

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

A_{cfm} = actual volumetric flow rate of air-vapor mixture, m^3/h	kg_s = kilograms of dry air
ahp = air power, kW	kg_w = kilograms of water
AWB = ambient wet bulb temperature, $^{\circ}C$	L = water rate, $kg/(m^2 \cdot h)$
B = combined water loss through blowdown and windage, % of circulating water or m^3/h	L/G = liquid to gas ratio, kg/kg
CWT = cold water temperature, $^{\circ}C$	Q = m^3/h
DB = dry bulb temperature, $^{\circ}C$	PF = performance factor, dimensionless
E = water evaporated, % of circulating water or m^3/h	R = cooling tower range, $^{\circ}C$
G = air rate, $kg/(m^2 \cdot h)$	V = air velocity, m/h
h_a = specific enthalpy of dry air, kJ/kg	v_a = specific volume of dry air, m^3/kg
h_{as} = $h_s - h_a$, kJ/kg	v_{as} = $v_s - v_a$, m^3/kg
h_s = enthalpy of moist air at saturation per kg of dry air, kJ/kg	v_s = volume of moist air at saturation per kg of dry air, m^3/kg
HWT = hot water temperature, $^{\circ}C$	W_s = kg_w/kg_a , humidity ratio at saturation
	WB = wet bulb temperature, $^{\circ}C$

DEFINITIONS OF WORDS AND PHRASES USED IN COOLING TOWERS

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

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

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 kilograms of water per million kilograms 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 8°C 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 24°C and 100% relative humidity has a 24°C “wet-bulb” temperature. 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.

FIG. 11-2
Psychrometric Chart

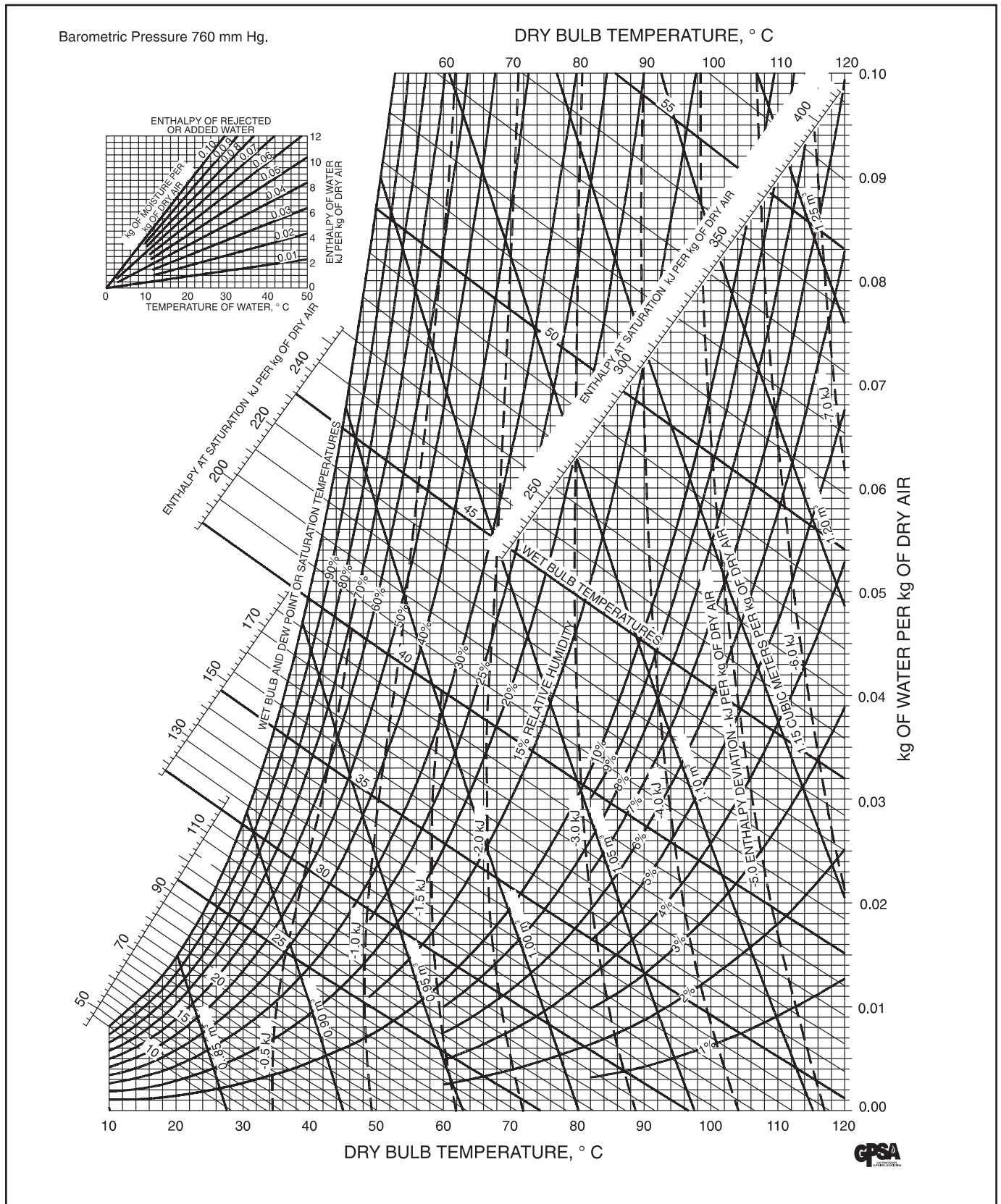


FIG. 11-3a
Dry Bulb/Wet Bulb Temperature Data²

U.S. State and Stations	Design Dry-Bulb °C 5%	Design Wet-Bulb °C 5%	U.S. State and Stations	Design Dry-Bulb °C 5%	Design Wet-Bulb °C 5%	U.S. State and Stations	Design Dry-Bulb °C 5%	Design Wet-Bulb °C 5%	U.S. State and Stations	Design Dry-Bulb °C 5%	Design Wet-Bulb °C 5%
ALABAMA			Petaluma	31	20	Sarasota	32	26	Hobart	29	23
Alexander City	33	26	Pomona	35	22	Tallahassee	32	26	Huntington	31	23
Anniston	33	26	Redding	38	20	Tampa	32	26	Indianapolis	31	24
Auburn	33	26	Redlands	36	22	West Palm Beach	32	26	Jeffersonville	32	24
Birmingham	33	24	Richmond	24	17	GEORGIA			Kokomo	31	23
Decatur	33	24	Riverside-March AFB	35	21	Albany,			Lafayette	31	24
Dothan	33	26	Sacramento	34	21	Turner AFB	34	26	La Porte	31	24
Florence	33	24	Salinas	19	15	Americus	33	25	Marion	31	23
Gadsden	33	24	San Bernardino,			Athens	32	24	Muncie	31	24
Huntsville	33	24	Norton AFB	36	22	Atlanta	32	24	Peru,		
Mobile AP	33	26	San Diego	26	20	Augusta	34	26	Bunker Hill AFB	30	23
Mobile CO	33	26	San Fernando	31	21	Brunswick	31	26	Richmond	31	24
Montgomery	34	26	San Francisco AP	23	17	Columbus,			Shelbyville	31	24
Selma-Craig	34	26	San Francisco CO	21	16	Lawson AFB	33	25	South Bend	30	23
Talladega	33	26	San Jose	25	18	Dalton	33	25	Terre Haute	32	24
Tuscaloosa	34	25	San Luis Obispo	29	21	Dublin	33	25	Valparaiso	31	24
ALASKA			Santa Ana	28	21	Gainesville	32	24	Vincennes	32	24
Anchorage	19	14	Santa Barbara	24	19	Griffin	31	24	IOWA		
Barrow	9	8	Santa Cruz	20	16	La Grange	32	24	Ames	31	24
Fairbanks	24	16	Santa Maria	23	17	Macon	33	25	Burlington	31	24
Juneau	19	14	Santa Monica	25	20	Marietta,			Cedar Rapids	30	24
Kodiak	17	13	Santa Paula	29	20	Dobbins AFB	32	24	Clinton	31	24
Nome	15	13	Santa Rosa	33	19	Moultrie	33	26	Council Bluffs	31	24
ARIZONA			Stockton	34	20	Rome	33	25	Des Moines	31	24
Douglas	34	20	Ukiah	33	19	Savannah-Travis	33	26	Dubuque	30	23
Flagstaff	27	15	Visalia	36	21	Valdosta-Moody AFB	33	26	Fort Dodge	30	23
Fort Huachuca	32	19	Yreka	32	18	Waycross	33	26	Iowa City	31	24
Kingman	36	21	Yuba City	37	20	HAWAII			Keokuk	32	24
Nogales	34	21	COLORADO			Hilo	28	23	Marshalltown	31	24
Phoenix	41	24	Alamosa	27	16	Honolulu	29	23	Mason City	29	23
Prescott	33	18	Boulder	32	17	Kaneohe Bay	28	24	Newton	31	24
Tucson	38	22	Colorado Springs	30	16	Wahiawa	29	23	Ottumwa	31	24
Winslow	34	18	Denver	32	17	IDAHO			Sioux City	32	24
Yuma	42	25	Durango	29	17	Boise	33	18	Waterloo	30	24
ARKANSAS			Fort Collins	32	17	Burley	33	16	KANSAS		
Blytheville	33	26	Grand Junction	33	17	Coeur d'Alene	28	16	Atchison	33	25
Camden	34	26	Greeley	33	17	Idaho Falls	29	16	Chanute	34	24
El Dorado	34	26	La Junta	35	21	Lewiston	32	18	Dodge City	35	22
Fayetteville	33	24	Leadville	26	12	Moscow	29	17	El Dorado	36	24
Fort Smith	35	26	Pueblo	33	18	Mountain Home AFB	34	17	Emporia	34	24
Hot Springs	34	26	Sterling	32	18	Pocatello	32	16	Garden City	34	22
Jonesboro	33	26	Trinidad	32	18	Twin Falls	33	16	Goodland	34	20
Little Rock	34	26	CONNECTICUT			ILLINOIS			Great Bend	35	24
Pine Bluff	35	27	Bridgeport	27	23	Aurora	31	24	Winchester	36	23
Texarkana	34	26	Hartford,			Belleville, Scott AFB	32	24	Liberal	34	22
CALIFORNIA			Brainard Field	29	23	Bloomington	31	24	Manhattan,		
Bakersfield	37	21	New Haven	28	23	Carbondale	32	25	Fort Riley	33	24
Barstow	39	21	New London	28	23	Champaign/Urbana	32	24	Parsons	34	24
Blythe	42	23	Norwalk	27	23	Chicago, Midway	31	23	Russell	35	24
Burbank	31	21	Norwich	28	23	Chicago, O'Hare	30	23	Salina	36	24
Chico	37	20	Waterbury	28	22	Chicago	31	24	Topeka	34	24
Concord	34	20	Windsor Locks,			Danville	31	24	Wichita	36	24
Covina	33	21	Bradley Field	29	23	Decatur	31	24	KENTUCKY		
Crescent City	17	15	DELAWARE			Dixon	31	24	Ashland	32	24
Downey	30	21	Dover AFB	31	24	Elgin	30	24	Bowling Green	32	24
El Cajon	26	20	Wilmington	31	24	Freeport	31	23	Corbin	32	24
El Centro	42	26	DISTRICT OF			Galesburg	31	24	Covington	31	23
Escondido	28	21	COLUMBIA			Greenville	32	24	Hopkinsville,		
Eureka/Arcata	17	15	Andrews AFB	31	24	Joliet	31	24	Campbell AFB	32	24
Fairfield-Travis AFB	33	19	Washington National	32	24	Kankakee	31	24	Lexington	31	24
Fresno	36	21	FLORIDA			La Salle/Peru	31	24	Louisville	32	24
Hamilton	27	19	Belle Glade	32	26	Macomb	32	24	Madisonville	32	25
Laguna Beach	25	20	Cape Kennedy	31	26	Moline	31	24	Owensboro	33	25
Livermore	34	20	Daytona Beach	31	26	Mt. Vernon	32	24	Paducah	33	25
Lompoc,			Fort Lauderdale	32	26	Peoria	31	24	LOUISIANA		
Vandenberg AFB	19	16	Fort Myers	33	26	Quincy	32	25	Alexandria	33	26
Long Beach	25	20	Fort Pierce	32	26	Rantoul,			Baton Rouge	33	26
Los Angeles AP	25	20	Gainesville	33	26	Chanute AFB	32	24	Bogalusa	33	26
Los Angeles CO	30	21	Jacksonville	33	26	Rockford	31	23	Houma	33	26
Merced-Castle AFB	36	21	Key West	32	26	Springfield	32	24	Lafayette	33	26
Modesto	35	21	Lakeland	32	26	Waukegan	31	24	Lake Charles	33	26
Monterey	20	16	Miami	32	26	INDIANA			Minden	34	26
Napa	33	20	Miami Beach	31	26	Anderson	32	24	Monroe	34	26
Needles	42	23	Ocala	33	26	Bedford	32	24	Natchitoches	34	26
Oakland	24	17	Orlando	33	26	Bloomington	32	24	New Orleans	32	26
Oceanside	25	20	Panama City,			Columbus,			Shreveport	34	26
Ontario	36	22	Tyndall AFB	32	26	Bakalar AFB	32	24	MAINE		
Oxnard	25	19	Pensacola	33	26	Crawfordsville	31	24	Augusta	28	21
Palmdale	37	19	St. Augustine	31	26	Evansville	33	25	Bangor, Dow AFB	27	21
Palm Springs	42	23	St. Petersburg	32	26	Fort Wayne	31	23	Caribou	26	19
Pasadena	33	21	Sanford	33	26	Goshen	30	23	Lewiston	28	21

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

U.S. State and Stations	Design Dry-Bulb °C 5%	Design Wet-Bulb °C 5%	U.S. State and Stations	Design Dry-Bulb °C 5%	Design Wet-Bulb °C 5%	U.S. State and Stations	Design Dry-Bulb °C 5%	Design Wet-Bulb °C 5%	U.S. State and Stations	Design Dry-Bulb °C 5%	Design Wet-Bulb °C 5%
Millinocket	27	20	Farmington	32	24	Artesia	36	21	Minot	30	20
Portland	27	21	Hannibal	32	25	Carlsbad	36	21	Williston	29	20
Waterville	27	21	Jefferson City	33	24	Clovis	33	19	OHIO		
MARYLAND			Joplin	34	24	Farmington	33	18	Akron-Canton	29	22
Baltimore AP	32	24	Kansas City	34	24	Gallup	30	16	Ashtabula	28	22
Baltimore CO	31	24	Kirksville	32	24	Grants	29	16	Athens	32	23
Cumberland	31	24	Mexico	33	24	Hobbs	36	21	Bowling Green	30	23
Frederick	31	24	Moberly	33	24	Las Cruces	34	19	Cambridge	31	24
Hagerstown	32	24	Poplar Bluff	33	26	Los Alamos	29	16	Chillicothe	32	23
Salisbury	31	24	Rolla	32	24	Raton	31	17	Cincinnati	31	23
MASSACHUSETTS			St. Joseph	33	25	Roswell	36	21	Cleveland	30	23
Boston	29	22	St. Louis AP	33	24	Walker AFB			Columbus	31	23
Clinton	29	22	St. Louis CO	33	24	Santa Fe	30	16	Dayton	30	23
Fall River	27	22	Sedalia	32	24	Silver City	33	17	Defiance	31	23
Framingham	28	22	Whiteman AFB			Socorro	34	18	Findlay	31	23
Gloucester	28	22	Sikeston	33	25	Tucumcari	35	20	Fremont	29	23
Greenfield	28	22	Springfield	33	24	NEW YORK			Hamilton	31	23
Lawrence	29	23	MONTANA			Albany AP	29	22	Lancaster	31	23
Lowell	29	23	Billings	31	18	Albany CO	29	22	Lima	31	23
New Bedford	27	22	Bozeman	29	16	Auburn	29	22	Mansfield	29	23
Pittsfield	27	21	Butte	27	14	Batavia	29	22	Marion	31	23
Springfield			Cut Bank	28	16	Binghamton	27	21	Middletown	31	23
Westover AFB	29	22	Glasgow	29	18	Buffalo	28	22	Newark	32	23
Taunton	28	23	Glendive	32	18	Cortland	28	22	Norwalk	29	23
Worcester	27	21	Great Falls	29	16	Dunkirk	28	22	Portsmouth	32	24
MICHIGAN			Havre	31	18	Elmira	28	22	Sandusky	31	23
Adrian	29	23	Helena	29	16	Geneva	29	22	Springfield	31	23
Alpena	28	21	Kalispell	29	17	Glen Falls	28	22	Steubenville	29	22
Battle Creek	29	23	Lewiston	28	17	Gloversville	28	22	Toledo	29	23
Benton Harbor	29	22	Livingston	29	16	Hornell	28	22	Warren	29	22
Detroit	30	23	Miles City	33	19	Ithaca	28	22	Wooster	29	22
Escanaba	27	21	Missoula	29	17	Jamestown	28	22	Youngstown	29	22
Flint	29	22	NEBRASKA			Kingston	29	23	Zanesville	31	24
Grand Rapids	29	22	Beatrice	33	24	Lockport	29	23	OKLAHOMA		
Holland	28	22	Chadron	33	20	Massena	27	21	Ada	35	24
Jackson	29	23	Columbus	33	24	Newburg			Altus AFB	37	24
Kalamazoo	29	23	Fremont	33	24	Stewart AFB	29	23	Ardmore	35	24
Lansing	29	22	Grand Island	33	23	NYC-Central Park	31	23	Bartlesville	35	24
Marquette	25	20	Hastings	33	23	NYC-Kennedy AP	29	23	Chickasha	35	24
Mt. Pleasant	29	22	Kearney	32	22	NYC-LaGuardia AP	31	23	Enid-Vance AFB	36	24
Muskegon	28	22	Lincoln	33	24	Niagara Falls	29	23	Lawton	36	24
Pontiac	29	23	McCook	33	22	Olean	27	22	McAlester	34	24
Port Huron	28	23	Norfolk	32	24	Oneonta	27	21	Muskogee	35	25
Saginaw	29	22	North Platte	32	22	Oswego	27	22	Norman	34	24
Sault St. Marie	25	20	Omaha	31	24	Plattsburg AFB	27	21	Oklahoma City	35	24
Traverse City	28	22	Scottsbluff	32	19	Poughkeepsie	30	23	Ponca City	34	24
Ypsilanti	30	22	Sidney	32	19	Rochester	29	22	Seminole	34	24
MINNESOTA			NEVADA			Rome-Griffiss AFB	28	22	Stillwater	34	24
Albert Lea	29	23	Carson City	32	16	Schenectady	29	22	Tulsa	35	25
Alexandria	29	22	Elko	32	16	Suffolk County AFB	27	23	Woodward	34	24
Bemidji	27	21	Ely	29	14	Syracuse	29	22	OREGON		
Brainerd	29	22	Las Vegas	40	21	Utica	28	22	Albany	30	19
Duluth	26	20	Lovelock	34	18	Watertown	27	22	Astoria	20	17
Fairbault	29	23	Reno AP	32	16	NORTH CAROLINA			Baker	30	16
Fergus Falls	29	22	Reno CO	33	16	Asheville	29	22	Bend	29	16
International Falls	27	20	Tonopah	32	16	Charlotte	33	24	Corvallis	30	19
Mankato	29	23	Winnemucca	33	16	Durham	32	24	Eugene	30	19
Minneapolis/St. Paul	30	23	NEW HAMPSHIRE			Elizabeth City	32	26	Grants Pass	34	20
Rochester	29	23	Berlin	27	21	Fayetteville	32	25	Klamath Falls	29	16
St. Cloud	29	22	Claremont	28	22	Pope AFB			Medford	33	19
Virginia	27	20	Concord	29	22	Goldsboro, Seymour-	32	25	Pendleton	32	17
Willmar	29	22	Keene	28	22	Johnson AFB			Portland AP	27	19
Winona	29	23	Laconia	28	22	Greensboro	32	24	Portland CO	28	19
MISSISSIPPI			Manchester			Greenville	32	25	Roseburg	31	19
Biloxi, Keesler AFB	32	27	Grenier AFB	29	22	Henderson	32	25	Salem	29	19
Clarksdale	33	26	Portsmouth			Hickory	31	23	The Dalles	29	19
Columbus AFB	33	26	Pease AFB	28	22	Jacksonville	31	26	PENNSYLVANIA		
Greenville AFB	33	26	NEW JERSEY			Lumberton	32	25	Allentown	30	23
Greenwood	33	26	Atlantic City	30	24	New Bern	31	26	Altoona	29	22
Hattiesburg	33	26	Long Branch	31	24	Raleigh/Durham	32	24	Butler	29	23
Jackson	34	26	Newark	31	24	Rocky Mount	32	25	Chambersburg	31	24
Laurel	33	26	New Brunswick	30	24	Wilmington	32	26	Erie	28	22
McComb	33	26	Paterson	31	24	Winston-Salem	32	23	Harrisburg	31	24
Meridian	34	26	Phillipsburg	30	23	NORTH DAKOTA			Johnstown	27	21
Natchez	33	26	Trenton	29	24	Bismark	31	21	Lancaster	31	24
Tupelo	33	26	Vineland	30	24	Devil's Lake	29	21	Meadville	28	22
Vicksburg	34	26	NEW MEXICO			Dickinson	31	20	New Castle	30	23
MISSOURI			Alamogordo			Fargo	29	22	Philadelphia	31	24
Cape Girardeau	33	25	Holloman AFB	34	19	Grand Forks	29	21	Pittsburgh AP	29	22
Columbia	33	24	Albuquerque	33	18	Jamestown	31	22	Pittsburgh CO	30	22