Evaporative cooler water use in Phoenix

This study takes a step toward showing how much water various evaporative cooling systems use.

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The authors undertook this study to learn what fraction of total per capita water consumption in growing southwestern Sunbelt cities is made up of water used by residential evaporative coolers. In a field study, water use was metered in sample homes during two cooling seasons. Meters were placed on incoming lines that provided makeup water to the evaporative cooler reservoir. Monitoring devices were configured to capture and meter the bleedoff water so water consumption for evaporation could be separated from total water delivered to the cooler. Average annual household use of water for all homes was 108,382 gal (410,271 L). Water used by each household for cooler operation, regardless of the kind of cooler system, averaged 66 gpd (250 L/d)—15 percent of total household water use—during the 214-day cooling season. Homes with a bleedoff system on the cooler used an average of nearly 50 percent more total water for cooler operation than did homes with no bleedoff system.

Evaporative coolers are major water-using appliances in homes in the arid southwestern United States. In Phoenix, Ariz., about 46 percent of the city's 246,000 single-family customers use evaporative cooling alone or in conjunction with air-conditioning (AC).[1,2] A single-case study of a new high-efficiency cooler operating in May 1992 in Phoenix indicated a possible daily water demand of 213 gal (806 L) per household, a significant contribution to summertime peak demand.[3]

Field-recorded data are rare in the literature. The only data about total consumption were recorded at the Casa del Agua demonstration house in Tucson.[4] Therefore, this field study is a step toward clarifying the actual volume of water used by various evaporative cooler systems and

For executive summary, see page 241.

TABLE 1 **Evaporative cooler and household water use according to cooling system configuration**

House Number*	Year	Cooling System Configuration: BS†	NBS	AC	NAC	Cooler Water Use: *gal*	*L*	Total Household Water Use: *gal*	*L*	Cooler/Total Use *percent*	Bleedoff: *gal*	*L*	Bleed-off/Cooler Use *percent*	Operating Hours	TDS‡ In-flow *mg/L*	TDS Out-flow *mg/L*
46	1993	X		X		4,483	16,970	121,993	461,792	3.7	§			1,661.8	320	4,043
31	1993	X		X		6,429	24,336	97,531	369,194	6.6	1,715	6,492	26.7	1,045.5	320	2,251
22	1993	X		X		7,103	26,888	51,124	193,525	13.9	1,755	6,643	24.7	1,605.5	384	1,243
34	1993	X		X		9,313	35,253	131,790	498,878	7.1	3,068	11,614	32.9	1,201.8	277	1,874
47	1993	X		X		10,309	39,024	49,470	187,264	20.8	2,471	9,354	24.0	1,222.4	320	885
9	1993	X		X		11,636	44,047	26,092	98,769	44.6	6,931	26,237	59.6	1,815.8	576	2,194
15	1993	X		X		11,817	44,732	66,525	251,824	17.8	4,880	18,473	41.3	3,310.8	384	1,131
25	1993	X		X		11,834	44,796	155,076	587,025	7.6	3,256	12,325	27.5	2,364.4	320	1,280
18	1993	X		X		13,658	51,701	81,723	309,354	16.7	4,155	15,728	30.4	1,898.6	704	1,696
21	1993	X		X		14,192	53,722	78,919	298,740	18.0	5,854	22,160	41.2	1,414.5	320	768
16	1993	X		X		15,290	57,879	68,524	259,391	22.3	4,279	16,198	28.0	1,370.0	320	736
42	1993	X		X		15,325	58,011	154,103	583,341	9.9				2,070.0	288	2,808
32	1993	X		X		16,105	60,964	69,519	263,157	23.2	10,375	39,274	64.4	1,141.6	341	755
43	1993	X		X		16,471	62,349	143,969	544,980	11.4	§			1,922.4	384	853
17	1993	X		X		21,463	81,246	104,814	396,763	20.5	6,005	22,731	28.0	1,467.8	384	1,888
46	1994	X		X		2,645	10,012	106,292	402,358	2.5	§			532.8	256	1,810
25	1994	X		X		7,675	29,053	183,968	696,392	4.2	2,475	9,369	32.2	1,088.3	384	1,461
16	1994	X		X		8,652	32,751	113,951	431,350	7.6	1,864	7,056	21.5	895.6	384	1,600
18	1994	X		X		8,774	33,213	87,469	331,105	10.0	2,739	10,368	31.2	1,181.5	512	1,813
38**	1994	X		X		9,730	36,832	161,807	612,504	6.0	§			1,160.3	320	3,584
32	1994	X		X		11,823	44,755	69,108	261,601	17.1	7,356	27,845	62.2	1,081.4	512	1,600
42	1994	X		X		12,806	48,476	164,829	623,944	7.8	§			984.5	384	3,954
14	1993		X	X		2,032	7,692	30,266	114,569	6.7				701.0	256	6,507
41	1993		X	X		4,061	15,373	90,905	344,112	4.5				991.2	320	4,768
29	1993		X	X		4,593	17,386	40,753	154,266	11.3				2,040.0	320	4,087
39	1993		X	X		5,529	20,929	84,958	321,600	6.5				1,001.6	533	4,715
33	1993		X	X		6,056	22,924	127,514	482,691	4.7				1,716.8	320	4,059
44	1993		X	X		6,386	24,174	52,269	197,859	12.2				658.4	320	4,160
40	1993		X	X		6,739	25,510	137,527	520,595	4.9				1,891.6	320	7,445
26	1993		X	X		7,174	27,156	46,662	176,634	15.4				2,657.3	320	4,488
1	1993		X	X		7,334	27,762	104,236	394,575	7.0				1,066.9	256	6,088
23	1993		X	X		7,502	28,398	132,003	499,684	5.7				1,871.2	256	4,896
36	1993		X	X		7,758	29,367	155,244	587,661	5.0				2,314.6	448	4,619
11	1993		X	X		7,843	29,689	199,051	753,488	3.9				1,492.1	320	7,744
13	1993		X	X		9,909	37,510	253,383	959,156	3.9				1,700.4	256	1,931
27	1993		X	X		10,098	38,225	116,650	441,567	8.7				4580.6	304	9,344
38**	1993		X	X		11,616	43,971	145,761	551,764	8.0				1780.2	288	2,743
29	1994		X	X		1,798	6,806	41,789	158,188	4.3				1,877.9	384	6,123
11	1994		X	X		5,029	19,037	100,307	379,702	5.0				1,031.3	448	6,160
26	1994		X	X		5,730	21,690	61,625	233,275	9.3				3,477.1	512	8,486
33	1994		X	X		8,807	33,338	225,185	852,415	3.9				2,081.7	320	4,059
27	1994		X	X		11,771	44,558	105,326	398,701	11.2				3,567.9	576	9,557
13	1994		X	X		19,365	73,304	39,698	150,273	48.8				3,437.0	256	5,349
24	1993	X			X	11,801	44,672	64,518	244,226	18.3	4,182	15,831	35.4	1,439.6	320	540
2	1993	X			X	12,890	48,794	58,668	222,082	22.0	1,291	4,887	10.0	1,932.8	320	782
8	1993	X			X	18,734	70,916	65,303	247,198	28.7	5,337	20,203	28.5	2,649.2	256	1,202
3	1993	X			X	23,141	87,598	86,401	327,062	26.8	7,687	29,098	33.2	3,211.0	320	1,704
6	1993	X			X	24,588	93,075	170,022	643,601	14.5	7,749	29,333	31.5	3,493.5	320	1,766
19	1993	X			X	30,960	117,196	205,816	779,096	15.0	21,812	82,567	70.5	1,746.5	320	981
30	1993	X			X	36,188	136,986	66,190	250,556	54.7	7,773	29,424	21.5	3,476.8	320	2,123
35	1993	X			X	37,782	143,020	215,389	815,334	17.5	20,979	79,414	55.5	2,825.5	320	375
28	1993	X			X	46,346	175,438	69,424	262,798	66.8	21,336	80,765	46.0	2,431.5	320	1,202
24	1994	X			X	11,753	44,490	39,963	151,276	29.4	1,782	6,746	15.2	1,720.6	256	1,136
19	1994	X			X	16,245	61,494	152,530	577,387	10.7	3,587	13,578	22.1	2,115.3	320	1,169
8	1994	X			X	19,575	74,099	76,395	289,186	25.6	7,434	28,141	38.0	3,804.0	512	1,338
37**	1994	X			X	25,472	96,422	146,950	556,265	17.3	14,687	55,596	57.7	3,418.2	256	939
28	1994	X			X	42,184	159,683	91,599	346,739	46.1	20,528	77,707	48.7	1,838.3	384	1,396
37**	1993		X		X	4,336	16,413	111,256	421,148	3.9				3,912.8	320	3,100
4	1993		X		X	15,110	57,197	127,877	484,066	11.8				3,778.4	384	9,557
5	1993		X		X	18,684	70,726	92,981	351,970	20.1				3,952.6	1,600	3,211
4	1994		X		X	17,243	65,272	190,336	720,498	9.1				4,560.4	256	8,685
1993 averages						13,586	51,429	106,005	401,270	15.5	7,280	27,560	36.2	2,067.3	371	3,061
1994 averages						13,004	49,226	113,638	430,166	14.5	6,939	26,267	36.5	2,097.6	381	3,696
1993–94 averages						13,405	50,743	108,382	410,271	15.2	7,178	27,172	36.3	2,076.7	374	3,258

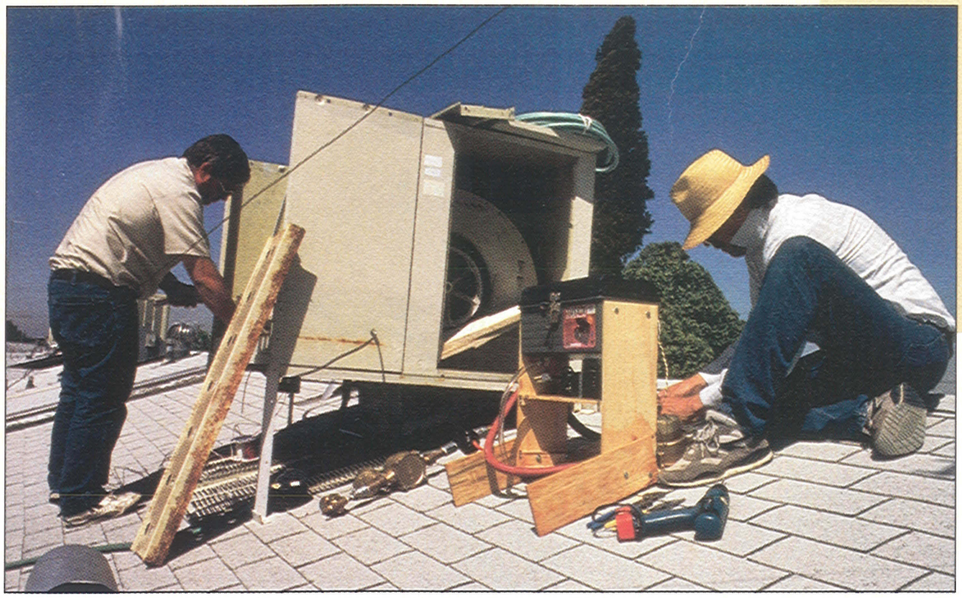
*Houses 7, 10, 12, and 45 were dropped or resigned from the 1993 study. House 20 was deleted because it had two evaporative coolers and NAC. Its total cooler use in 1993 was 49,355 gal (186,828 L).

†AC—air-conditioning, BS—bleedoff system, NAC—no air-conditioning, NBS—no bleedoff system

‡TDS—Total dissolved solids

§Bleedoff volume not measured

**Houses 37 and 38 did not have bleedoff in 1993, but did have bleedoff in 1994.



Glenn France (left) and Harold Johnson (right) install monitoring equipment to measure evaporative cooler water use at a Phoenix household.

may lead to improved water-use efficiency of these appliances.

Evaporative cooling requires less energy than AC

Evaporative cooling, one of the most ancient and, to date, most energy-efficient methods of adiabatic cooling (i.e., cooling that occurs without loss or gain of heat) without use of a compressed refrigerant,[5,6] has long been regarded as environmentally safe. The process typically uses no ozone-depleting chemicals and demands one fourth the energy used by refrigeration during peak cooling months. In dry climates, evaporative cooling can be used to cool relatively large occupied areas.[5,7,8] Because direct evaporative cooling adds moisture to the air, uncomfortably humid indoor air can result, especially in humid climates or during the rainy season in the desert Southwest. In Phoenix, those who have the option usually switch to AC during July and return to evaporative cooling sometime in September.[2]

In the most common form of residential evaporative cooling, water is sent to the top of a vertical pad of cellulose fiber. A fan draws air through the porous pad as water runs down the fiber and is absorbed (Figure 1). As dry outside air moves over the wet pad into the house, water evaporates, providing the cooling effect.

If the water has high mineral content, a bleedoff system (BS) is often used to decrease salt buildup on the cooler's parts by dumping some of the recirculating water and replacing it with fresh water. However, BSs increase water use.[9,10]

Research plan designed to monitor performance of coolers

Phoenix households randomly selected from the entire water services base of 246,000 single-family homes were surveyed in 1993 to determine the demographic makeup of the cooler-using population.[11] Households were selected on the basis of home size, cooler size (4,500– 6,500 cu ft/min [127–184 m^3/min]), and whether the cooler was operational. Forty-six households were selected for participation the first year, but only 42 completed the study.* To confirm the findings, 20 of these houses were also studied the following year (only 19 households completed the study year). Downdraft and side-draft coolers were monitored (the most common pad configuration was four pads). Twenty houses had no BS during the first field study. Six houses had no BS during the study the second year.

A research plan was designed to monitor performance of the evaporative coolers. To quantify the volume of water used, residential 5/8-in. (16-mm) water meters† were placed on incoming lines that provide makeup water to the cooler reservoir. Residential water meters can record flow rates of 0.25 gpm (0.016 L/s) or 15 gph (57 L/h) with an accuracy of 97–102 percent. They also record slower flow rates at varying degrees of accuracy. However, flow rates can be much less than 15 gph (57 L/h), especially in coolers not equipped with BSs.

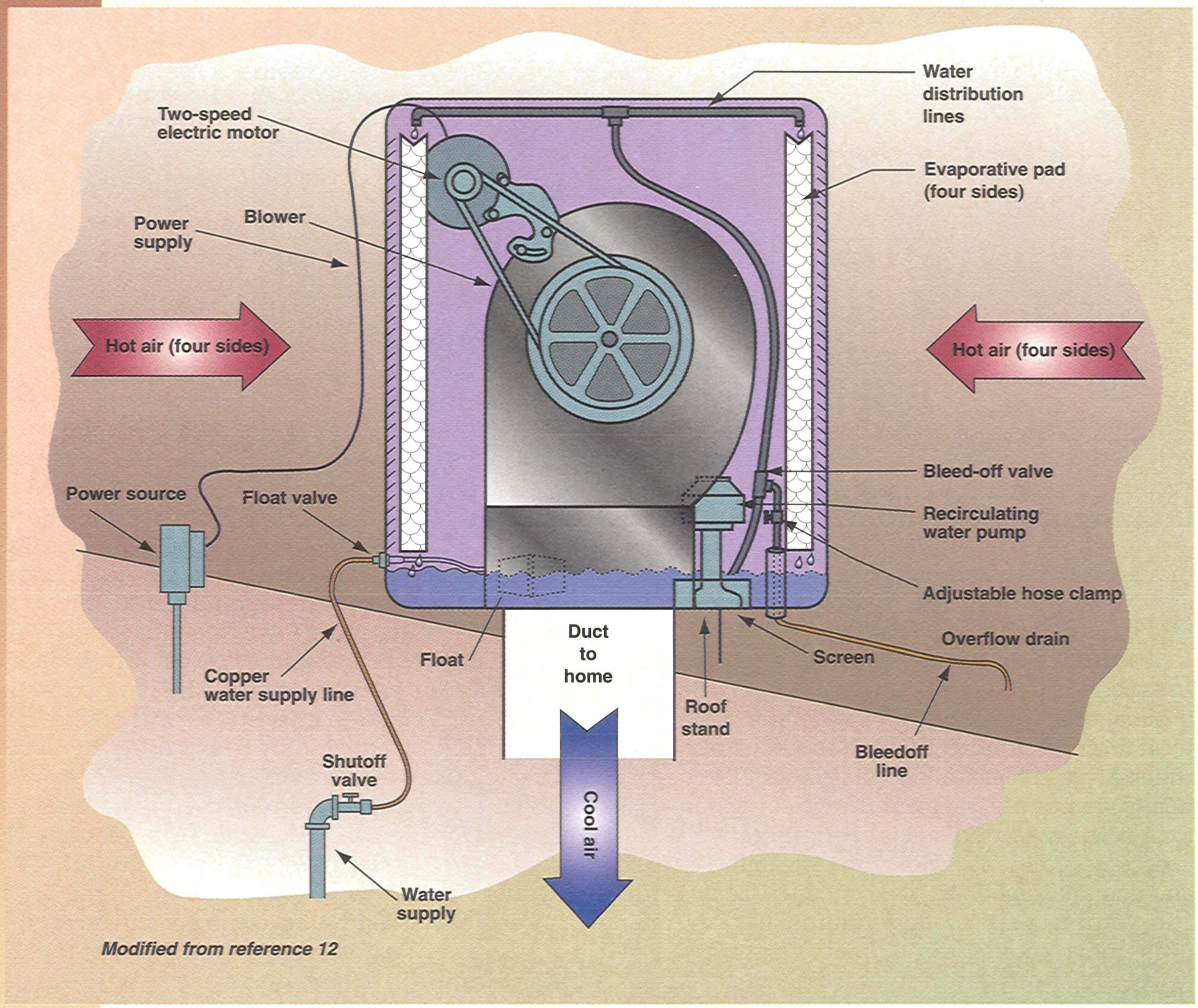
Total cooler water use ranged from 2.5 to 66.8 percent of total household water use.

Because bleedoff generally occurs at extremely slow flow rates, it is impossible to directly measure volume using a water meter. Therefore, a special sys-

*Forty-seven candidate houses were identified in 1993, and 46 of these were selected for statistical monitoring. House 20 was monitored for the entire cooling season, but its data were not included in the statistical analyses because it had two evaporative coolers. Homes 7, 10, 12, and 45 were dropped or resigned from the study in 1993, resulting in a total of 42 houses that were used for the statistical analyses. During 1994, 20 of the 42 homes were monitored. However, only 19 completed the study year. Statistical evaluations conducted after the data sets were merged included 42 houses from 1993 and 19 houses from 1994.

†Badger Model 25 Bronze, Badger Meter Inc., Milwaukee, Wis.

FIGURE 1 **Typical downdraft evaporative cooler**



Modified from reference 12

tem (see photograph on page 125) was designed to measure BS volume. This system included four elements: (1) a cistern to capture BS water; (2) an electronic control box that operated the cistern's draining system, triggered by the rising level of captured BS water within the cistern; (3) a direct-current submersible marine pump that powered drainage of the cistern; and (4) a water meter through which the water flowed before it was discharged. These units were installed at all homes with BSs. Homeowners controlled the BS flow rates.

Backup data were necessary if the BS volume measurement system failed. Therefore, before the study began, the actual BS flow rate was calculated after manual measurement of the volume of water collected in a graduated cylinder during a period of time measured using a stopwatch. A recording clock installed in the cooler operated only while the cooler's circulating pump was running. Therefore, if the BS failed, BS total volume for the cooling system could be calculated by determining flow rate and time of operation.

Meters were installed during mid-March. Readings of all meters, including the main residential municipal water meter, were taken every other week from April through October. If problems occurred between scheduled readings, a reading was taken when repairs were made. Because homeowners participated voluntarily, all problems they reported were assessed and repaired within 24 hours to limit loss of data and to provide greater volunteer satisfaction. At houses that converted to AC during the seven-month cooling season, readings or inspections (or both) were made monthly. Records of maintenance procedures and problems were kept for each house.

Study shows consumption, disposition of water, and statistical trends

The study provided information about water consumption by residential evaporative coolers, BS water volumes and disposition, and statistical treatment of data on cooler water use from the two combined cooling seasons.

A special system was designed to measure bleedoff volume. The system included a cistern to capture bleedoff water, an electronic control box, a submersible marine pump, and a water meter. These units were installed at all homes that had a bleedoff system.

Some field study houses have AC and BSs. In 1993, 46 houses were chosen for the study. Four were dropped or withdrew. Thirty of the remaining 42 houses were equipped with AC, and 24 used BSs. In 1994, 13 of the 19 houses had AC, and 12 used BSs. Two houses (37 and 38) had no bleedoff system (NBS) during the first cooling season but used BSs during the second.

Data collected in 1993 from house 20, which had two evaporative coolers and no AC, and 1994 data from house 40, where the resident decided to switch to AC rather than repair the cooler, are not included in the following statistical analysis.

Consumption per cooler varied greatly. Total water consumption by each evaporative cooler according to the combined data for two years varied between 1,798 and 46,346 gal (6,806 and 175,438 L) (Table 1). Water use data for both years, grouped by household cooling system configuration for each house for each year, are shown in Table 1 and summarized in Table 2. Houses with BSs—whether the houses had AC or no AC (NAC)—generally used more water to operate the cooler than did houses with NBSs (Table 2). Ten houses with BSs used more total water for coolers than the highest amount of water used by a residence without a BS (Table 1).

Of the group with BSs, NAC houses consumed more water than did houses with AC (a study maximum of 46,346 gal versus 21,463 gal [175,438 L versus 81,246 L] for BS–NAC and BS–AC, respectively). Houses with NBS and AC used less water. Although the numbers are not significant for the NBS–NAC group because of the small sample size, houses in this group appeared to use more water than those in the NBS–AC group.

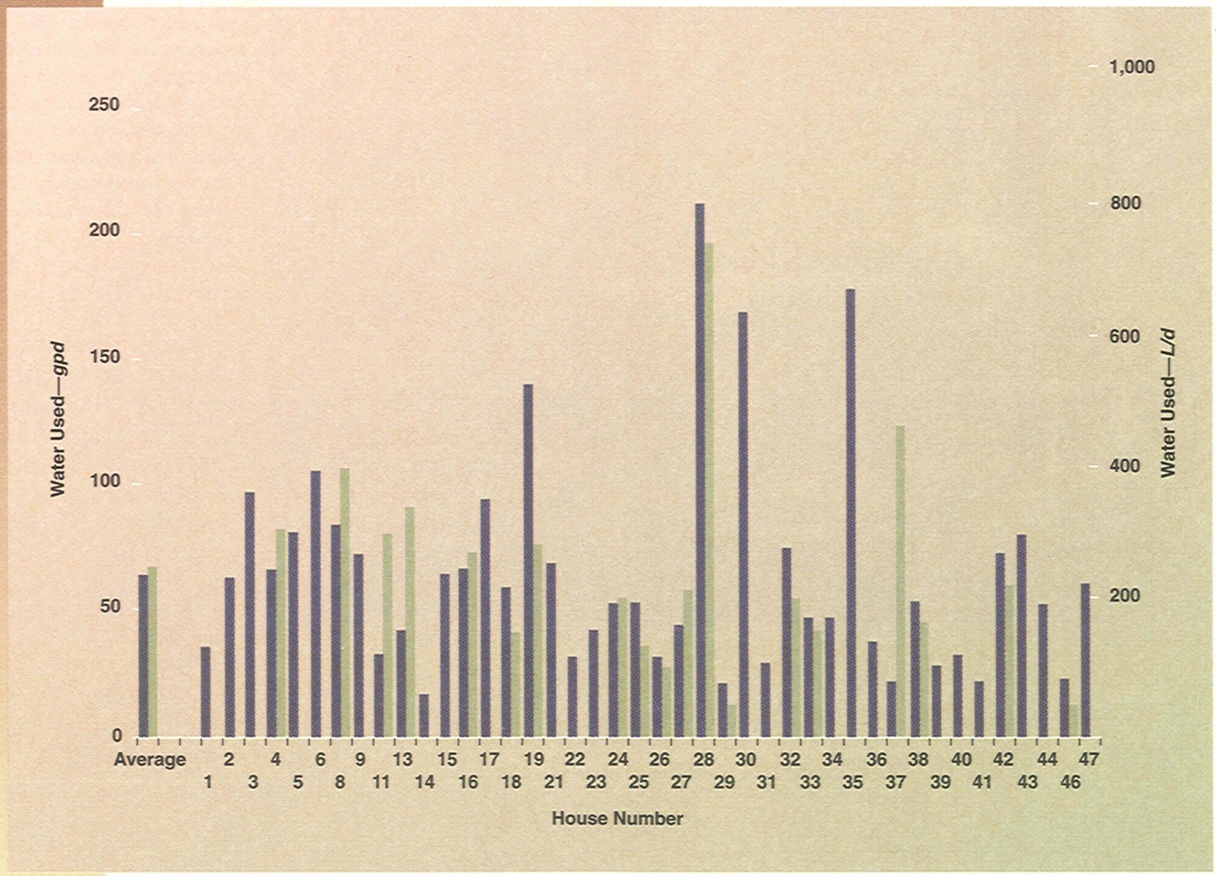
During both cooling seasons, average water use by evaporative coolers with BSs was 50 percent greater than for coolers not equipped with BSs (16,811 gal [63,636 L] compared with 8,500 gal [32,176 L]; Table 2). The average daily cooler water use for all houses (Figure 2) was similar for both years (64.7 gpd [245 L/d] the first year and 67.3 gpd [256 L/d] the second). The first year, the

TABLE 2 **Average annual cooler and household water use according to cooling system configuration**

Household Cooling System Configuration	Cooler Water Use		Total Household Water Use		Cooler/ Total Use
	gal	*L*	*gal*	*L*	*percent*
1993					
AC* with BS and NBS	9,669	36,601	103,945	393,473	9.3
NAC with BS and NBS	23,380	88,503	111,154	420,762	21.0
BS with AC and NAC	17,827	67,482	100,121	378,998	17.8
NBS with AC and NAC	7,931	30,022	113,850	430,968	7.0
1994					
AC with BS and NBS	8,816	33,372	112,412	425,524	7.8
NAC with BS and NBS	22,079	83,578	116,295	440,223	19.0
BS with AC and NAC	14,778	55,941	116,238	440,007	127.0
NBS with AC and NAC	9,963	37,714	109,181	413,294	9.1
1993 and 1994					
AC with BS and NBS	9,411	35,624	106,505	403,164	8.8
NAC with BS and NBS	23,380	88,503	111,154	420,762	21.0
BS with AC and NAC	16,811	63,636	105,493	399,333	15.9
NBS with AC and NAC	8,500	32,176	112,542	426,020	7.6

*AC—air-conditioning, BS—bleedoff system, NAC—no air-conditioning, NBS—no bleedoff system

FIGURE 2 **Average daily cooler water use by household: 1993–94**



NBS–NAC households used an average of 3.3 gph (12.4 L/h) during operation, compared with 3.8 gph (14.4 L/h) the second year. Households using coolers equipped with BSs used an average of 10.4 gph (39.4 L/h) and 10.6 gph (40.1 L/h), respectively, for the two cooling seasons. The range for bleedoff volumes was 1,291–21,812 gal (4,887–82,567 L) for houses that had properly functioning water meters (Table 1).

Average water use by a house with AC was 9,411 gal (35,624 L); for an NAC house, it was 23,380 gal (88,503 L) (Table 2). These averages, however, cannot be shown to be statistically different because of the large variability in the amount of water used among houses.

For both years, Table 1 shows total household and total evaporative cooler water use volumes and cooler water use as a percentage of total household water use. Total annual household water use ranged from 26,092 to 253,383 gal (98,769 to 959,156 L) (Table 1). Average annual municipal water use per household was 106,005 gal (401,270 L) for 1993 and 113,638 gal (430,165 L) for 1994, or an average of 108,382 gal (410,271 L) for both years (Table 1). Average annual household water use for both years for homes that had coolers with BSs was 105,493 gal (399,333 L). For homes that had coolers without BSs, average annual household water use was 112,542 gal (426,020 L) (Table 2). Total cooler water use ranged from 2.5 to 66.8 percent of total household water use (Table 1). Average cooler water use as a percentage of total water use was 15.5 percent during 1993, 14.5 percent during 1994, and 15.2 percent for both years (Table 1). In 1994, in BS–NAC households, average cooler water use accounted for 25.8 percent of household water use.

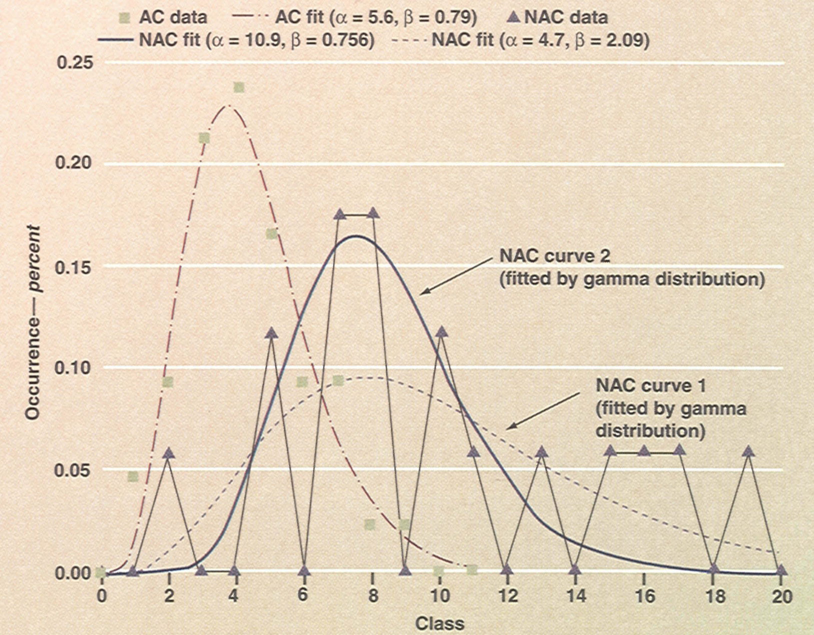
Houses with bleedoff systems generally used more water to operate the cooler.

Average time of operation passes 2,000 hours. During the combined seasons, coolers operated from 532.8 to 4,580.6 hours (Table 1). Average time per household was almost the same each year—2,067 and 2,098 hours, respectively (Table 1). During the combined seasons, the per-household average total operating hours for evaporative coolers in BS–NAC homes was 2,579 hours. Residents at BS–AC homes operated the coolers for about 1,474 hours.

Total dissolved solids (TDS) can interfere with cooler operation. TDS, naturally occurring minerals and salts that are present in the municipal water supply, form deposits on the surfaces of evaporative coolers as they operate. High TDS concentrations can accelerate buildup of minerals, calling for extra maintenance and leading to deterioration of metal parts. TDS also make evaporation less efficient, because highly saline water evaporates less readily than does water with a lower salt content.

Concentrations of TDS in both incoming cooler and BS water (or cooler pan water if no BS existed) are listed in Table 1. TDS concentration in incoming cooler water varied from 256 to 1,600 mg/L, averaging approximately 371 mg/L the first year and 381 mg/L the second. House 5, which used softened water in the cooler, had an extremely high TDS concentration of 1,600 mg/L.

FIGURE 3 Percent occurrence of AC and NAC among users during two cooling seasons



Class unit volume consumed = 2,500 gal (9,460 L); AC—air-conditioning, NAC—no air-conditioning

TDS concentrations in water in the cooler reservoir pan were measured for NBS houses. Amounts ranged from 1,931 to 9,557 mg/L. TDS concentrations in BS water were typically lower than in cooler pan water, varying from 375 to 4,043 mg/L (Table 1). Average TDS in BS water and in the reservoir water were 1,580 mg/L and 5,675 mg/L, respectively.

Many households reused bleedoff water. During this study, eight households did not reuse their BS water. Nine used it to irrigate lawns and eight to irrigate gardens or trees. One household dumped the water into a pool.

Generally, BS houses had less lush exterior landscaping than did NBS houses. TDS concentrations in BS water typically are not high enough to interfere with the growth of Bermuda grass. If the concentration can be kept lower than 5,000 mg/L, BS water can be safely used to irrigate salt-tolerant plants such as Bermuda and salt grass.[12,13] However, citrus trees (especially lemon) and almond, apple, peach, and pear trees have poor tolerance for salt (<2,000 mg/L TDS)[13] and would be poor candidates for irrigation with BS water.

Average temperature of the water in the cooler pan reservoir the second year was similar for both BS and NBS coolers (69.6°F [20.9°C] and 68.6°F [20.3°C], respectively) and should not interfere with vegetation growth.

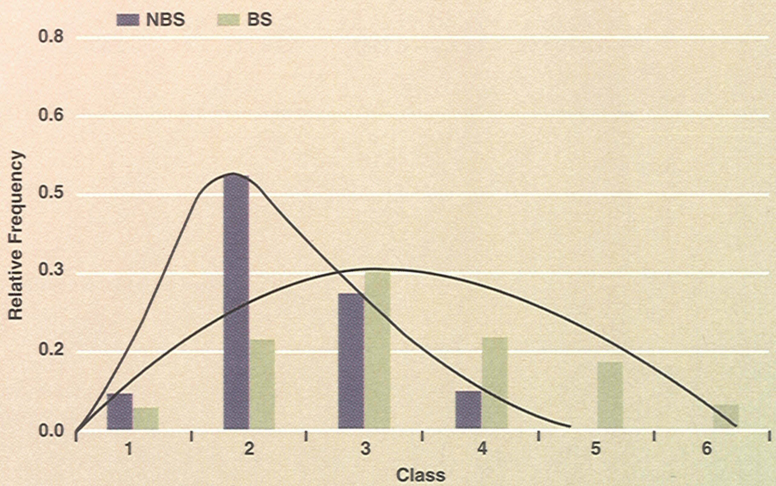
Statistical evaluation conducted after merging compatible data sets

Years combined to expand sample. For statistical analysis, data were used from 42 and 19 houses monitored in the first and second years of the study, respectively. The complexity of the data set, including the variation within categories, means that precise characterizations of the population were not possible. Therefore, strategies were adopted to give best reasonable estimates. These strategies include merging compatible data sets and using fitted distributions to the data to provide a workable model to represent the real population.

To create a larger sample size, the number of gallons (litres) used by the sample households' coolers in both years were combined and ranked. This formed an expanded sample to describe the distribution of water-use values. This merging was justified because both years of data were statistically the same except for three atypical points. This was verified by Student's *t*-test at the 95 percent confidence level. From this group, two major subgroups could be plotted as histograms and probability density functions, thus describing the pattern of water use for the two-year interval.

Two major user groups that appeared to be most mutually exclusive were users with AC and users with NAC. Further distinctions of cooler water use

FIGURE 4 Statistical evaluation of AC houses



Class unit volume consumed = 4,000 gal (15,140L); BS—bleed-off system, NBS—no bleed-off system

groups (i.e., those with BSs or NBSs) were not significantly differentiated subgroups within the main classes. However, a discussion of BS or NBS cooler water use, as well as the effect of TDS, is included.

Model curve can be fit to data. Figure 3 is the result of analysis of the merged data sets for gallons (litres) consumed in both cooling seasons. The relative frequency values for the AC-classed data are indicated on the abscissa by square markers. The relative frequency values for the NAC-classed data are indicated by triangular markers and are connected by a light solid line to show the shape of this histogram formed by the NAC data.

The NAC curve has several zero values because data are lacking within the corresponding water consumption class. These gaps are attributable to the small size of the sample. However, a model curve can be fit to the data—either by including all the empty classes or by not including them in the fitting process.

The curve used to fit the data as a hypothetical model is the gamma distribution

$$f(x{:}\alpha,\beta) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}} \qquad (1)$$

in which α and β are the scaling parameters. This distribution was chosen because of the following observations about the data histograms:

- they are constrained by zero at the lower boundary,
- they are theoretically unbounded at the upper end, and
- the farther from the origin a data group lies, the more diffuse and less peaked the distribution becomes.

The fitted distributions are fitted to very close tolerances using a chi-squared goodness-of-fit iterative method.

The AC curve shows a modal peak at 3.5 (8,750 gal [33,122 L]) and a curve average of $\alpha\beta$ = 4.4 (11,000 gal [41,639 L]). The curve average is slightly higher than the data set average of 9,526 gal (36,060 L), but the standard deviations $s = \sqrt{\alpha\beta^2}$ are quite close—4,695 and 4,510 gal (17,772 and 17,072 L) for curve and data, respectively. Because the curve is a hypothesis of data distribution for large sample sizes (which would include some higher water-use values than in the sample) and because the curve fits the data at hand extremely well, the curve average would be more reliable than the sample mean for estimating population behavior.

The NAC data present some challenges in the zero values for class data at 1, 3, 6, 9, 12, 14, 18, and 20. The first curve fits all the NAC households as plotted. It shows a modal peak at 8.0 (20,000 gal [75,708 L]) with a curve average of 9.8 (24,500 gal [92,742 L]) and a standard deviation of 4.5 (11,250 gal [42,586]). These values agree closely with the sample parameters (Table 3).

This first NAC curve is influenced by the zero class values, especially near the mode, and so it represents the extremes of the data better than the modal area of the data. To compensate for the bias produced in the first NAC curve, a second NAC curve is shown for which zero values at 6, 9, and 12 are not used in the fitting process. The result is a curve that more closely represents the central tendency of the data—a curve mode at 7.5 (18,750 gal [70,976 L]) and an average at 8.24 (20,600 gal [77,979 L]).

The standard deviation for the curve of 2.5 (6,250 gal [23,659 L]) is much tighter than the standard deviation of 11,627 gal (44,013 L) for the data, reflecting the stronger central fit of this second curve. This interplay of central fit on one hand and the high values of the tail on the other may indicate that two populations are in the NAC group: the high peak of curve 2 shows a central tendency population and a separate population for the tail region. Such a putative curve would be represented by the last five nonzero points of the NAC sample.

The sample mean for these five points and standard deviation are shown in Table 3, which summarizes the curve and sample parameters. This hypothetical curve is not shown on Figure 3 but is labeled as curve 3 in Table 3.

TABLE 3 Summary of statistical evaluation of evaporative cooler water use

AC* or NAC [curve]	α	β	Mode	$\bar{x}_T$	$\bar{x}_D$	s_T	s_D
AC [n/a]	5.6	0.79	3.5	4.4	3.8	1.87	1.8
gal			8,750	11,000	9,526	4,695	4,510
L			33,122	41,639	36,060	17,772	17,072
NAC [1]	4.7	2.09	8.0	9.8	9.4	4.5	4.65
gal			20,000	24,500	23,514	11,250	11,627
L			75,708	92,742	89,010	42,586	44,013
NAC [2]	10.9	0.756	7.25	8.24	9.4	2.5	4.65
gal			18,125	20,600	23,514	6,250	11,687
L			68,610	77,979	89,010	23,659	44,240
NAC [3]	43	0.35		15	15.5	2.3	2.35
gal				37,500	38,692	5,750	5,866
L				141,953	146,465	21,766	22,205

*AC—air-conditioning, NAC—no air-conditioning

AC and NAC households overlap. The overlap of the right tail of the AC curve and the left tail of the NAC curve is about 38 percent when either NAC curve 1 or NAC curve 2 is considered. The hypothesized NAC curve 3 would have about 5 percent overlap with the AC curve. Thus the AC curve and the hypothesized NAC curve 3 are significantly separate. The AC curve and the hypothesized NAC curve 3 may represent the separation of sensitive users (i.e., those who are sensitive to the cost of water or to the "conservative" use of water and whose population shows a strong central tendency) from relatively insensitive users (whose population extends into the highest range of water-use values) with a weak central tendency.

Bleedoff and the presence of AC. For the AC group, NBS values are mostly less than BS values. NBS values peak at about 6,000 gal (22,712 L), whereas BS values have a lesser-amplitude peak at about 10,000 gal (37,854 L). The NBS peak has a 50 percent relative frequency, and the BS peak has about a 35 percent relative frequency (Figure 4). The overlap between the two groups is about 60 percent. Thus, although the peak frequency values tend to separate, only 40 percent of each group is mutually exclusive. The BS group, however, does extend at least two classes beyond the NBS values of water consumption.

Water use by evaporative coolers for all studied households averaged about 66 gpd for the cooling season or approximately 14,100 gal a year.

NAC households with and without BSs are mostly equivalent in their range of water-use values. However, because of the small sample sizes, the distributions in the data do not reliably represent the real population.

Percentage of bleedoff unrelated to total household consumption. When the averages are linearly regressed against the class number, the regression coefficient is effectively zero, and no overall relationship is seen. Thus, the volume of water used in BSs does not appear to be related to the total water use of a household (Table 1).

NAC households' coolers generally use more water. When Table 1 data are classified into AC and NAC households, Student's *t*-test at the 95 percent confidence interval shows that the average ratio of cooler to household water use for NAC households is twice that for AC households.

TDS concentrations are lower if BS is present. When the data in Table 1 are classified into BS and NBS groups, with each group composed of AC and NAC users, Student's *t*-test at the 95 percent confidence interval shows that the presence of a BS keeps TDS concentrations in the pan water in the cooler about 3.5 times lower than in NBS coolers.

Conclusions and recommendations noted

For both years, the data are statistically the same, although there were 46 study homes in 1993 and only 20 in 1994. Water use by evaporative coolers for all studied households averaged about 66 gpd (250 L/d) for the cooling season or approximately 14,100 gal (53,298 L) a year. Average total cooler operation per household for the cooling season was about 2,100 hours.

Detailed assessment indicates that the presence or absence of AC is a better determinant of total water use by evaporative coolers than the presence or absence of a BS. Houses having both AC and a BS-equipped evaporative cooler used an average 11,252 gal (42,593 L) per cooling season; households with NAC and BSs used 25,547 gal (96,706 L). Average water use by evaporative coolers was about 15.2 percent of total water use in an average household for the entire study period. However, for both seasons, households that had only BS-equipped coolers used an average of 28.1 percent of total household water for the cooler. Average total household water use was about 106,000 gal (401,200 L) the first season and 113,600 gal (430,200 L) the second season. For the combined cooling seasons, households with BSs used nearly 50 percent more water, on average, to operate their coolers than did NBS households.

Generally, more durable coolers with a single thick evaporative pad appear to be more efficient. Coolers that bleed off some of the recirculating water use more water for cooling. However, BS systems should not be viewed as wasteful if the quality of the BS water is maintained at a reasonable level of electrical conductivity (hardness) and if the water is reused in a beneficial manner, replacing the use of freshwater. A controlled study should be conducted to find an optimum BS flow rate and to test improved evaporative cooling systems.

One of the most important findings to be drawn from this study is that no "average" user of cooler water exists. The user must be adequately classified to be defined. Defined user group consumption can be modeled using a gamma distribution. The gamma distribution curves' fit to the available data will most likely provide good water-use frequency distributions for any population estimate. The most important distinction for classifying the probability group that defines the user is the presence or absence of AC in the household.

Somewhat surprisingly, these data indicate that in AC households, coolers equipped with BSs tend to use less water than coolers without BSs. This does not seem to hold for NAC households, which use more water than AC households. This use pattern may be the result of user sensitivity to increased efficiency in the cooler system. An inverse relation of user sensitivity to expected cooler water use may be postulated.

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References

1. Hernandez, B. Behavior Research Center. City of Phoenix Attitude Survey (draft rept.). Phoenix, Ariz. (1993).
2. Kiefer, J.C. Planning and Management Consultants Ltd. City of Phoenix Water Use Monitoring Program: Evaluation of Water Conservation Programs. Carbondale, Ill. (1989).
3. Terry, A. How Much Water Does Your Evaporative Cooler Bleed Off? City of Phoenix Water Services (Apr. 28, 1992).
4. Karpiscak, M.M. et al. Casa del Agua: Five Years of Water Conservation, Summary Rept. Office of Arid Lands Studies, Univ. of Arizona, Tucson (1991).
5. *Evaporative Cooling, the State of the Art: Space Cooling and Air Handling*. E-Source Inc., Boulder, Colo. (Aug. 1992).
6. Turner, R.H. Water Consumption of Evaporative Cooling Systems. Proc. 1986 Conf. Advancing Toward Technology Breakout in Energy Conversion. Amer. Chem. Soc., Washington.
7. Anonymous. Freon-free Cooling: It's No Sweat with Evaporative Coolers. *Energy Auditor & Retrofitter* (Sept.–Oct. 1985).
8. Babcock, T.M. You Can Save Water, Money, and Your Health With an Evaporative Cooler. City of Phoenix Water Services (1993).
9. Babcock, T.M. Memo to William R. Mee re: Summary of Interviews With Industry Representatives Relative to Data on Evaporative Cooler Water Use (Nov. 30, 1992).
10. Karpiscak, M.M. et al. Evaporative Cooler Water Use Within the City of Phoenix: Final Rept. for 1993 Cooling Season. Univ. of Arizona Ofce. of Arid Lands Studies, Tucson, Ariz., and City of Phoenix Water and Wastewater Dept., Phoenix, Ariz. (1994).
11. Karpiscak, M.M. et al. Evaporative Cooler Use in Phoenix, Ariz.: Current Status and Future Policy Issues. (Unpubl.).
12. Karpiscak, M.M. & Marion, M.H. Evaporative Cooler Water Use. Paper 291045, Cooperative Extension, Univ. of Arizona, College of Agriculture, Tucson, Ariz. (1994).
13. Foerman, B.R. & Rauschkolb, R. Crop Tolerances to Salt in Desert Soils. Cooperative Extension, Univ. of Arizona, College of Agriculture, Tucson, Ariz. (1968)

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