

SECTION 11

Cooling Towers

INTRODUCTION

The purpose of this section is to provide a basic understanding of the design and operation of a cooling tower. A cooling tower allows water to be cooled by ambient air through evaporation.

COOLING TOWER PSYCHROMETRICS

Psychrometry is the study of cooling by evaporation. Maximum evaporation takes place when water, in the form of tiny droplets, is exposed to the maximum air flow for the longest possible time. The process of evaporation through removal of latent

FIG. 11-1
Nomenclature

Acfm = actual volumetric flow rate of air-vapor mixture, cu ft/min	HWT = hot water temperature, °F
ahp = air horsepower, hp	lb_a = pounds of dry air
AWB = ambient wet bulb temperature, °F	lb_w = pounds of water
B = combined water loss through blowdown and windage, % of circulating water or cu ft/min	L = water rate, lb/(sq ft · hr)
CWT = cold water temperature, °F	LG = liquid to gas ratio, lb/lb
DB = dry bulb temperature, °F	Q = cu ft/min
E = water evaporated, % of circulating water or cu ft/min	PF = performance factor, dimensionless
gpm = gallons per minute	R = cooling tower range, °F
G = air rate, lb/(sq ft · hr)	V = air velocity, ft/min
h_a = specific enthalpy of dry air, BTU/lb	v_a = specific volume of dry air, cu ft/lb
h_{as} = h _s – h _a , BTU/lb	v_{as} = v _s – v _a , cu ft/lb
h_s = enthalpy of moist air at saturation per lb of dry air, BTU/lb	v_s = volume of moist air at saturation per lb of dry air, cu ft/lb
	Ws = lb _w /lb _a , humidity ratio at saturation
	WB = wet bulb temperature, °F

DEFINITIONS OF WORDS AND PHRASES USED IN COOLING TOWERS

Air horsepower: The power output developed by a fan in moving a given air rate against a given resistance.

Air inlet: Opening in a cooling tower through which air enters. Sometimes referred to as the louvered face on induced draft towers.

Air rate: Mass flow of dry air per square foot of cross-sectional area in the tower's heat transfer region per hour.

Air velocity: Velocity of air-vapor mixture through a specific region of the tower (i.e. the fan).

Ambient wet-bulb temperature: The wet-bulb temperature of the air encompassing a cooling tower, not including any temperature contribution by the tower itself. Generally measured upwind of a tower, in a number of locations sufficient to account for all extraneous sources of heat.

Approach: Difference between the cold water temperature and the entering wet-bulb temperature.

Blowdown: Water discharged from the system to control concentrations of salt or other impurities in the circulating water.

Capacity: The amount of water that a cooling tower will cool through a specified range, at a specified approach and wet-bulb temperature.

Cell: Smallest tower subdivision which can function as an independent unit with regard to air and water flow; it is bounded by either exterior walls or partition walls. Each cell may have one or more fans and one or more distribution systems.

Circulation rate: Actual water flow rate through a given tower.

Cold water temperature: Temperature of the water leaving the collection basin, exclusive of any temperature effects incurred by the addition of makeup and/or the removal of blowdown.

Collection basin: Chamber below and integral with the tower where water is transiently collected and directed to the sump or pump suction line.

Counterflow: Air flow direction through the fill is countercurrent to that of the falling water.

Crossflow: Air flow direction through the fill is essentially perpendicular to that of the falling water.

Distribution basin: Shallow pan-type elevated basin used to distribute hot water over the tower fill by means of orifices in the basin floor. Application is normally limited to crossflow towers.

Double-flow: A crossflow cooling tower where two opposed fill banks are served by a common air plenum.

Drift: Circulating water loss from the tower as liquid droplets entrained in the exhaust air stream. Units percent of circulating water rate or gpm. [For more precise work, an L/G parameter is used, and drift becomes pounds of water per million pounds of exhaust air (ppmw).]

Drift eliminators: An assembly of baffles or labyrinth passages through which the air passes prior to its exit from the tower, for the purpose of removing entrained water droplets from the exhaust air.

Dry-bulb temperature: The temperature of the entering or ambient air adjacent to the cooling tower as measured with a dry-bulb thermometer.

Evaporation loss: Water evaporated from the circulating water into the air stream in the cooling process.

Fan cylinder: Cylindrical or venturi-shaped structure in which a propeller fan operates. Sometimes referred to as a fan “stack” on larger towers.

Fan deck: Surface enclosing the top of an induced draft cooling tower, exclusive of the distribution basins on a crossflow tower.

Fan pitch: The angle which the blades of a propeller fan make with the plane of rotation, measured at a prescribed point on each blade.

Fill: That portion of a cooling tower which constitutes its primary heat transfer surface. Sometimes referred to as “packing.”

Forced draft: Refers to the movement of air under pressure through a cooling tower. Fans of forced draft towers are located at the air inlets to “force” air through the tower.

Hot water temperature: Temperature of circulating water entering the cooling tower’s distribution system.

Induced draft: Refers to the movement of air through a cooling tower by means of an induced partial vacuum. Fans of induced draft towers are located at the air discharges to “draw” air through the tower.

Liquid-to-gas ratio: A ratio of the total mass flows of water and dry air in a cooling tower. (See Air Rate and Water Rate)

Louvers: Blade or passage type assemblies installed at the air inlet face of a cooling tower to control water splashout and/or promote uniform air flow through the fill. In the case of film-type crossflow fill, they may be integrally molded to the fill sheets.

Makeup: Water added to the circulating water system to replace water lost by evaporation, drift, windage, blowdown, and leakage.

Natural draft: Refers to the movement of air through a cooling tower purely by natural means. Typically, by the driving force of a density differential.

Net effect volume: That portion of the total structural volume within which the circulating water is in intimate contact with the flowing air.

Performance factor: Variable used in determining performance characteristics in cooling towers.

Psychrometer: An instrument incorporating both a dry-bulb and a wet-bulb thermometer, by which simultaneous dry-bulb and wet-bulb temperature readings can be taken.

Range: Difference between the hot water temperature and the cold water temperature.

Recirculation: Describes a condition in which a portion of the tower’s discharge air re-enters the air inlets along with the fresh air. Its effect is an elevation of the average entering wet-bulb temperatures compared to the ambient.

Water rate: Mass flow of water per square foot of fill plan area of the cooling tower per hour.

Wet-bulb temperature: the temperature of the entering or ambient air adjacent to the cooling tower as measured with a wet-bulb thermometer.

Wet-bulb thermometer: A thermometer whose bulb is encased within a wetted wick.

Windage: Water lost from the tower because of the effects of wind.

Wind load: The load imposed upon a structure by a wind blowing against its surface.

heat allows the water to be cooled below the ambient dry-bulb temperature. The dry air enters the cooling tower and begins to gain moisture and enthalpy in an effort to reach equilibrium with the water. The water may be cooled 15°F or more while the air mass dry-bulb temperature may increase only slightly. A psychrometric chart (Fig. 11-2) may be used to illustrate the relationships between wet- and dry-bulb temperatures. All nomenclature is indicated in Fig. 11-1.

Wet-bulb Temperature

The basis for thermal design of an evaporative type cooling tower is the wet-bulb temperature of the air entering the tower. Water cannot be cooled below the wet-bulb temperature by evaporation. The air entering the tower at a temperature of 75°F and 100% relative humidity has a 75°F “wet-bulb” tem-

perature. The wet-bulb temperature is usually measured using a sling psychrometer. Wet bulb and dry bulb data for various locations around the world are shown in Figs. 11-3a and 11-3b.

Types of Cooling Systems

Cooling water is circulated through equipment to absorb and carry away heat. The basic cooling systems are shown in Fig. 11-4. The open recirculating system is the most common for industrial plants.

The open recirculating system routes cooled water through the heat-exchange equipment. Effluent warm water then is cooled by contact with air in a cooling tower. The cooling effect is produced by evaporation of a portion of the circulating water, and this evaporation causes the dissolved solids in the

FIG. 11-2
Psychrometric Chart

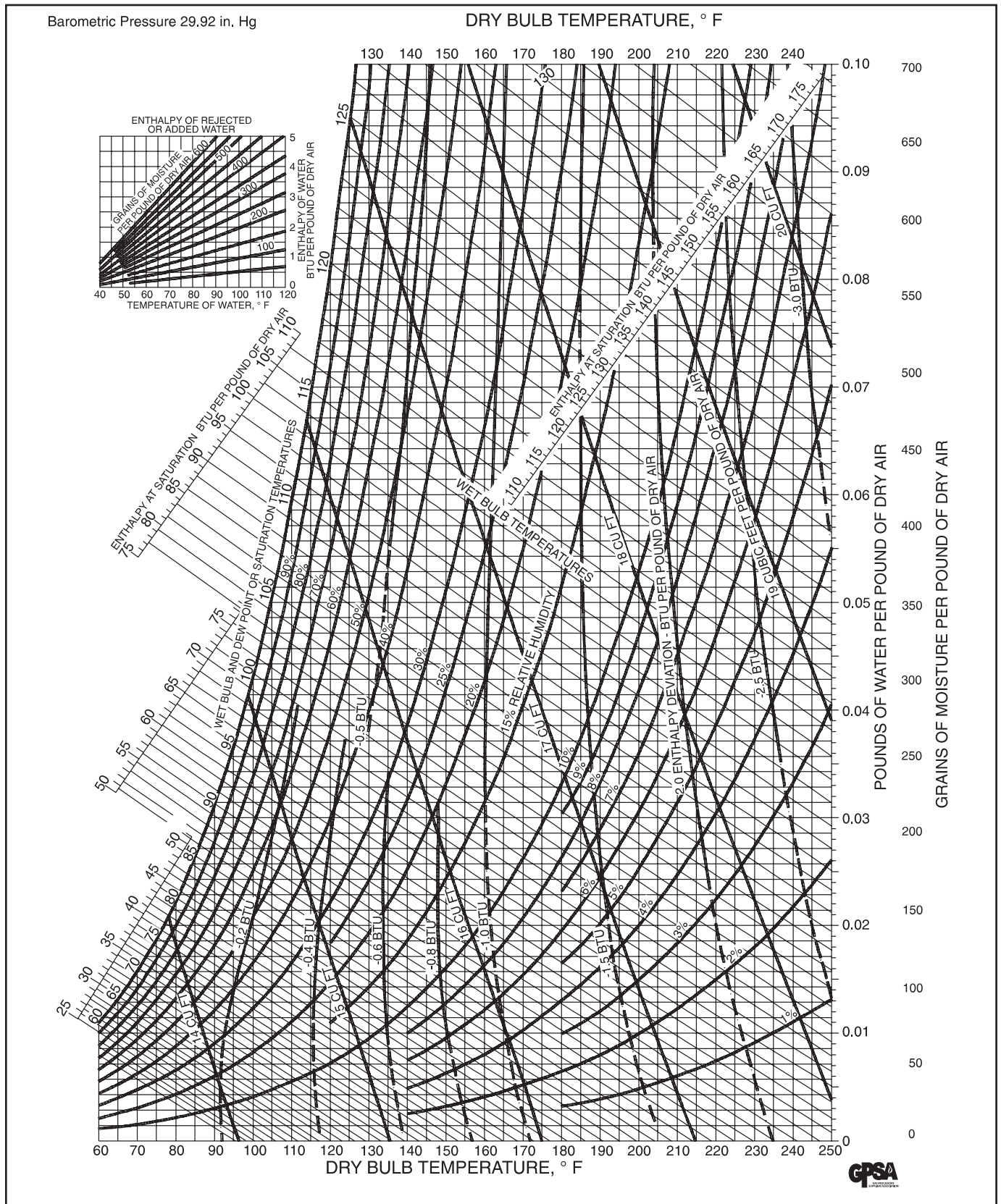


FIG. 11-3a
Dry Bulb/Wet Bulb Temperature Data²

U.S. State and Stations	Design Dry-Bulb °F 5%	Design Wet-Bulb °F 5%	U.S. State and Stations	Design Dry-Bulb °F 5%	Design Wet-Bulb °F 5%	U.S. State and Stations	Design Dry-Bulb °F 5%	Design Wet-Bulb °F 5%	U.S. State and Stations	Design Dry-Bulb °F 5%	Design Wet-Bulb °F 5%
ALABAMA			Palm Springs	108	73	Panama City,	89	79	INDIANA		
Alexander City	91	78	Pasadena	92	70	Tyndall AFB			Anderson	89	76
Anniston	92	78	Petaluma	87	68	Pensacola	91	79	Bedford	89	76
Auburn	91	78	Pomona	95	71	St. Augustine	87	79	Bloomington	89	76
Birmingham	92	76	Redding	100	68	St. Petersburg	90	78	Columbus,	90	76
Decatur	91	76	Redlands	96	71	Sanford	91	78	Bakalar AFB		
Dothan	91	78	Richmond	75	63	Sarasota	90	78	Crawfordsville	88	76
Florence	92	76	Riverside-March	95	70	Tallahassee	90	78	Evansville	91	77
Gadsden	92	76	AFB			Tampa	90	78	Fort Wayne	87	74
Huntsville	91	76	Sacramento	94	70	West Palm Beach	90	79	Goshen	86	74
Mobile AP	91	78	Salinas	67	59	GEORGIA			Hobart	85	74
Mobile CO	91	78	San Bernardino,	96	71	Albany, Turner	93	78	Huntington	87	74
Montgomery	93	78	Norton AFB			AFB			Indianapolis	87	75
Selma-Craig	93	79	San Diego	78	68	Americus	92	77	Jeffersonville	90	76
Talladega	92	78	San Fernando	88	69	Athens	90	76	Kokomo	88	74
Tuscaloosa	94	77	San Francisco AP	73	62	Atlanta	90	75	Lafayette	88	75
ALASKA			San Francisco CO	69	61	Augusta	93	78	La Porte	87	75
Anchorage	66	57	San Jose	77	65	Brunswick	87	79	Marion	88	74
Barrow	49	47	San Luis Obispo	84	70	Columbus,	91	77	Muncie	87	75
Fairbanks	75	60	Santa Ana	82	69	Lawson AFB			Peru, Bunker	86	74
Juneau	67	58	Santa Barbara	75	66	Dalton	91	77	Hill AFB		
Kodiak	62	56	Santa Cruz	68	61	Dublin	91	77	Richmond	87	75
Nome	59	55	Santa Maria	73	63	Gainesville	89	75	Shelbyville	88	75
ARIZONA			Santa Monica	77	68	Griffin	88	76	South Bend	86	74
Douglas	93	68	Santa Paula	84	68	La Grange	89	76	Terre Haute	89	76
Flagstaff	80	59	Santa Rosa	91	67	Macon	91	77	Valparaiso	87	75
Fort Huachuca	90	67	Stockton	94	68	Marietta,	90	76	Vincennes	90	76
Kingman	97	69	Ukiah	91	67	Dobbins AFB			IOWA		
Nogales	94	69	Visalia	97	70	Moultrie	92	78	Ames	87	75
Phoenix	105	75	Yreka	89	64	Rome	91	77	Burlington	88	75
Prescott	92	64	Yuba City	99	68	Savannah-Travis	91	78	Cedar Rapids	86	75
Tucson	100	71	COLORADO			Valdosta-Moody	92	78	Clinton	87	75
Winslow	93	64	Alamosa	80	60	AFB			Council Bluffs	88	75
Yuma	107	77	Boulder	89	62	Waycross	91	78	Des Moines	88	75
ARKANSAS			Colorado Springs	86	61	HAWAII			Dubuque	86	74
Blytheville	91	78	Denver	89	62	Hilo	82	74	Fort Dodge	86	74
Camden	94	78	Durango	85	62	Honolulu	85	74	Iowa City	87	76
El Dorado	94	78	Fort Collins	89	62	Kaneohe Bay	83	75	Keokuk	89	76
Fayetteville	92	75	Grand Junction	92	62	Wahiawa	84	73	Marshalltown	88	75
Fort Smith	95	78	Greeley	92	63	IDAHO			Mason City	85	74
Hot Springs	94	78	La Junta	95	69	Boise	91	65	Newton	88	75
Jonesboro	91	78	Leadville	78	54	Burley	92	61	Ottumwa	88	75
Little Rock	94	78	Pueblo	92	65	Coeur d'Alene	83	61	Sioux City	89	75
Pine Bluff	95	80	Sterling	90	65	Idaho Falls	84	61	Waterloo	86	75
Texarkana	93	78	Trinidad	89	64	Lewiston	90	64	KANSAS		
CALIFORNIA			CONNECTICUT			Moscow	84	62	Atchison	91	77
Bakersfield	98	70	Bridgeport	81	73	Mountain Home	94	63	Chanute	94	76
Barstow	102	70	Hartford,	85	74	AFB			Dodge City	95	71
Blythe	108	74	Brainard Field			Pocatello	89	61	El Dorado	96	75
Burbank	88	69	New Haven	82	74	Twin Falls	92	61	Emporia	94	76
Chico	98	68	New London	83	74	ILLINOIS			Garden City	94	71
Concord	94	68	Norwalk	81	73	Aurora	88	76	Goodland	93	68
Covina	92	70	Norwich	83	74	Belleville, Scott AFB	89	76	Great Bend	95	75
Crescent City	63	59	Waterbury	82	72	Bloomington	88	75	Hutchinson	97	74
Downey	86	70	Windsor Locks,	85	73	Carbondale	90	77	Liberal	94	71
El Cajon	78	68	Bradley Field			Champaign/Urbana	90	75	Manhattan,	92	76
El Centro	108	78	DELAWARE			Chicago, Midway	88	74	Fort Riley		
Escondido	82	69	Dover AFB	87	76	Chicago, O'Hare	86	74	Parsons	94	76
Eureka/Arcata	63	59	Wilmington	87	75	Chicago	88	75	Russell	95	75
Fairfield-Travis AFB	91	67	DISTRICT OF			Danville	88	75	Salina	97	75
Fresno	97	70	COLUMBIA			Decatur	88	75	Topeka	93	76
Hamilton	80	67	Andrews AFB	87	75	Dixon	88	75	Wichita	96	75
Laguna Beach	77	68	Washington	89	76	Elgin	86	75	KENTUCKY		
Livermore	93	68	National			Freeport	87	74	Ashland	89	75
Lompoc,	67	60	FLORIDA			Galesburg	88	75	Bowling Green	89	76
Vandenberg AFB			Belle Glade	89	78	Greenville	89	76	Corbin	89	75
Long Beach	77	68	Cape Kennedy	87	79	Joliet	88	75	Covington	88	74
Los Angeles AP	77	68	Daytona Beach	88	78	Kankakee	88	75	Hopkinsville,	89	76
Los Angeles CO	86	70	Fort Lauderdale	90	79	La Salle/Peru	88	75	Campbell AFB		
Merced-Castle AFB	96	70	Fort Myers	91	79	Macomb	89	76	Lexington	88	75
Modesto	95	69	Fort Pierce	89	79	Moline	88	75	Louisville	90	76
Monterey	68	61	Gainesville	92	78	Mt. Vernon	89	76	Madisonville	90	77
Napa	92	68	Jacksonville	92	78	Peoria	87	75	Owensboro	91	77
Needles	108	74	Key West	89	79	Quincy	90	77	Paducah	92	77
Oakland	75	63	Lakeland	89	78	Rantoul,	89	75	LOUISIANA		
Oceanside	77	68	Miami	89	78	Chanute AFB			Alexandria	92	78
Ontario	96	71	Miami Beach	88	78	Rockford	87	74	Baton Rouge	92	79
Oxnard	77	67	Ocala	92	78	Springfield	89	76	Bogalusa	92	79
Palmdale	98	66	Orando	91	78	Waukegan	87	75	Houma	92	79

FIG. 11-3a (Cont'd)
Dry Bulb/Wet Bulb Temperature Data²

U.S. State and Stations	Design Dry-Bulb °F 5%	Design Wet-Bulb °F 5%	U.S. State and Stations	Design Dry-Bulb °F 5%	Design Wet-Bulb °F 5%	U.S. State and Stations	Design Dry-Bulb °F 5%	Design Wet-Bulb °F 5%	U.S. State and Stations	Design Dry-Bulb °F 5%	Design Wet-Bulb °F 5%
Lafayette	92	79	Columbus AFB	91	78	Portsmouth, Pease AFB	83	72	Goldsboro,	89	77
Lake Charles	92	79	Greenville AFB	91	78	NEW JERSEY			Seymour-Johnson AFB		
Minden	94	78	Greenwood	91	78	Atlantic City	86	75	Greensboro	89	75
Monroe	94	78	Hattiesburg	92	79	Long Branch	87	75	Greenville	89	77
Natchitoches	93	78	Jackson	93	78	Newark	88	75	Henderson	90	77
New Orleans	90	79	Laurel	92	79	New Brunswick	86	75	Hickory	88	73
Shreveport	94	78	McComb	92	78	Paterson	88	75	Jacksonville	88	78
MAINE			Meridian	93	78	Phillipsburg	86	74	Lumberton	90	77
Augusta	82	70	Natchez	92	79	Trenton	85	75	New Bern	88	78
Bangor, Dow AFB	80	69	Tupelo	92	78	Vineland	86	75	Raleigh/Durham	90	76
Caribou	78	67	Vicksburg	93	79	NEW MEXICO			Rocky Mount	89	77
Lewiston	82	70	MISSOURI			Alamogordo,	94	67	Wilmington	89	79
Millinocket	80	68	Cape Girardeau	92	77	Holloman AFB			Winston-Salem	89	74
Portland	81	70	Columbia	91	76	Albuquerque	92	64	NORTH DAKOTA		
Waterville	81	70	Farmington	90	75	Artesia	97	70	Bismark	88	70
MARYLAND			Hannibal	90	77	Carlsbad	97	70	Devil's Lake	85	69
Baltimore AP	89	76	Jefferson City	92	76	Clovis	91	67	Dickinson	87	68
Baltimore CO	87	76	Joplin	94	76	Farmington	91	64	Fargo	85	72
Cumberland	87	75	Kansas City	93	76	Gallup	86	61	Grand Forks	84	70
Frederick	88	76	Kirksville	90	76	Grants	85	61	Jamestown	87	71
Hagerstown	89	75	Mexico	91	76	Hobbs	97	69	Minot	86	68
Salisbury	88	76	Moberly	91	76	Las Cruces	94	67	Williston	85	68
MASSACHUSETTS			Poplar Bluff	92	78	Los Alamos	85	60	OHIO		
Boston	85	72	Rolla	89	76	Raton	87	63	Akron-Canton	84	72
Clinton	84	72	St. Joseph	91	77	Roswell, Walker	96	69	Ashtabula	83	72
Fall River	81	72	St. Louis AP	91	76	AFB			Athens	90	74
Framingham	83	71	St. Louis CO	91	76	Santa Fe	86	61	Bowling Green	86	73
Gloucester	83	72	Sedalia,	90	76	Silver City	91	63	Cambridge	87	75
Greenfield	82	71	Whiteman AFB			Socorro	93	65	Chilllicothe	90	74
Lawrence	84	73	Sikeston	92	77	Tucumcari	95	68	Cincinnati	88	74
Lowell	85	73	Springfield	91	75	NEW YORK			Cleveland	86	73
New Bedford	80	72	MONTANA			Albany AP	85	72	Columbus	87	74
Pittsfield	81	70	Billings	88	64	Albany CO	85	72	Dayton	86	73
Springfield,	84	72	Bozeman	84	60	Auburn	84	72	Defiance	88	74
Westover AFB			Butte	80	57	Batavia	84	72	Findlay	87	74
Taunton	83	73	Cut Bank	82	61	Binghamton	81	70	Fremont	85	73
Worcester	81	70	Glasgow	85	64	Buffalo	83	72	Hamilton	87	73
MICHIGAN			Glendive	89	65	Cortland	82	71	Lancaster	88	74
Adrian	85	73	Great Falls	85	60	Dunkirk	83	72	Lima	88	74
Alpena	83	70	Havre	87	65	Elmira	83	71	Mansfield	85	73
Battle Creek	85	73	Helena	85	61	Geneva	84	72	Marion	88	74
Benton Harbor	85	72	Kalispell	84	62	Glen Falls	82	71	Middletown	87	73
Detroit	86	73	Lewiston	83	62	Gloversville	83	72	Newark	89	74
Escanaba	80	69	Livingston	84	60	Hornell	82	72	Norwalk	85	73
Flint	85	72	Miles City	92	67	Ithaca	82	71	Portsmouth	89	75
Grand Rapids	85	72	Missoula	85	62	Jamestown	83	71	Sandusky	88	73
Holland	83	72	NEBRASKA			Kingston	85	73	Springfield	87	74
Jackson	85	73	Beatrice	92	76	Lockport	84	73	Staubenville	84	72
Kalamazoo	85	73	Chadron	91	68	Massena	80	70	Toledo	85	73
Lansing	84	72	Columbus	92	75	Newburg-	85	73	Warren	85	71
Marquette	77	68	Fremont	92	76	Stewart AFB			Wooster	84	72
Mt. Pleasant	84	72	Grand Island	91	73	NYC-Central Park	87	74	Youngstown	84	71
Muskegon	82	72	Hastings	91	73	NYC-Kennedy AP	84	74	Zanesville	87	75
Pontiac	85	73	Kearney	90	72	NYC-LaGuardia	87	74	OKLAHOMA		
Port Huron	83	73	Lincoln	92	76	AP			Ada	95	75
Saginaw	84	72	McCook	91	71	Niagara Falls	84	73	Altus AFB	98	75
Sault St. Marie	77	68	Norfolk	90	75	Olean	81	71	Ardmore	95	76
Traverse City	83	71	North Platte	90	71	Oneonta	80	70	Bartlesville	95	76
Ypsilanti	86	72	Omaha	88	75	Oswego	80	72	Chickasha	95	76
MINNESOTA			Scottsbluff	90	67	Plattsburg AFB	80	70	Enid-Vance AFB	97	76
Albert Lea	84	73	Sidney	90	67	Poughkeepsie	86	74	Lawton	96	76
Alexandria	85	72	NEVADA			Rochester	85	72	McAlester	93	75
Bemidji	81	69	Carson City	89	60	Rome-Griffiss AFB	83	71	Muskogee	95	77
Brainerd	84	71	Elko	90	60	Schenectady	84	72	Norman	94	75
Duluth	79	68	Ely	85	58	Suffolk County	80	73	Oklahoma City	95	76
Fairbault	85	73	Las Vegas	104	69	AFB			Ponca City	94	76
Fergus Falls	85	72	Lovelock	93	64	Syracuse	84	72	Seminole	94	75
International Falls	80	68	Reno AP	90	61	Utica	82	71	Stillwater	93	75
Mankato	85	73	Reno CO	91	61	Watertown	81	72	Tulsa	95	77
Minneapolis/St. Paul	86	73	Tonopah	90	61	NORTH CAROLINA			Woodward	94	75
Rochester	84	73	Winnemucca	92	61	Asheville	85	72	OREGON		
St. Cloud	85	72	NEW HAMPSHIRE			Charlotte	91	76	Albany	86	66
Virginia	80	68	Berlin	81	70	Durham	90	76	Astoria	68	62
Willmar	85	72	Claremont	83	71	Elizabeth City	89	78	Baker	86	61
Winona	85	74	Concord	84	71	Fayetteville,	90	77	Bend	84	60
MISSISSIPPI			Keene	83	71	Pope AFB			Corvallis	86	66
Biloxi, Keesler	90	80	Laconia	83	71				Eugene	86	66
AFB			Manchester,	85	72				Grants Pass	93	68
Clarksdale	92	78	Grenier AFB								