

REFERENCES

- ¹ William Thomson: On the economy of heating and cooling of buildings by means of currents of air (*Glasgow Phil. Soc. Proc.*, Vol. 3, December 1852).
- ² T. G. N. Haldane: The heat pump—an economical method of producing low-grade heat from electricity (*Journal of Institution of Electrical Engineers*, London, June 1930).
- ³ A. R. Stevenson, Jr.: Refrigeration (*Journal Franklin Institute*, Vol. 208, August 1929).
- ⁴ Philip Sporn and D. W. McLennan: An all electric heating cooling and air conditioning system (ASHVE JOURNAL SECTION, Heating, Piping and Air Conditioning, August 1935).
- ⁵ Experience with a reversed-cycle heating system (*Power*, August 1941).
- ⁶ Philip Sporn, E. R. Ambrose, and Theodore Bannister: *Heat Pumps* (John Wiley & Sons, New York, 1947).
- ⁷ E. N. Kemler and Sabert Oglesby, Jr.: *Heat Pump Applications* (McGraw-Hill Book Co., New York, 1950).
- ⁸ Bibliography of the Heat Pump through 1951 (*Edison Electric Institute Publication No. 53-4*).
- ⁹ Heat Pump Bibliography (compiled by Southern Research Institute for Southeastern Electric Exchange).
- ¹⁰ Philip Sporn: Electric Heating and Year-Round Air Conditioning and the Heat Pump (*Edison Electric Institute Bulletin*, May 1955).
- ¹¹ J. D. Kroeker and R. C. Chewning: Heat pump in an office building (ASHVE TRANSACTIONS, Vol. 54, 1948, p. 221).
- ¹² J. D. Kroeker, J. H. Bonebrake, and J. A. Melvin: Heat pump application to a newspaper plant (ASHVE TRANSACTIONS, Vol. 57, 1951, p. 467).
- ¹³ Philip Sporn and E. R. Ambrose: Two-year performance of a heat pump system furnishing year-round air conditioning in modern office building (ASHVE TRANSACTIONS, Vol. 57, 1951, p. 483).
- ¹⁴ J. D. Kroeker and R. C. Chewning: Costs of operating the heat pump in the Equitable building (ASHVE TRANSACTIONS, Vol. 60, 1954, p. 157).
- ¹⁵ E. G. Heller and H. C. Weingartner: Methods of frozen juice concentration (*Refrigerating Engineering*, July 1950, p. 673).
- ¹⁶ T. F. Thomas: The air cycle heat pump (*Engineer*, August 22, 1947, p. 180; August 29, 1947, p. 205).
- ¹⁷ W. F. Friend: Future electronic, solar, and nuclear developments (ASHAE TRANSACTIONS, Vol. 62, 1956, p. 563).
- ¹⁸ W. F. Stoecker: How frost formation on coils affect refrigeration systems (*Refrigerating Engineering*, February 1957, p. 42).
- ¹⁹ Heat Pump Electricity Usages and Other Operating Characteristics as Experienced under Various Weather Conditions (*Southern Research Institute Report No. 2371-288-SVIII*, July 22, 1955).
- ²⁰ L. R. Ingersoll and H. J. Plasa: Theory of the ground pipe heat source for the heat pump (ASHVE TRANSACTIONS, Vol. 54, 1948, p. 339).
- ²¹ E. W. Guernsey, P. L. Beta, and N. H. Skau: Earth as a heat source or storage medium for the heat pump (ASHVE TRANSACTIONS, Vol. 55, 1949, p. 321).
- ²² A. B. Algren: Ground temperatures as affected by weather conditions (ASHVE TRANSACTIONS, Vol. 55, 1949, p. 363).
- ²³ G. S. Smith and Thomas Yamanchi: Thermal conductivity of soils for design of heat pump installations (ASHVE TRANSACTIONS, Vol. 56, 1950, p. 365).
- ²⁴ L. R. Ingersoll, T. T. Adler, H. J. Plasa, and A. C. Ingersoll: Theory of earth heat exchangers for the heat pump (ASHVE TRANSACTIONS, Vol. 57, 1951, p. 167).

- ²⁵ G. S. Smith: Factors useful in ground grid design for heat pumps (ASHVE TRANSACTIONS, Vol. 57, 1951, p. 189).
- ²⁶ Merl Baker: Design and performance of a residential earth heat pump (ASHVE TRANSACTIONS, Vol. 59, 1953, p. 371).
- ²⁷ W. A. Hadley and Raymond Eisenstadt: Moisture movement in soils due to temperature difference (ASHVE TRANSACTIONS, Vol. 59, 1953, p. 395).
- ²⁸ G. S. Smith: Intermittent ground grids for heat pumps (ASHAE TRANSACTIONS, Vol. 63, 1956, p. 473).
- ²⁹ W. A. Hadley: Operating Characteristics of Heat Pump Ground Coils (*Edison Electric Institute Bulletin*, Vol. 17, December 1949, p. 457).
- ³⁰ Joint AEIC-EIE Heat Pump Committee: Research Results Concerning Earth as a Heat Source or Sink (*Edison Electric Institute Bulletin*, September 1953).
- ³¹ D. M. Vestal and B. J. Fluker: Earth as heat source and sink for heat pumps (ASHAE TRANSACTIONS, Vol. 63, 1957, p. 41).
- ³² D. M. Vestal, Jr. and B. J. Fluker: A Proposed Procedure for the Design of a Heat Pump Buried Coil (*Texas A & M Bulletin*).
- ³³ R. C. Jordan and J. L. Threlkeld: Availability and utilization of solar energy (ASHVE TRANSACTIONS, Vol. 60, 1954, p. 177).
- ³⁴ Philip Sporn and E. R. Ambrose: The heat pump and solar energy (Association for Applied Solar Energy, *Proceedings World Symposium on Applied Solar Energy*, November 1955).
- ³⁵ C. P. Davies, Jr. and R. I. Lipper: Sun energy assistance for air-type heat pumps (ASHAE TRANSACTIONS, Vol. 64, 1958).
- ³⁶ F. H. Bridges, D. D. Paxton, and R. W. Haines: Performance of a solar heated office building (ASHAE TRANSACTIONS, Vol. 64, 1958).
- ³⁷ F. R. Ellenberger, A. B. Hubbard, W. R. Foote, F. Burggraf, and J. J. Martin, Jr.: Evaluating heat pump performance (ASHVE TRANSACTIONS, Vol. 56, 1950, p. 37).
- ³⁸ U. S. Weather Bureau Forms E-1-D, E-4-D, E-6-D (U. S. Department of Commerce).
- ³⁹ Alfred Koestel and G. L. Tuve: Performance and evaluation of room air distribution systems (ASHAE TRANSACTIONS, Vol. 61, 1955, p. 533).
- ⁴⁰ Philip Sporn and E. R. Ambrose: Heat pump system using water storage (*Mechanical Engineering*, Vol. 69, November 1947, p. 699).
- ⁴¹ Philip Sporn and E. R. Ambrose: The heat pump, an all-electric year-round air conditioning system (*Heating and Ventilating*, January 1944, p. 68).
- ⁴² T. L. Elherington: A dynamic heat storage system (ASHAE TRANSACTIONS, Vol. 64, 1958).

BIBLIOGRAPHY

- W. E. Johnson: Economic and technical aspects of the heat pump (ASHVE TRANSACTIONS, Vol. 54, 1948, p. 201).
- J. D. Kroeker, R. C. Chewning, and C. E. Graham: Heat pump results in Equitable building (ASHVE TRANSACTIONS, Vol. 55, 1949, p. 345).
- J. F. Sandfort: Thermodynamic criteria for heat pump performance (ASHVE TRANSACTIONS, Vol. 55, 1949, p. 363).
- G. S. Smith: Climatology as an aid in heat pump design (ASHVE TRANSACTIONS, Vol. 57, 1951, p. 499).
- C. F. Kayan: Electrical analoguer application to the heat pump process (ASHVE TRANSACTIONS, Vol. 59, 1953, p. 361).
- Applied Solar Energy Research (Stanford Research Institute, 1955—contains numerous heat pump references).
- Heat Pump Data Sheets on Residential and Commercial Installations (*Edison Electric Institute Publication No. 56-12*).

CHAPTER 40

EVAPORATIVE APPARATUS FOR HEAT REJECTION

Water Cooling Methods, Water Use and Conservation, Rivers and Lakes, Spray Ponds, Atmospheric and Mechanical Draft Towers, Cooling Tower Theory, Design Conditions, Selection and Evaluation, Tower Location, Operation and Maintenance, Evaporative Condensers

REFRIGERATING systems and many other industrial processes generate heat that must be removed and dissipated. Small quantities of heat can be rejected directly to the atmosphere by convection and radiation. When large quantities are involved, the most effective procedure is to transfer the heat to cooling water flowing through a heat exchanger.¹ The water, if cheap and plentiful, may be wasted to a sewer or open waterway such as a stream or lake. The source of the cooling water may be wells, a public water system, or a lake or river.

WATER COOLING METHODS

Water Use and Conservation

The rapidly expanding demand for water is depleting what was once looked upon as an inexhaustible natural resource. The water table is receding in most localities. Communities are finding their present water systems inadequate to supply the increasing demands of domestic and industrial users. Heavy industrialization along flowing streams causes pollution. The temperature of the water that may be discharged into the stream is frequently limited in order to protect wild life. Many cities do not have adequate sanitary or storm sewers to handle cooling water. As a result of the increasing demand and the lack of an adequate supply or disposal system, users are being forced to conserve water by using recirculating systems. Heat must be removed from the circulating water by some type of water cooling apparatus.

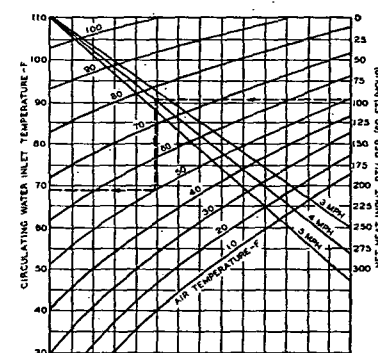
Rivers and Lakes

Plants located on flowing streams can use a once-through system, discharging the heated water downstream from the intake to prevent mixing. Intake screens and sometimes settling basins, are needed to remove debris. The intake structure must be designed to handle flow conditions varying from flood stage to the minimum flow during periods of drought. The operation can be hampered during cold weather by ice clogging of the intake or by ice jams restricting the flow of the stream. Since water treatment is seldom economical, scale and corrosion may be a problem. Intermittent chlorination may be used, however, to control the growth of slime and algae on heat exchanger surfaces. If the stream temperature becomes too high, it may be necessary to cool the effluent before discharging it into the stream.

Lakes or ponds may also be used as a source of cooling water.² The water temperature in lakes or streams tends to follow the average dry-bulb temperature of the surrounding

air. The temperature gradient of a lake will vary with the season of the year. Applying a heat load will raise the average water temperature and decrease the temperature gradient from the surface to the bottom although stratification will remain. The cold water intake should, logically, be located as far below the surface of the water as practicable, and remote from the hot water return to prevent bypassing. Dikes or piers have been built into lakes to prevent bypassing where cold water intakes are adjacent to hot water returns, but they offer little advantage unless they extend into a lake for a distance of at least 300 ft.

Warm water discharged near the surface spreads out as a thin film. The temperature near the surface of a cooling pond will average about 4 F deg above the bottom temperature. A suction pipe located at the bottom of the pond will not withdraw water at the temperature of the lowest stratum. A hydraulic gradient is set up which withdraws water from all strata, and the intake temperature will be about 2 F deg below the surface temperature. The heat dissipation is a function of wind velocity and the temperature difference between water surface and the dry-bulb temperature. Fig. 1 is a typical performance chart for lake cooling, with wind velocity measured 5 ft above water level. Throne³ has developed additional charts for other conditions. The heat dissipation of a



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Fig. 1 Performance Chart for Lake Cooling