EVAPORATIVE AIR-CONDITIONING CONTRIBUTIONS TO REDUCING GREENHOUSE GAS EMISSIONS AND GLOBAL WARMING

Robert E. Foster
Southwest Technology Development Institute
New Mexico State University
rfoster@nmsu.edu

ABSTRACT

Evaporative air-conditioning (EAC) is an environmentally friendly and energy efficient cooling method that only uses water as the working fluid. EAC provides superior indoor air quality over vapor-compression systems since 100% outdoor air is used. The use of EAC instead of vapor-compression systems also helps reduce global CO_2, CFC, and other greenhouse gas emissions.

Over 20 million residential evaporative coolers are in operation today worldwide. Around the globe EAC residential units directly obviate at least 118 million pounds of HCFC-22. These residential coolers save approximately 60 million barrels of oil annually and 27 billion pounds of annual CO_2 emissions in lieu of using vapor-compression air-conditioning systems. Contributions from commercial and industrial applications of EAC are on a similar order of magnitude as well.

However, EAC is an under-utilized technology worldwide that has yet to fulfill its' full potential. The potential future global market and environmental benefits of this technology with increased market penetration is enormous. EAC technologies alone, as well as coupled with desiccant technologies, could displace the need for vapor-compression air-conditioning for many applications. As developing nation economies grow, energy saving technologies such as EAC will assist with future development. The energy savings and corresponding greenhouse gas emission reductions from more widespread adoption of EAC can play an important part in the challenge of meeting global CO_2 and other greenhouse gas emission reductions targets.

INTRODUCTION

Evaporative air-conditioning (EAC) technologies are growing worldwide, however they are still widely underutilized and often even unknown in many parts of the world. Through EAC superior cooling and ventilation can be provided with minimal energy consumption and without the use of CFCs or other similar ozone-depleting chemicals. EAC can provide comfort cooling throughout the many arid and semi-arid regions of the world, as well as relief cooling for commercial and industrial applications such as greenhouses, buses, laundries, warehouses, factories, kitchens, and poultry houses.

Evaporative air conditioning is the cooling effect provided by the adiabatic evaporation of water. Water is a universal coolant and the working fluid that can meet many air-conditioning needs in both residential and commercial applications. Two principle methods of evaporative air conditioning are commonly used: direct cooling, in which water evaporates directly into the airstream, thus reducing the air’s dry-bulb temperature while humidifying the air, and indirect cooling, where 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. Direct and indirect processes can be combined (indirect/direct). Compared to vapor compression systems, increased air flowrates are used for direct evaporative comfort cooling to compensate for higher supply air temperatures.

DIRECT EVAPORATIVE AIR CONDITIONING

In direct EAC 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). Note that there is no sensible cooling and that this is essentially an isenthalpic process for direct evaporative air conditioning (also termed evaporative "cooling").

In arid regions direct coolers provide comfort cooling, while more humid areas can use direct cooling for specialized applications. Direct EAC consumes significantly less energy than vapor compression refrigeration. The only power consuming components of an evaporative cooler are fans and small water pumps. 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.

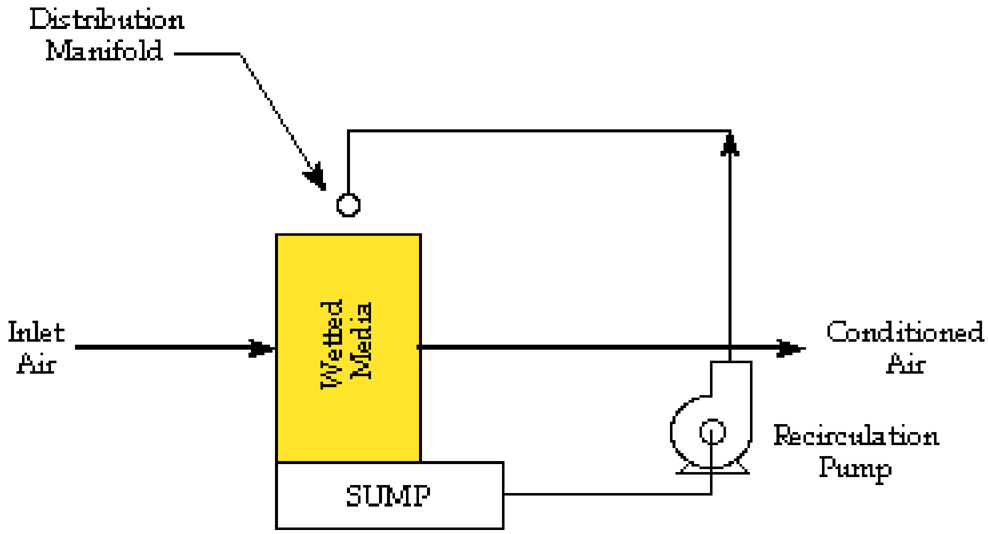
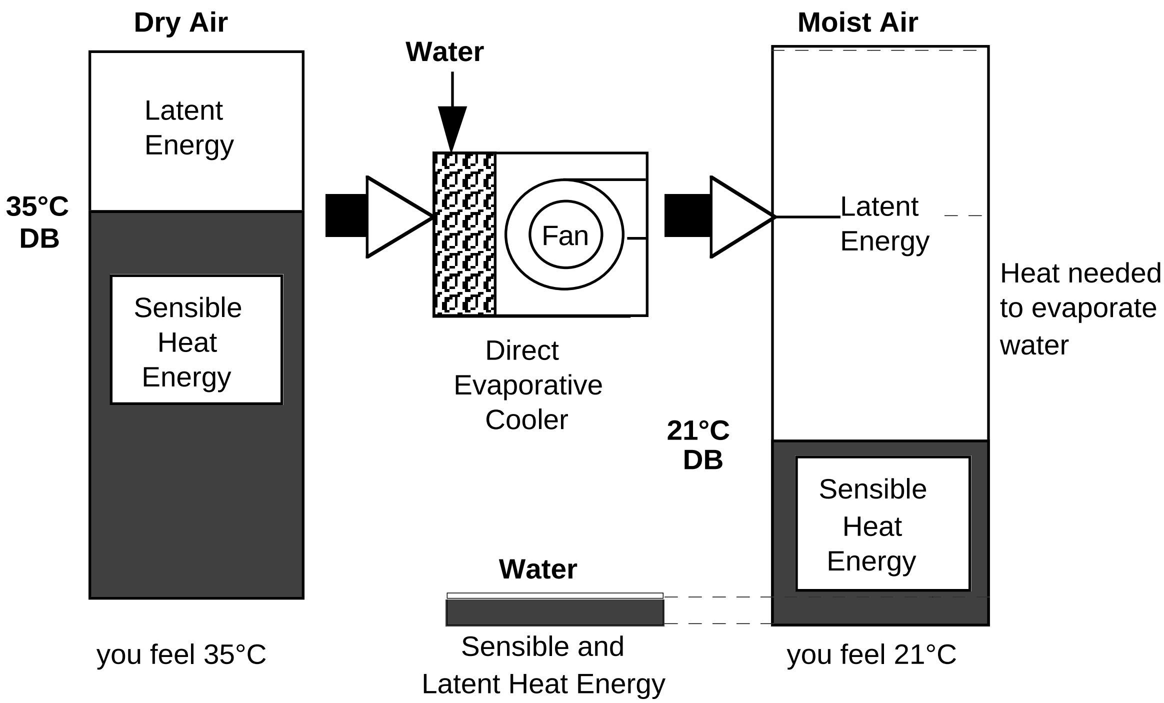


Fig. 1: Direct evaporative air-conditioner schematic typical for many systems.

An efficient wetted pad can reduce the air temperature by as much as 95% of the wet-bulb depression (ambient dry-bulb temperature less wet-bulb temperature), while an inefficient and poorly designed pad may only reduce this by 50%, or worse. A simplified process diagram for direct EAC is shown below in Figure 2. There is actually very little change in energy state of the air (i.e. there is no sensible cooling) other than energy inputs from the fan and make-up water. Direct EAC is simple and cheap but it has the disadvantage that if the ambient wet-bulb temperature is higher than 21˚C, the cooling effect is not sufficient for indoor comfort cooling applications, but is still sufficient for relief cooling applications (e.g., greenhouses and industrial spot cooling). Direct evaporative coolers do not and should not recirculate indoor air in applications which leads to superior indoor air-quality.



Sensible heat in the air is used to evaporate water

--(transferred to latent energy in the moist air)--

Fig. 2: Simplified Evaporative Air-Conditioning Process

The saturation effectiveness of a direct evaporative air-conditioner best describes the performance of an EAC unit. Saturation effectiveness is defined as the difference between the entering and exit dry-bulb temperatures over the wet-bulb depression.

A psychrometric chart, which shows moist air properties, demonstrates the evaporative cooling process. The initial dry-bulb and wet-bulb temperatures are shown at the start of the process, and the end-point of the evaporative cooling process is found to the left at the end of the arrow along the line of constant wet-bulb temperature. For example taking 1% design conditions for Ciudad Juárez, Mexico of 37.7˚C dry-bulb temperature at a mean coincident wet-bulb temperature of 17.7˚C, and using evaporative media that has a saturation effectiveness of 85%, we find that the evaporative media will change the state of the airstream to a dry-bulb temperature (supply air) of 20.7˚C as shown below in Figure 3 for Ciudad Juárez.

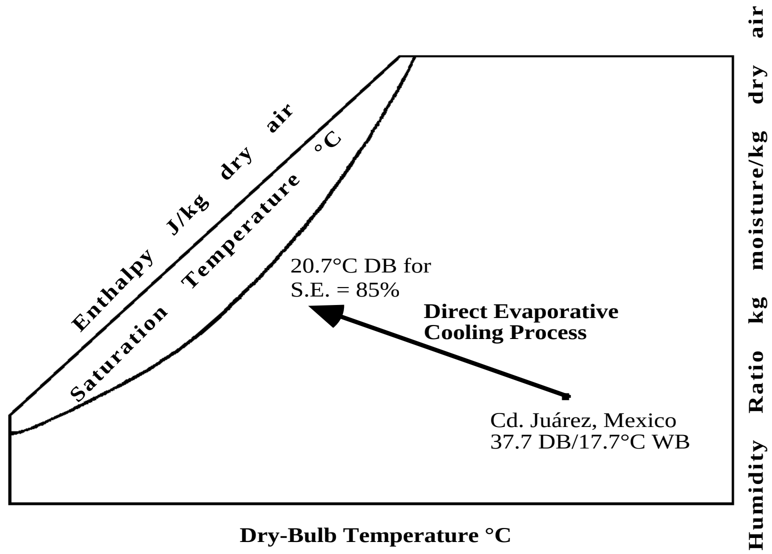


Fig. 3: Example Psychrometric Process for Direct Evaporative Cooling in Mexico.

INDIRECT/DIRECT EVAPORATIVE AIR CONDITIONING

Indirect EAC uses a heat exchanger to cool primary air without adding water, while the secondary air carries away the heat energy from the primary air as generated vapor. The indirect stage is sensibly cooling the airstream. Often a second direct stage is then added to further cool the air. In this system the outside air is pre-cooled in an indirect stage and then further cooled in a subsequent direct stage. The first stage cools the air without adding moisture and in the second stage moisture is added. The result is that the final air temperature leaving the air-conditioner is generally about 3.5 ˚C lower than what could be achieved with a direct EAC only. This expands the application of EAC considerably to areas with slightly higher wet-bulb temperatures. Commonly 65% indirect stage efficiency (performance factor) is reached which allows an ambient wet-bulb temperature of up to 25˚C to provide low enough room temperature for real comfort.

Many buildings in drier regions that use vapor-compression air-conditioning can replace it with indirect/direct EAC systems to provide comfort cooling or stand-alone indirect systems for precooling. One potential problem for retrofit situations is that existing building or residential ducts may be inadequately sized for the increased airflow delivery required by indirect/direct evaporative coolers over vapor-compression systems.

One indirect method of cooling uses coils with water that has been evaporatively cooled. Water evaporatively cooled through a cooling tower is circulated through a heat exchanger. The supply air to the space is passed over the other side of the heat exchanger. If the evaporatively cooled water is colder than the supply air passing over the heat exchanger fin, than the supply air will be cooled without the addition of moisture to the airstream.

Another common method used employs air-to-air heat exchanger, one side of which is wetted. The evaporative cooling occurs on the wet-side and heat is transferred from the conditioned airstream on the dry-side. Figure 4 below shows a typical type of indirect/direct EAC system using a plate heat exchanger. The first stage (indirect) sensibly cools the air, which is then passed through the second stage (direct) which evaporatively cools the air.

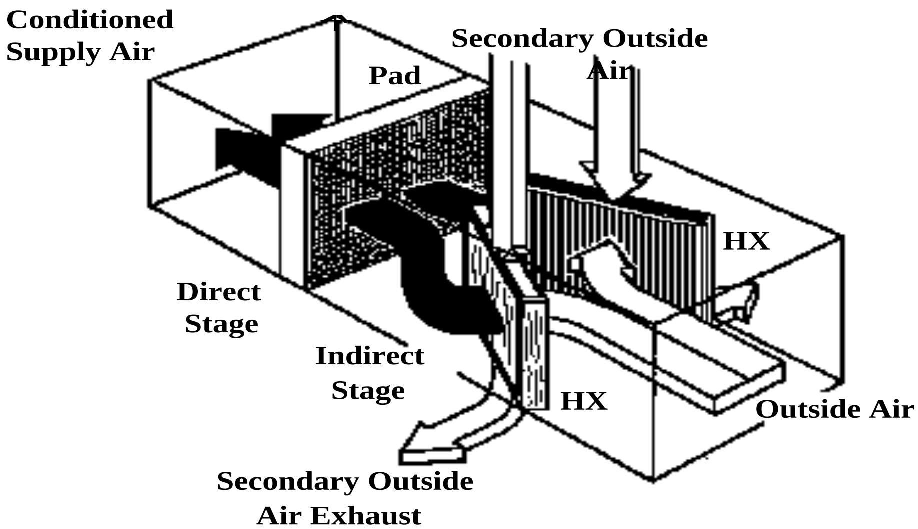


Fig. 4: Schematic of plate-type indirect/direct evaporative air-conditioner

Performance of indirect evaporative cooling is measured by the performance factor which is the ratio of the reduction of the dry-bulb temperature of the dry-side airstream to the initial difference between dry-side dry-bulb and set-side wet-bulb temperature. The performance factor is affected by equipment size and effectiveness, as well as overall air and water quantities. Industry ratings are normally based on a specific ratio between dry-side and wet-side air quantities.

The indirect process is shown as a sensible cooling process on the psychrometric chart in Figure 5 (the identical process for vapor-compression refrigeration). This process follows a line along a constant humidity ratio since no moisture is introduced in the indirect stage. Often a direct stage is introduced after the indirect stage, and sometimes several indirect stages can be used to further enhance the sensible cooling effect. Some larger commercial units are designed to use the building exhaust air coupled with evaporative cooling on the heat exchanger to provide even better performance. The figure below shows an indirect/direct evaporative cooling process for Ciudad Juárez, Mexico for 1% design conditions of 37.7˚C(DB)/17.7˚C(WB). Whereas with only a direct stage a supply air temperature of 20.7˚C was possible, adding an indirect stage with a performance factor of 65% followed by an 85% effective direct stage yields a final supply air temperature of 15˚C(DB), which is 5.7˚C less than a direct stage alone.

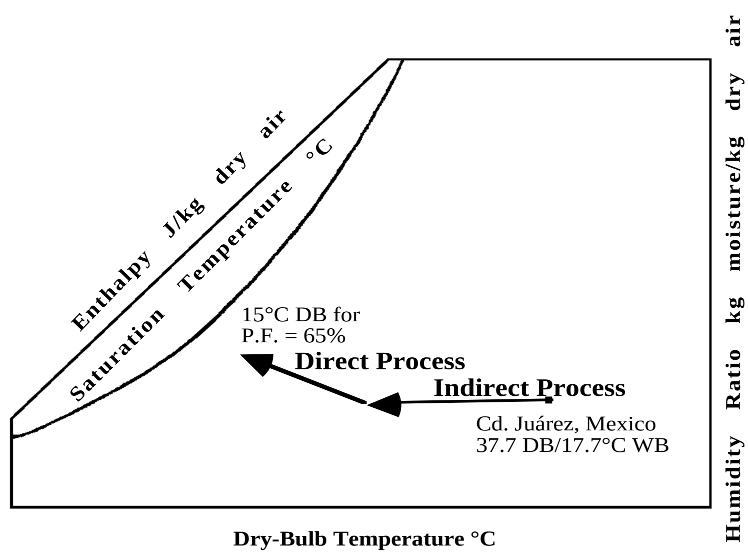


Fig. 5: Indirect/direct evaporative air-conditioning process for Mexico

EAC PERFORMANCE

The expected performance for both direct and indirect/direct EAC units commonly found in the market for selected locations in North America is given in Table I. Performance is calculated for 1% design conditions with the mean coincident wet-bulb for these locations. The direct EAC saturation effectiveness is assumed to be 85%, while the overall performance factor for the indirect/direct EAC is assumed to be 65%. Supply air dry-bulb temperatures are estimated based on these assumptions for the different locations.

Table I
EAC Performance for Selected Locations for 1% Cooling Design Conditions

Location	1% Design[a] Conditions DB/WB	Direct[b] Supply Air DB	Indirect/ Direct[c] Supply Air DB
Los Angeles, California, USA	35.6/20.0	22.3	18.2
Denver, Colorado, USA	33.9/15.0	17.8	12.2
Albuquerque, New Mexico, USA	35.6/16.1	18.1	13.3
Las Vegas, Nevada, USA	42.2/18.9	22.4	16.1
Dallas, Texas, USA	38.9/23.9	26.1	22.2
Guadalajara, Mexico	33.9/18.9[2]	21.1	17.2
Mexico City, Mexico	28.9/15.6	17.6	13.9
Ciudad Juárez, Mexico	37.8/17.8[1]	20.8	15.2

[a] Temperatures in °C, 1% Dry-bulb/Mean Coincident Wet-bulb design conditions
1: 1% design dry bulb condition and 5% design wet-bulb condition.

[b] Direct saturation effectiveness of 85% is assumed; dry-bulb supply temperature °C.

[c] All cases assume an overall performance factor of 65% for the indirect process and a saturation effectiveness of 85% for the direct process; dry-bulb supply temperature °C.

EAC BENEFITS

Evaporative air conditioning does not use CFC refrigerants and only requires water. Its use in place of vapor compression systems eliminates CFC and other greenhouse gas emissions. Over 20 million residential evaporative coolers are in operation today worldwide. Around the globe EAC residential units directly obviate the need at least 118 million pounds of HCFC-22. These residential coolers save approximately 60 million barrels of oil annually and 27 billion pounds of annual carbon dioxide emissions in lieu of using vapor-compression air-conditioning systems. Contributions from commercial and industrial applications of evaporative air conditioning are in addition. Principle advantages of evaporative air conditioning technologies are as follows:

- Significant local fabrication and employment
- Substantial energy and cost savings
- No chlorofluorocarbon (CFC) usage
- Reduced peak power demand
- Reduced CO_2 and power plant emissions
- Improved indoor air quality
- Life cycle cost effectiveness
- Easily integrated into built-up systems
- Wide variety of packages available
- Provide humidification when needed
- Easy to use with direct digital control (DDC)
- Greater regional energy independence

EAC ECONOMICS

Evaporative coolers are considerably more inexpensive to purchase and operate as compared to vapor compression air-conditioners. At least 20 million residential units are installed across the globe. The current EAC residential market in the USA alone is about US$180 million per year in sales with over 4 million units installed.

The smallest coolers in India will cost about US$35. The largest systems some US$150 or more. The most expensive two stage units in Australia and the USA are over US$1,200. The simple direct EAC packaged units most commonly used in the USA and

Australia on average cost from US$300-700, while the small simple indoor units are available for US$40 and up. An installed residential evaporative air conditioning system in the USA, complete with ducting, has an initial cost of about US$2,000.

Direct evaporative coolers in the desert regions typically require 70% less energy than conventional compressor driven systems in residences. For instance, in El Paso, Texas, the typical evaporative cooler consumes only 609 kWh per cooling season as compared to 3,901 kWh per season for a typical vapor compression air conditioner of SEER 10. This equates to an average demand of .51 kW based on 1,200 operating hours, as compared to an average demand of 3.25 kW for a vapor compression air conditioner. Thus, a vapor compression unit requires 2.74 kW or almost six times the electrical demand of the evaporative cooler.

Depending on climate conditions, many buildings can use indirect/direct evaporative air conditioning systems to provide comfort cooling. Indirect/direct systems realize a 40 to 50% energy savings in moderate humidity zones.

EAC MANUFACTURING

EAC is essentially a relatively simple technology that can be wholly or partially produced in less developed countries, depending on the existing industrial base. In India and Pakistan for instance, large volumes of complete units are being produced locally. Small enterprises use a labor intensive production process in India (1 million units a year by some 300-400 enterprises in New Delhi alone). The products are made of sheet metal, wood fiber pads and a simple pump, finding their way on the market either as finished products or as kits, transported all over the India. The other type of fabrication are more sophisticated indirect-direct EAC production in Australia and the USA, with coated sheet metal, plastics or fiberglass, efficient cellulose paper-pads, computerized thermostats and bleed-offs. These units are marketed with glossy folders and exported to a number of countries.

Certain components are easier to make than others and the electric motors, fans and water circulation pump are items that can only be produced in those countries with a reasonably large industrial base. India, Pakistan and China are examples of such countries. For countries where such items cannot yet be made locally, they should be imported. Whether the motor, fan and pump are made locally or imported is of not much consequence to the manufacturers of the coolers because for them these are items to be purchased and not to be made by themselves. The production of coolers is essentially sheet metal working, the other items are usually purchased. This type of work can be done on a small scale and requires very little in the way of investments in machines, molds or accommodation. EAC technologies are a good product for small time entrepreneurs as well as for larger companies.

Fig. 6: Kamla market in New Delhi, India where over 150 small locally owned shops fabricate and sell nearly 1 million evaporative air-conditioning units per year.

FUTURE OUTLOOK

Worldwide, the potential of using EAC technologies is much greater than is currently realized. Existing vapor compression AC can be replaced with EAC in many cases from buildings and homes, to buses and kitchens. Replacement of conventional AC with EAC results in significant savings in operating and replacement costs. In some developing regions of the world where air-conditioning has scarcely arrived, EAC could bring affordable comfort, as the widespread expansion of vapor compression AC may not be realistic due to high investment and operating costs.

The EAC market will continue to grow worldwide as ever increasing interest in applying evaporative air conditioning as an energy conservation, demand side management, improved indoor air-quality, and CFC obviation tool. The potential market penetration of this technology, given advances with indirect and hybrid systems, is enormous. There are few technologies as simple and appropriate as cooling with water. For many regions of the globe, EAC technologies are the ideal solution for meeting many of their cooling needs.

REFERENCES

American Society of Heating, Regrigerating and Air-Conditioning Engineers, 1993 ASHRAE Handbook: Fundamentals, Weather Data, Ch. 24, ASHRAE, Atlanta, GA, 1993.

U.S. Departments of the Air Force, the Army, and the Navy, Engineering Weather Data, AFM 88-29, TM 5-785, NAVFAC P-89, Washington, D.C., July, 1978.

Foster, R. E., G. McDonald and M. Heller Turietta, "Phaseout of Chlorofluorocarbon Refrigerants and Opportunities for Evaporative Cooling," Proceedings of the 1990 United States National Committee of The International Institute of Refrigeration (USNC/IIR) Purdue Refrigeration Conference/ASHRAE-Purdue CFC Conference, Purdue University, West Lafayette, Indiana, July 17-20, 1990, pp. 1-9.

Foster, R. E., "Evaporative Air Conditioning Technologies: Reducing Energy and CFC Usage Nationwide," Commercial Applications for Evaporative Cooling Systems, Washington State Energy Office, Spokane, Washington, March, 1995.

Foster, R.E. and E. Dijkstra, "Evaporative Air-Conditioning Fundamentals: Environmental and Economic Benefits Worldwide," Applications for Natural Refrigerants '96, Refrigeration Science and Technology Proceedings, ISSN 0151 1637, International Institute of Refrigeration, Danish Technological Institute, Danish Refrigeration Association, Aarhus, Denmark, Septebmer 3-6, 1996, pp. 101-110.

El Paso Electric Company, Life Cycle Cost Analyses: Evaporative Cooler vs. Refrigerated Air Conditioning, Volume I, El Paso, Texas, October, 1991.

Watt, J.R., Evaporative Air Conditioning Handbook, second edition, Chapman & Hall, New York, 1986.

Bon, G. J., Foster, R. E., Dykstra, E., and M. Tummers, For a Better Climate: Evaporative Air Conditioning, unpublished draft submitted to the World Bank, Washington, D.C., March, 1996.