Example 2. It is desired to cool 150,000 lb of water per hour (about 100 tons of mechanical refrigeration) from 110 to 84 F with 125,000 lb of dry air per hour, with a design wet-bulb air temperature of 75 F. These conditions could prevail with a steam-turbine driven centrifugal refrigeration compressor. Determine the *Tower Performance Factor*; show in tabular form the successive steps for this mechanical integration by selecting two-degree intervals of the water-temperature range.

Solution. The accompanying Table 5 shows the sequence of mechanical integration for the given water and air temperatures. The first column shows the water temperature θ in increments of two degrees ($\Delta\theta = 2$ F deg). Column 2 gives the enthalpies of the saturated air-vapor mixture at the water temperature, Btu per pound of dry air. The enthalpy of air, h_a in column 3, has an original value of 38.61 Btu per lb corresponding to the 75 F entering wet-bulb temperature of the ambient air; this value of h_a increases in equal increments of 1.2 $\left(\frac{L}{G}\text{ratio}\right)$ Btu per F deg, hence, $\Delta h = \Delta\theta \times \frac{L}{G} = 2 \times \frac{150{,}000\text{ lb}}{125{,}000\text{ lb}} = 2.4$. The potential for mass heat transfer is $(h'' - h_a)$ as shown in column 4; this is frequently called the tower driving force potential. The values in column 5 for each increment are determined by dividing 2.4 Btu per F deg by the average value of $(h'' - h_a)$; and column 6 is calculated in a similar manner, except that the increments are two degrees instead of 2.4 Btu.

TABLE 5. SEQUENCE OF MECHANICAL INTEGRATION TOWER PERFORMANCE FACTOR

1 Water Temp. θ	2 Enthalpy of Film h''	3 Enthalpy of Air h_a	4 Enthalpy Difference $(h'' - h_a)$	5 $\frac{\Delta h}{(h'' - h_a)}$ (avg.)	6 $\frac{\Delta\theta}{(h'' - h_a)}$ (avg.)
84	48.22	38.61	9.61	0.249	0.208
86	50.66	41.01	9.65	0.247	0.206
88	53.23	43.41	9.82	0.241	0.201
90	55.93	45.81	10.12	0.232	0.194
92	58.78	48.21	10.57	0.221	0.184
94	61.77	50.61	11.16	0.208	0.173
96	64.92	53.01	11.91	0.194	0.162
98	68.23	55.41	12.82	0.180	0.150
100	71.73	57.81	13.92	0.165	0.137
102	75.42	60.21	15.21	0.150	0.125
104	79.31	62.61	16.70	0.137	0.114
106	83.42	65.01	18.41	0.124	0.103
108	87.76	67.41	20.35	0.112	0.093
110	92.34	69.81	22.53		
				Tower Performance Factor = 2.460	or 2.050

Hence, the mechanical integration for the above conditions gives two results:

$$\frac{KaV}{G} = \sum \frac{dh}{h'' - h_a} = 2.46, \textit{ Tower Performance Factor}$$

and

$$\frac{KaV}{L} = \sum \frac{d\theta}{h'' - h_a} = 2.05, \textit{ Tower Performance Factor}$$

The results obtained in Example 2 are designated as the *Tower Performance Factor* (*TPF*) or the *Number of Tower Units* (*NTU*); these figures represent correlated values that are directly proportional to the performance being considered. Similar calculations could be made for other quantities and temperatures of air and water. It should be noted that this factor is not related to the equipment doing the cooling, that any numerical value may represent an infinite number of possible performance conditions, and that any cooling tower arrangement may give almost any performance under certain conditions. Also the mechanical integration

procedure used above applies only to counterflow apparatus. However, the same principles may be applied to crossflow atmospheric water-cooling towers, although the method is more involved.

The basic mathematical theory for water-cooling towers is now well established and recognized, but each manufacturer relies upon experimental results and practical experience with his own tower designs to establish a system for rating each unit that he builds. The problem of cooling tower design or selection is based on a knowledge of the characteristics of the equipment being considered. The *Tower Performance Factor* is a variable which is a function of the design; it also varies with the water loading and air velocity. Experimental data indicate that it varies with the heat load, although this variation may be due to deviations from the theoretical calculations which become more pronounced at the higher temperatures. The reference literature contains *Tower Performance Factors* which have been reported by various investigators, but the reader should be warned that the use of such factors, without a full understanding of the source, may lead to erroneous results.

SELECTION OF WATER-COOLING TOWERS

The correct type and size of water-cooling equipment for a given service cannot be determined intelligently without considering the characteristics of the various types, together with the many correlated requirement factors. Very few installations are exactly alike in details of requirements, hence, conditions affecting performance and operation of the several types of water-cooling equipment vary widely because of the many diversified applications and wide-spread geographical locations.

Before the characteristics of a specific water-cooling apparatus can be judged desirable or undesirable for a given heat load and wet-bulb temperature, a survey should consider the importance of each of the following items: first cost including all necessary auxiliaries, area, height, weight, effect of wind velocity and direction, rigidity of structure to withstand high winds, safety, conformity to building codes, drift nuisance, make-up water requirements and cost of chemical treatment if needed, total power for pumping (plus fan operation in the case of mechanical draft), maintenance, available locations (with due thought to possible future expansion, wind restrictions, space cost, proximity and accessibility, etc.), appearance, the equipment's operating flexibility for the most economical conformance to varying loads or seasonal changes, and other considerations occurring with regard to a specific application.

For a definite heat-load dissipation, the type and size of a water-cooling tower is primarily affected by the following conditions:

1. Gallons per minute of cooling water.
2. Geographical location of the tower installation.
3. Wet-bulb design temperature of ambient air (see Table 3, Chapter 12).
4. Temperature of the hot water entering the tower at normal rating.
5. Temperature of the cold water leaving the tower at normal rating.
6. Ground, roof, or sub-structure installation.
7. Area available for cooling tower.
8. Proximity to other structures.
9. Surface of water exposed to each unit quantity of air.
10. Time of contact of the air with the water; this depends upon height (or length) of tower, and upon the relative velocity of air and water.