Simplified Method of Calculating Evaporation From Swimming Pools

Introducing tables intended to make highly accurate formulas easier to use

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Accurate calculation of evaporation from swimming pools is needed for proper sizing of ventilation and dehumidification equipment. Calculations are needed for both occupied and unoccupied conditions for proper modulation of equipment capacity, as well as estimation of energy consumption. The most common method is the one recommended in ASHRAE Handbook—HVAC Applications.[1] It involves calculation of evaporation using the Carrier equation[2] and correction of the output using activity factors. Comparisons with test data have shown this method is inaccurate. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is undertaking a research program to test it and other methods.

In 2002 and 2003,[3,4] the author developed formulas for occupied and unoccupied pools that were verified with a wide range of data. Those formulas were summarized in an article in *HPAC Engineering*.[5] Despite the formulas' proven accuracy, many engineers found them difficult to use, as computer programming is needed for accurate calculation of air properties. To simplify use of the formulas, this article presents tables that give the results of calculations over a wide range of conditions. Additionally, the article introduces a formula for the rare condition in which natural convection does not occur.

Although the article is written in inch-pound (I-P) units, results are given in both I-P and Systeme International (SI) units in the tables.

Author's Formulas

Unoccupied pools. For unoccupied pools, evaporation is the larger of the results of the following equations:

$$E_0 = 290\, D_w (D_r - D_w)^{1/3} (W_w - W_r) \quad (1)$$

$$E_0 = 0.125\, (p_w - p_r) \quad (2)$$

where:

E_0 = evaporation from unoccupied pool, pounds per hour per square foot

D_w = density of air saturated at water temperature, pounds per cubic foot of dry air

D_r = density of air at room condition, pounds per cubic foot of dry air

W_w = humidity ratio, air saturated at water temperature, pounds per pound

W_r = humidity ratio, air at room condition, pounds per pound

p_w = water-vapor pressure in air, air saturated at water temperature, inches of mercury

p_r = water-vapor pressure in air, air at room condition, inches of mercury

Equation 1 gives the rate of evaporation caused by natural convection. It was obtained from the analogy between heat and mass transfer without any empirical factor. Its full derivation can be seen in Shah (2008).[6] Equation 2 gives the rate of evaporation attributed to forced convection by air currents generated by a building ventilation system. It was obtained by analyzing test data for conditions in which the density of air at the surface of water was greater than the density of air in the room.

This method of calculation differs from the one given in Shah (2004)[5], as it includes negative-density differences. Further, the 2004 method uses only Equation 1, increasing the calculated evaporation at very low density differences by 15 percent. The present method was compared with the same extensive database as the earlier method. The overall mean deviation was the same, although individual data points had higher or lower deviations. The ranges of the test data are given in Table 1.

Occupied pools. For occupied pools, the author gave an analytical formula, as well as an empirical formula. The empirical formula produces much closer agreement. For

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fully occupied pools:

$$E = 0.023 - 0.0000162 \div U + 0.041\,(p_w - p_r) \qquad (3)$$

where:

E = evaporation from pool, pounds per hour per square foot

U = utilization factor (number of people in pool area multiplied by 48.4 divided by pool area), the applicable range of which is 0.1 (10-percent occupied) to 1 (fully occupied). The ranges of test data are given in Table 1.

Tables

Table 2 gives values of evaporation from unoccupied pools calculated using the method above. (Table 3 gives the corresponding values in SI units.) Values are given at 2-degree intervals. For in-between temperatures, linear interpolation can be performed. This table is applicable to all types of pools with an undisturbed water surface.

Table 4 gives values of evaporation from fully occupied pools calculated using Equation 3. (Table 5 gives the

	Unoccupied pools	Occupied pools
Pool area, square feet	0.78 to 4,573	687 to 13,008
Water temperature, degrees Fahrenheit	45 to 201	77 to 86
Air temperature, degrees Fahrenheit	43 to 95	80 to 90
Air relative humidity, percent	28 to 98	33 to 72
($p_w - p_r$), millimeters of mercury	0.062 to 23.7	0.31 to 0.61
($p_r - p_w$), pounds per cubic foot	-0.00025 to +0.062	0.0013 to 0.000081
Number of occupants	0	8 to 180
Utilization factor	0	0.1 to 1.5
Number of data sources	9	4

TABLE 1. Verified ranges of author's formulas.

Water temperature, degrees Fahrenheit	Space air temperature, degrees Fahrenheit, and relative humidity, percent											
	76°F		78°F		80°F		82°F		84°F		86°F	
	50%	60%	50%	60%	50%	60%	50%	60%	50%	60%	50%	60%
76	0.0213	0.0159	0.0176	0.0120	0.0135	0.0099	0.0123	0.0085	0.0110	0.0069	0.0097	0.0053
78	0.0269	0.0211	0.0232	0.0173	0.0193	0.0133	0.0149	0.0106	0.0132	0.0091	0.0118	0.0075
80	0.0327	0.0266	0.0291	0.0228	0.0252	0.0188	0.0212	0.0146	0.0166	0.0114	0.0141	0.0098
82	0.0390	0.0326	0.0353	0.0287	0.0315	0.0246	0.0274	0.0204	0.0232	0.0160	0.0185	0.0110
84	0.0458	0.0391	0.0420	0.0350	0.0381	0.0309	0.0340	0.0266	0.0298	0.0222	0.0253	0.0176
86	0.0530	0.0461	0.0492	0.0419	0.0452	0.0377	0.0410	0.0333	0.0368	0.0288	0.0323	0.0241
88	0.0608	0.0536	0.0569	0.0494	0.0528	0.0450	0.0486	0.0405	0.0442	0.0358	0.0397	0.0311
90	0.0692	0.0618	0.0651	0.0574	0.0610	0.0529	0.0567	0.0482	0.0522	0.0435	0.0476	0.0386
102	0.1335	0.1250	0.1289	0.1199	0.1241	0.1147	0.1192	0.1093	0.1142	0.1037	0.1089	0.0979
104	0.1469	0.1383	0.1422	0.1331	0.1374	0.1277	0.1324	0.1222	0.1272	0.1165	0.1219	0.1106

TABLE 2. Evaporation from unoccupied pools calculated by the author's method, pounds per hour per square foot.

Water temperature, degrees Celsius	Space air temperature, degrees Celsius, and relative humidity, percent											
	25°C		26°C		27°C		28°C		29°C		30°C	
	50%	60%	50%	60%	50%	60%	50%	60%	50%	60%	50%	60%
25	0.1085	0.0809	0.0918	0.0636	0.0732	0.0515	0.0498	0.0450	0.0583	0.0382	0.0523	0.0311
26	0.1355	0.1042	0.1171	0.0872	0.0997	0.0693	0.0806	0.0547	0.0575	0.0479	0.0626	0.0479
27	0.1579	0.1290	0.1433	0.1118	0.1262	0.0941	0.1081	0.0753	0.0885	0.0582	0.0723	0.0510
28	0.1877	0.1556	0.1711	0.1380	0.1539	0.1200	0.1360	0.1014	0.1171	0.0818	0.0960	0.0618
29	0.2174	0.1841	0.2006	0.1661	0.1831	0.1477	0.1651	0.1287	0.1644	0.1092	0.1268	0.0888
30	0.232	0.2146	0.2143	0.1962	0.1960	0.1773	0.1772	0.1579	0.1576	0.1380	0.1372	0.1176
31	0.2831	0.2474	0.2655	0.2285	0.2475	0.2091	0.2289	0.1892	0.2098	0.1688	0.1900	0.1480
32	0.3192	0.2825	0.3013	0.2631	0.2829	0.2432	0.2639	0.2228	0.2445	0.2019	0.2445	0.1805
39	0.6461	0.6035	0.6256	0.5808	0.6045	0.5575	0.5827	0.5334	0.5604	0.5087	0.5379	0.4833
40	0.7051	0.6617	0.6842	0.6386	0.6627	0.6148	0.6405	0.5903	0.6177	0.5655	0.5943	0.5391

TABLE 3. Evaporation from unoccupied pools calculated by the author's method, kilograms per hour per square meter.

Water temperature, °F	Space air temperature, degrees Fahrenheit, and relative humidity, percent											
	76°F		78°F		80°F		82°F		84°F		86°F	
	50%	60%	50%	60%	50%	60%	50%	60%	50%	60%	50%	60%
76	0.0416	0.0379	0.0403	0.0363	0.039	0.0347	0.0375	0.033	0.036	0.0312	0.0344	0.0293
78	0.0441	0.0404	0.0428	0.0389	0.0415	0.0373	0.0401	0.0356	0.0386	0.0337	0.037	0.0318
80	0.0468	0.0431	0.0455	0.0416	0.0442	0.0400	0.0428	0.0382	0.0413	0.0382	0.0397	0.0364
82	0.0497	0.0459	0.0484	0.0444	0.0470	0.0428	0.0456	0.0411	0.0411	0.0393	0.0425	0.0374
84	0.0527	0.0490	0.0514	0.0474	0.0501	0.0458	0.0486	0.0441	0.0471	0.0423	0.0451	0.0404
86	0.0559	0.0521	0.0546	0.0506	0.0532	0.0490	0.0518	0.0473	0.0503	0.0455	0.0487	0.0436

TABLE 4. Evaporation from fully occupied pools calculated using Equation 3, pounds per hour per square foot.

Water temperature, °C	Space air temperature, degrees Celsius, and relative humidity, percent											
	25°C		26°C		27°C		28°C		29°C		30°C	
	50%	60%	50%	60%	50%	60%	50%	60%	50%	60%	50%	60%
25	0.2065	0.1878	0.2007	0.1809	0.1947	0.1737	0.1884	0.1660	0.1817	0.1580	0.1747	0.1496
26	0.2179	0.1992	0.2122	0.1923	0.2062	0.1851	0.1998	0.1775	0.1932	0.1695	0.1861	0.1611
27	0.2300	0.2113	0.2242	0.2044	0.2182	0.1972	0.2119	0.1895	0.2052	0.1815	0.1982	0.1731
28	0.2427	0.2239	0.2369	0.2171	0.2309	0.2098	0.2246	0.2022	0.2179	0.1942	0.2109	0.1858
29	0.2560	0.2373	0.2503	0.2304	0.2442	0.2232	0.2379	0.2156	0.2312	0.2076	0.2242	0.1992
30	0.2700	0.2513	0.2643	0.2445	0.2583	0.2372	0.2519	0.2296	0.2453	0.2216	0.2383	0.2132

TABLE 5. Evaporation from fully occupied pools calculated using Equation 3, kilograms per hour per square meter.

corresponding values in SI units.) The data are applicable to pools with air temperatures of 76°F to 90°F and water temperatures of 76°F to 86°F.

Use of the tables can be illustrated with two examples:

Example 1. A 10,000-sq-ft public swimming pool has a water temperature of 80°F, an air temperature of 78°F, and relative humidity of 50 percent.

From Table 2:

- Evaporation when pool is unoccupied: 0.0291 lb per hour per square foot.
- Total evaporation: 0.0291 × 10,000 = 291 lb per hour.

From Table 4:

- Evaporation when pool is fully occupied: 0.0455 lb per hour per square foot.
- Total evaporation: 0.0455 × 10,000 = 455 lb per hour.

Example 2. A 10,000-sq-ft public swimming pool has a water temperature of 79°F, an air temperature of 78°F, and relative humidity of 50 percent.

Table 2 does not list 79°F water temperature, so interpolation is required. Evaporation at 78°F water temperature is 0.0232 lb per hour per square foot, while evaporation at 80°F water temperature is 0.0291 lb per hour per square foot. Evaporation at 79°F water temperature, then, is:

$$(0.0232 + 0.0291) \div 2 = 0.026 \text{ lb per hour per square foot}$$

Discussion

The method for unoccupied pools presented here has been verified with a wide range of test data and has a firm theoretical foundation. It can be used with confidence for all types of pools.

The method for occupied pools presented here was verified with test data from four public pools. The ASHRAE Handbook[1] method was found to have a mean deviation of 36.9 percent, while the method presented here had a mean deviation of only 16.2 percent.

References

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