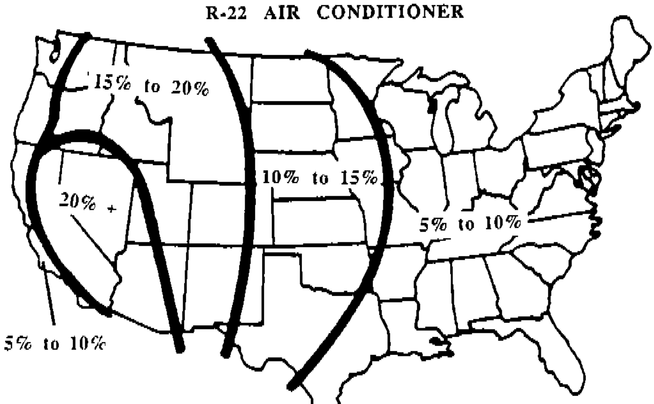


FIGURE D
ENERGY SAVINGS FOR DIRECT EVAPORATIVE PRECOOLERS IN U.S.

CONCLUSIONS

Residential evaporative cooling will play no significant role in alleviating ozone depletion since R-22, which is the dominant refrigerant in unitary applications, is a negligible contributor to ozone depletion. Current residential evaporative coolers have prevented the direct usage of at least 21 million pounds of R-22. If R-22 is regulated or banned in the future, there will be new opportunities for evaporative cooling.

In the West, indirect/direct evaporative coolers can generally provide supply air from 55° to 65°F, eliminating the need for refrigerated air conditioning for commercial buildings.

Cooling systems that incorporate R-11 and R-12, typical in commercial applications, may need to use alternative refrigerants by the end of the decade, resulting in a decrease of cooling capacity of 10 to 20%. Enhancement of refrigeration systems through evaporative precooling will be an economically attractive option. Indirect evaporative precoolers for ventilation air can augment system cooling capacity from 5 to 20%, depending on ambient conditions. Direct evaporative precoolers on air-cooled condenser coils increase capacity similarly, as well as realize energy savings from 5 to 20%, again dependent on local design conditions.

Evaporative precoolers can offset a cooling system's capacity loss due to a substitute refrigerant without a costly upgrade or retrofit of an existing chiller and realize energy savings. Indirect/direct and direct evaporative coolers will also gain importance due to energy savings and non-use of CFCs. Evaporative cooling, simple and benign, offers a partial solution to the CFC crisis.

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