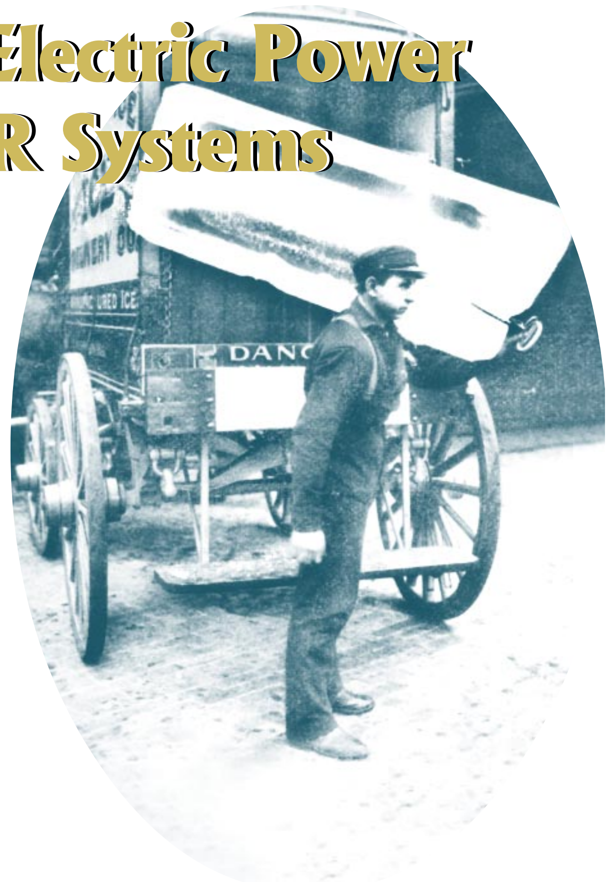
From Blocks of Pond Ice to Hermetic Motors

Application of Electric Power In HVAC&R Systems



The First Century of Air Conditioning

This is the second article in our special series. As we approach the year 2000, these articles commemorate a century of innovation in the HVAC&R arts and sciences and salute the start of a new millennium, which will undoubtedly bring further progress.

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Prior to the late 1800s, rotating shaft power was limited mainly to trains and ships. There were wind and water mills for pumping water and grinding grains and some steam-driven water pumps and ventilation fans. However, few people lived in windy regions or near fast-moving streams. Some ventilation fan designs for mine shafts were powered by man, wind or water pressure.

Early Refrigeration

Refrigeration was provided by ice from frozen ponds and rivers in the more northern climates. This ice was harvested and stored in winter and then sold during warmer weather. Ice trade became a major industry in the United States. Frederic Tudor of Boston started shipping ice to warmer climates in 1815. He became known in 1864 as the "Ice King of the World," and Boston ice was shipped to every major seaport in South America, the Far East, China, the Philippines, India and Australia.[1]

As pollution around the cities increased, particularly in the form of sewage run-off, the market emerged for artificial ice. Use of steam boilers to drive the thermodynamic process cycle and produce ice was growing rapidly. Daniel L. Holden and J. Andrew Muhl built and operated mechanical refrigeration plants in 1865 and 1867 in San Antonio, Texas. Holden designed improvements to the Carré absorption units of Paris, which made San Antonio in 1867 and New Orleans in 1869 the southern regional leaders in making artificial ice[2] (see *Figure 1*).

The areas that could harvest "natural" ice tried to convince people that the "artificial" ice was somehow unnatural and to be avoided. But the areas that were producing manufactured ice were able to convince people that "natural" ice was contaminated. As costs came into line with the natural ice costs, producers of artificial ice were able to make significant inroads into the northern monopoly on ice.[3]

Ice delivery was hard work. Imagine lugging around a 300 to 400 lb (140 to 180 kg) block of ice on your shoulder like the young man above![4] By 1909, ice was produced in approximately 2,000 refrigeration plants.[5]

Heating: From Stoves to Steam

Heating was provided by wood-burning fireplaces, which were later replaced with cast-iron radiant stoves that burned wood and/or coal. As cities became more populated, fire control became much more important. Fireproof construction was mandated by some city codes after several large and costly fires destroyed central districts.

Steam boilers became a standard for heating buildings. Central district steam plants that sold steam to buildings were de-

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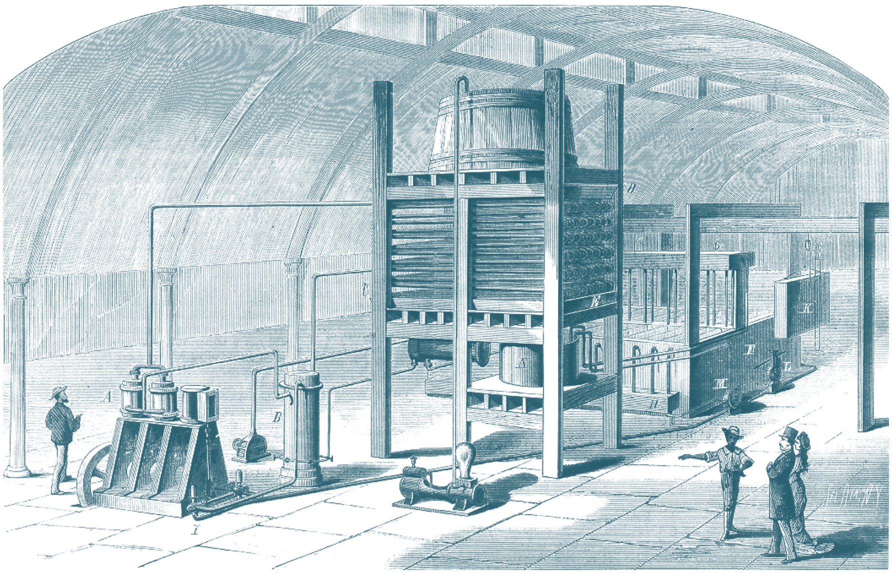

Figure 1: Holden's improved ice plant. The structure in the center is a condenser with a "zig-zag" heat exchanger (from **Scientific American,** *May 22, 1880, p. 322).*

veloped. The steam boilers were large and expensive to operate and required supervision and maintenance. Coal-handling bunkers and stokers also constituted a portion of the overhead.

As steam-driven engines developed as a reliable means of rotating shaft power and heat sources, they began to be used as the power source for refrigeration and ventilation systems (see *Figure 2*). Of the steam engines used for this purpose in 1914, more than 90% exceeded 15 million calories/hour (63 MJ).

Facilities that had a large steam boiler used the steam to provide for ventilation with large, low rpm centrifugal fans because they could convert the steam to rotary shaft work. Smaller, steam-driven piston engines were developed for the purchasers of central district steam to convert steam to rotary shaft horsepower for all manner of equipment (see *Figure 3*).

Wood- and coal-burning steam-driven vehicles were developed in the late 1890s. An experienced operator could achieve sustained vehicle movement or sustained rotation of the steam-driven power take-off wheel from a cold start after about 1 ½ to 2 hours of hard work. The engines were quite powerful, but they weighed several tons. The Stanley Steamer automobile was fairly impressive in appearance, size and speed.

Early Ventilation

In other areas, ventilation was almost non-existent. Natural ventilation was controlled by the building orientation and placement of windows to catch the prevailing breezes. High ceilings and large, open central staircases with ventilated domes provided some assistance to gravity and Mother Nature. Ventilation did not truly take off until after the mid-1880s, when the use of steam and electricity had spread. An exception was a kerosene-powered fan sold by the Whirlwind Fan Company. The sales slogan for this unit boasted, "It will give you greater efficiency and enable you to do more and better work."

The electrical industry was growing rapidly. New patents and ideas for residential electrical appliances were being advertised as the best or most natural way of life. The world was rather unsophisticated and uneducated, but some of the biggest changes to affect humankind were taking place. The development of steam and electric-powered equipment surged ahead due to better understanding of electrical, mechanical and thermodynamic principles.

Direct or Alternating Current?

The competition between direct current (DC) and alternating current (AC) was fierce. Thomas Edison was a prime proponent of DC power because of his involvement in the design and marketing of direct current lighting, power distribution and motors. He felt that AC power was only good for electrocutions. DC power did provide a flicker-free light and could vary the speed of a motor by varying the voltage. Its major drawback, however, was its inability to transmit via wire over long distances.

George Westinghouse, Jr. was the principal proponent of AC power. The flicker problem with incandescent lighting was resolved by using more cycles per sec-

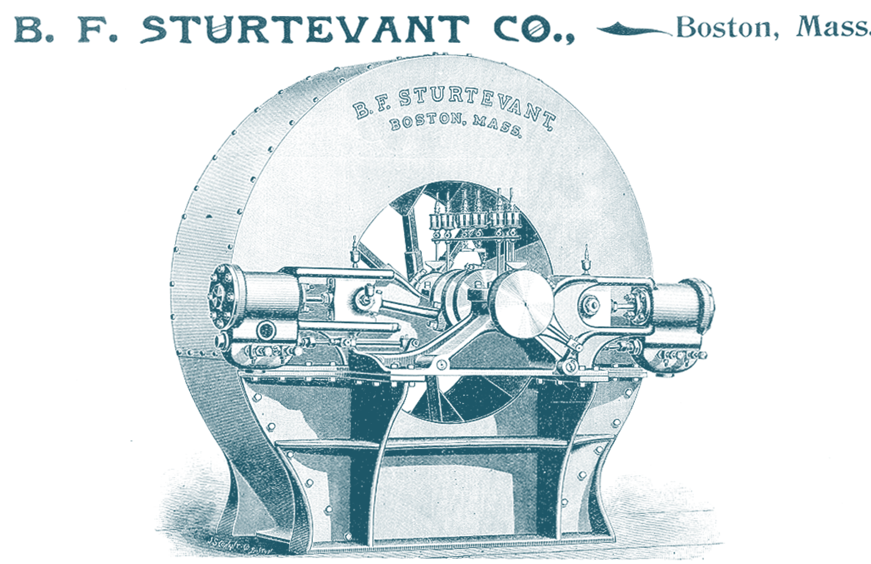

Figure 2: Early steam fan from B. F. Sturtevant Co. **(from Heating and Ventilation, June 1895, p. xvii).**

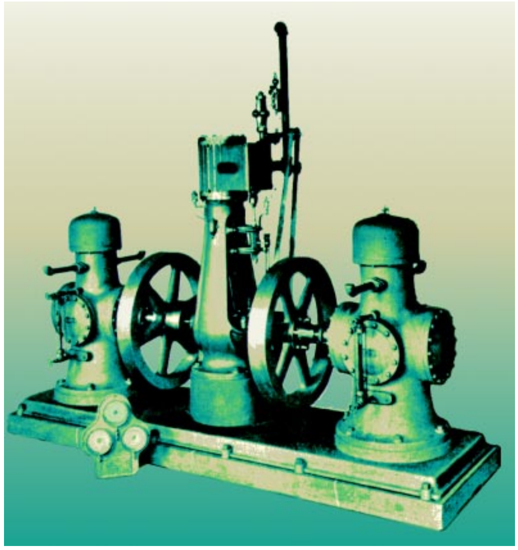

Figure 3: Two single-acting duplex compressors and steam engine direct connected (from the Victor Ice and Refrigerating Machines, 1899. Stilwell-Bierce & Smith-Vaile Co., Dayton, Ohio).

ond, ranging from 133½ to 25 cycles per second.[6] The various voltages and cycles for AC power transmission were being tested, and the ones that worked best were retained.

By 1914, most frequencies above 60 cycles per second had been abandoned, but it took another 20 to 25 years for 60 cycles per second power to become the standard in the United States. Some other countries settled on 50 cycles per second.

Generally, the only electrical load of a central power generator plant was the street lighting at night in the central business district. Some single-phase, induction-type motors with brushes and commutators became popular, especially among small industries in suburban towns.

Use of small electric fans, curling irons, irons for laundry, washing machines and hair dryers increased the use of electric power, particularly during the idle daytime period when the generators were under-utilized.[7,8] This trend has reversed in the present day. Modern utility companies now offer premiums to shift the daytime power consumption to evening hours because their generating capacity is underutilized at night.

Single-phase induction and synchronous motors for AC power were popular with the public (see *Figure 4*). To properly start synchronous motors, however, required experience.[9] The power utility companies liked the synchronous motors because they could be operated with a 1.0 or higher leading power factor to help correct the lagging power factor of the utility distribution system.[10] Automatic starters were developed later. Because it was difficult to control the motor speed, almost all the applications used belt-drive connections to drive the machinery.

Advances in Motor Technology

The physicist and inventor Nikola Tesla began working on AC electrical designs as a college student in Croatia during the 1870s. At this time, it was thought impossible to construct a motor without a commutator. Tesla worked as a telephone engineer before quitting to develop in his mind a complete alternating current power system with generators, transformers and motors. He then took a job as an electrical engineer, but no one was interested in his seemingly incredible ideas. He developed working models of generators and motors while on a long-term assignment in Strasbourg, then part of Germany. Tesla moved to the United States in 1887, at age 31, where he filed for 25 patents covering virtually the entire field of alternating current generation, distribution and polyphase, brushless induction AC motors. Shortly after, he sold his patents to George Westinghouse, who implemented widespread use of alternating current.[11]

Prior to 1891, there had been no demonstration of electrical transmission of any considerable amount of power over any considerable distance. A demonstration of the capability to transmit 100 hp (75 kW) of AC electricity a distance of 106 miles (171 km) from Lauffen to Frankfurt in Germany was staged in 1891 for a technical exhibition. The wye-connected, three-phase generators were wound for 55 volts and driven by hydraulic turbines. A transformer increased the voltage to approximately 30,000 volts.

The three copper conductors were only 4 mm (0.16 in.) in diameter each. The incoming power was stepped-down to drive a 60-hp (45-kW), four-pole polyphase induction motor at a speed of 1,200 rpm and supplied power for incandescent lights and some other small motors.[12]

The AC polyphase motor became more popular. The HVAC&R industry was able to capitalize on its popularity as the

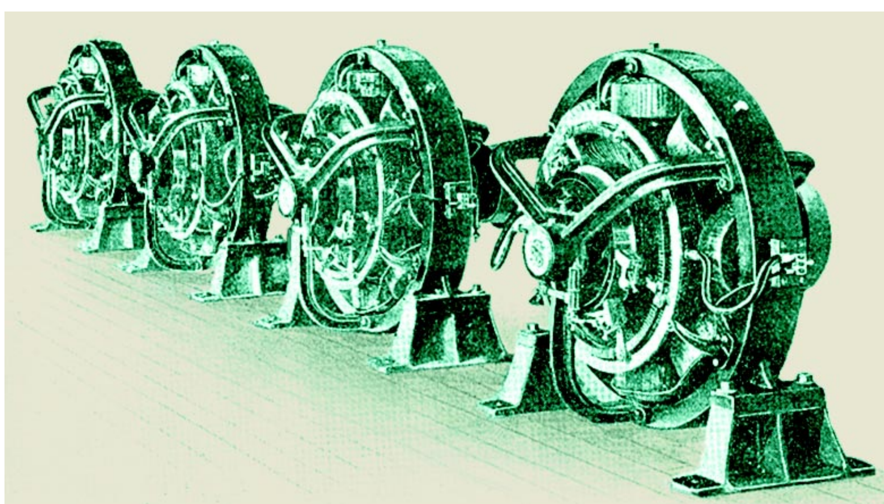

Figure 4: Precursor to open drip-proof motors (from **Engineering Review,** *Feb. 1902, p. xxi).*

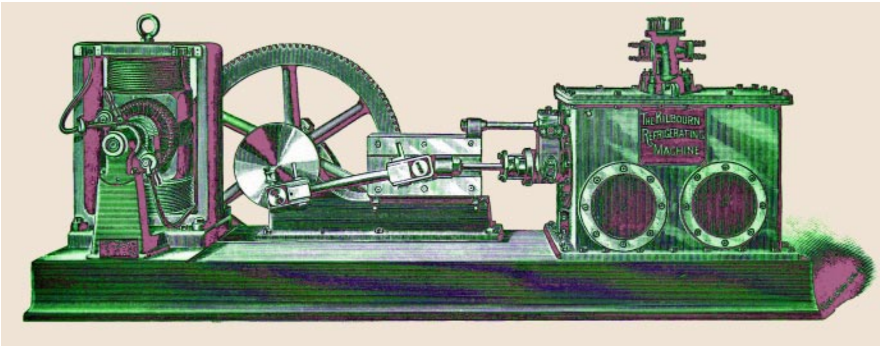

Figure 5: Early electric-drive refrigeration compressor (from* Ice and Refrigeration, *Aug. 1895, p. 88).

polyphase motor spread to small, commercial applications. Electric power costs in 1897 averaged about $0.10/kWh.[13] The price dropped to approximately $0.03/kWh in 1950 and is now approaching $0.10/kWh again.

Fans and pumps continued to be direct-drive with several available rpm configurations. By 1925, the electric motor was the preferred method of drive, providing 62%, vs. 32% for steam engine drives, while diesel and gas engines were used 4% and 2% of the time, respectively.[3] As refrigeration systems that were powered by electrical motors became available (see *Figure 5*) and the electrical infrastructure developed, the use of natural and artificial ice for refrigerating effect was discontinued. This was a welcome development for merchants and consumers who had suffered the messiness of the ice refrigeration systems.[14] The *Ice Refrigeration Blue Book* listed 100 different refrigeration equipment options in 1909, which increased to more than 260 in 1911.[15]

The use of hermetic motors evolved in the early 1930s, driven by the competition between General Electric, Frigidaire, Servel and Westinghouse to capture the greatest portion of the emerging home refrigerator market and the expanding commercial refrigeration market. Westinghouse applied a variant of the hermetic refrigeration compressor to air conditioning by making a console-style room air conditioner in 1933.[16]

Conclusion

Comfort air conditioning has expanded from the wealthy residential and upscale commercial establishments to become a virtual necessity in contemporary times. It is possible in many areas to go from an air-conditioned home to an air-conditioned office in an air-conditioned car without experiencing more than a few moments of discomfort from the ambient outdoor temperature and humidity. And modern refrigerators require no one to carry hundreds of pounds of ice up rickety ladders propped precariously against the side of a building.

From* Ice and Refrigeration, *Aug. 1905, p. 55.

References

1. Donaldson, B. and B. Nagengast, eds. 1994. *Heat & Cold—Mastering the Great Indoors,* 22, 23; 45–64; 65–160; 189–243. ASHRAE.

2. “Steam versus electrically driven plants.” Aug. 1925. *Ice and Refrigeration,* 115.

3. “Prime movers for ice making and refrigerating plants.” Aug. 1925. *Ice and Refrigeration,* 115.

4. From *Ice and Refrigeration,* 81. April 1905.

5. Tweedy, E. 1913. “Mechanical refrigeration and ice making from a central station point of view.” *General Electric Review* (16)8:584–593.

6. *A Century of Electric Fans,* 22–34. 1957. General Electric.

7. “Refrigeration at the electrical show.” 1908. *Ice and Refrigeration* (34):32.

8. Kimball, F. 1907. “The utility of the single phase motor.” *General Electric Review* 9(6):243–244.

9. Hibbard, T. 1925. *Refrigerating Engineer Review* 11(11):392–398.

10. Newbury, F. and P. Alger. 1934. “The development of electrical machinery in the United States, Part II: transformers and motors.” *General Electric Review* 35(4):455–464.

11. Nagengast. B. 1982–83. *Pioneers in Electrical Research,* 1–2. ASHRAE Research Pamphlet.

12. *Some Events in the Early Days of the Polyphase Induction Motor.* General Electric Historical Film Script, 42–49.

13. Thornton, F. *Electrical Home Appliances—100 Years.* National Electrical Manufacturers Association Engineering Bulletin #45.

14. Goddard, G. Jan. 1908. “Motor-driven refrigeration machines.” *Ice and Refrigeration,* 11.

15. “Electrical refrigeration in the ice cream business.” May 25, 1912. *Electrical Review and Western Electrician* 60(21):983–987.

16. Nagengast, B. 1998. “History of sealed refrigeration systems, Part 3.” *ASHRAE Journal* 40(1): 43–47.