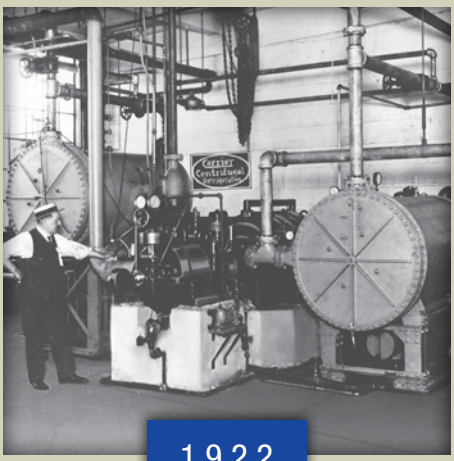
COMMEMORATING 100 YEARS OF

WILLIS CARRIER'S INVENTION OF CENTRIFUGAL CHILLER TECHNOLOGY

MAKING MODERN LIFE POSSIBLE



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THE IMPACT OF CENTRIFUGAL CHILLER TECHNOLOGY HAS SPANNED A CENTURY, AFFECTING BUILDINGS, INDUSTRIES AND COUNTLESS ASPECTS OF LIFE

Across the Globe.

This is the story of how Willis Carrier's invention of the centrifugal chiller fundamentally changed the way we live, work, learn and play. And how the dedicated employees of the global company that bears his name, Carrier, have continuously advanced the technology to deliver more sustainable, reliable and efficient cooling for both comfort and industrial processes.

Making Modern Life Possible: The Centrifugal Chiller Turns 100

In June 1920, Willis Haviland Carrier authored "Development Possibilities for Improvement in Refrigeration," a confidential memo he sent to a handful of his colleagues. The document described a novel machine and refrigerant that might significantly advance traditional "process air conditioning" used in factory production. His idea also had the potential to create an enormous new category, "comfort air," meant to cool the occupants of theaters, stores, ships and office buildings.

Carrier laid out a plan to develop this new machine. But his first important task, he told colleagues, was to go on vacation.

A Vision of Centrifugal Chilling

Already renowned for his 1911 "Rational Psychrometric Formulae," Carrier had become frustrated over the decade by the slow advance of refrigeration technology. Inspired by the application of centrifugal motors in heating and electrical generation, he envisioned in his 1920 memo "a centrifugal compressor combined with [a] compact shell-and-tube heat transfer surface."

RATIONAL PSYCHROMETRIC FORMULAE

The refrigerant for this device, he said, must be non-toxic and non-flammable, have a high molecular weight to minimize the cost of the compressor, and have a boiling point around 110°F (43.3°C) to reduce pressures.

Willis Carrier's *Rational Psychrometric Formulae* brought science to what had been the often hit-or-miss design of air-conditioning systems, in the process making Carrier an international name. The chart would be updated and reprinted regularly, serving as an essential tool to generations of engineers.

Disappointed by the tepid response among manufacturers in the United States, Carrier took his working "vacation" in Europe to visit engineers who might help him piece together this puzzle. He was delighted to find that German chemists had developed a dielene (dichloroethylene, $C_2H_2Cl_2$) for use as a cleaning fluid that met the needs of his refrigerant.

Carrier also found an economical and reliable centrifugal compressor manufactured by the C. H. Jaeger Company of Leipzig. The compressor would require adaptions "entirely foreign to the usual conception of centrifugal machinery," Carrier wrote. These included the perfect sealing between the housing and the shaft without the use of packing whether the machine was in operation or shut down; the successful evaporation of a refrigerant having a low vapor pressure with small temperature head available for efficient operation; the handling of a gas with low pressure difference; the successful operation of an enclosed lubricating system; and the doing away with expansion values and multitudinous joints.

Carrier believed these challenges were matters of mechanical design and invention, work that would result in 20 patents filed between 1921 and 1929.

In practical terms, the centrifugal chiller would be more affordable and deliver the same capacity as traditional ammonia systems while requiring about 25% of the footprint. Unlike ammonia, the combination of dielene with centrifugal compression would make safe and reliable air conditioning available wherever people congregated.

In retrospect, Carrier's invention of the centrifugal chiller was an inflection point in the history of modern air conditioning, the first significant advance in refrigeration since the original ammonia compressor of 1872. Not only would comfort air sweep the world in the next century, but traditional process air would also be transformed.

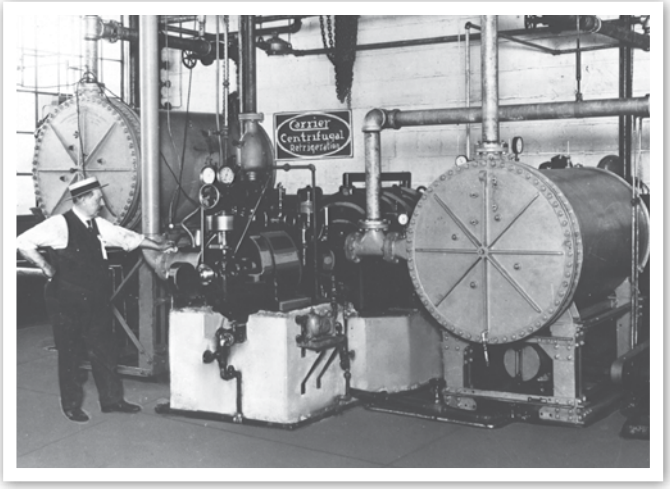
"Carrier's idea to combine a centrifugal refrigeration compressor with a shell-and-tube type condenser and chiller in a package on one frame," wrote engineer-historian Bernard Nagengast, "was revolutionary in its time."

In a world before cool, everyone suffered. Retailers saw their patrons disappear during the hot summer months. Ticket sales slumped in movie theaters. Office workers, shoppers, travelers, and patients in hospitals all sweltered. Variations in heat and humidity plagued factory production. Willis Carrier revolutionized the world of manufacturing with the invention of modern air conditioning in 1902. Twenty years later, he led a second revolution when he unveiled centrifugal chilling, a product that not only enhanced process cooling, but ushered in the era of comfort cooling and made modern life possible.

A Combination of Complementary Innovations

On the evening of May 22, 1922, some 300 people, primarily members of the New York sections of the American Society of Refrigerating Engineers and American Society of Heating and Ventilating Engineers, were invited to a dressed-up sheet metal shop in Newark, New Jersey, for a free meal and boxing match followed by the unveiling of the first centrifugal chiller unit. “After a few brief speeches, the big doors were rolled back and there was the number one machine, perking along under a fair load,” engineer and attendee Logan Lewis recalled, “running at the almost unheard of speed of 3500 rpm.”

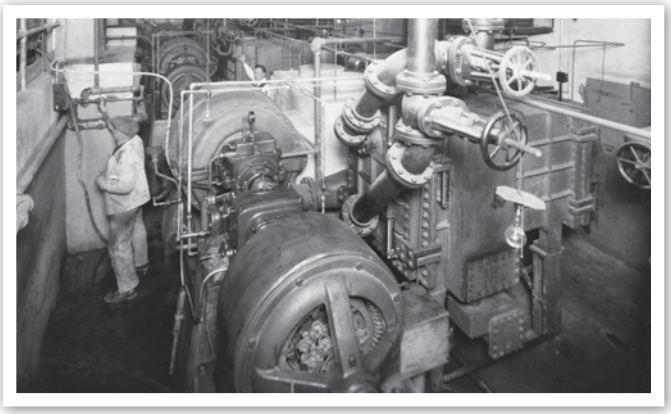
The most pressing issue plaguing the early chillers arose during their shutdown when oil became impregnated with dielene. Upon startup, Lewis wrote, the dielene “would foam violently. Failures in oil pressure would follow and seal after seal burned out.” Getting the new chiller to market, like most revolutionary innovations, required a village. “Success would have been impossible,” Lewis added, “without the great devotion to duty shown by dozens of men ranging from mechanics in [the] field or shop and on up through the organization.”



Shown in the Carrier plant in 1922, the centrifugal chiller prototype that made its debut in Newark would cool the factory of Onondaga Pottery Company in Syracuse, New York, for decades before moving to its permanent home at the Smithsonian in 1964. Its groundbreaking design would open the door to large-scale comfort air conditioning around the world.

Along with hard work and growing expertise, two complementary innovations bolstered the early success of the centrifugal chiller. The “by-pass system,” which mixed conditioned air with air that had “bypassed” the air washer, reduced refrigeration capacity and the need for a heater. This invention was coupled with a novel “down-draft” system that used trumpet-shaped ceiling distributors to gently diffuse cool air over a wide area, replacing the traditional “mushroom” registers that froze the feet of theatergoers.

The first customer installation of centrifugal chilling was in 1923, helping to cool Stephen F. Whitman & Sons’ candy plant in Philadelphia. The chiller that had made its debut before a 1922 dinner audience in Newark was placed at Onondaga Pottery Company in Syracuse in 1924. Forty years later, this iconic machine was displayed at the Smithsonian Institution in Washington, D.C., where it resides permanently.



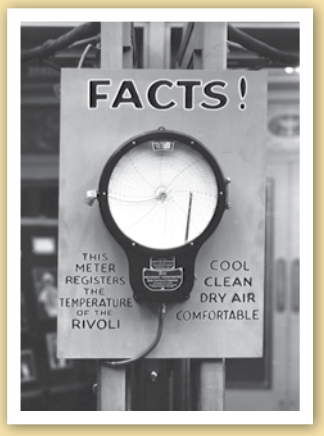
Three 75-ton compressors at the Stephen F. Whitman & Sons’ candy plant in Philadelphia, Pennsylvania, became the first installation of Carrier’s historic centrifugal chiller. Success led to the rapid adoption of centrifugal chilling by the confectionery industry. Important customers included W. F. Schrafft and Sons, American Chicle Co., Beechnut Packing Co., Luden, Inc. and Wm. Wrigley Jr. Co.

Continuous Innovation, Dramatic Growth

As the centrifugal chiller matured, it climbed two different but equally steep growth curves. The first was in the development of comfort air applications.

In 1923, J. L. Hudson's Department Store addressed the oppressive heat of summertime shopping by adding seven centrifugal chillers with a combined refrigerating capacity of 1,700 tons. By 1929, centrifugal chillers were also cooling shoppers at Kern's Department Store in Detroit, Bon Marché in Seattle, Wm. Filene & Sons Co. in Boston, and a half-dozen other locations, including R. H. Macy, Inc. in Manhattan.

In movie theaters, the comfort air revolution came on Memorial Day 1925 at the Rivoli Theatre in Manhattan, where a combination of dielene and centrifugal chilling, by-pass and down-draft systems magically cooled a grateful audience. "It has now been demonstrated that the hotter the weather here," the *Rivoli Times* reported on July 1, 1925, "the more people attend the Rivoli." This marquee installation repaid its $100,000 installation cost in three months.



Carrier's centrifugal chiller brought comfort air to delighted moviegoers at the Rivoli Theatre in New York City on Memorial Day 1925. The adoption of centrifugal chilling by theaters around the country introduced the general public to comfort air, created new demand for summer movie entertainment, and improved the fortunes of Hollywood and the theater industry.

The Milam Building was the first high-rise office building to have comfort air installed from basement to roof at its opening in 1928. Some of the original centrifugal chilling equipment remained in use until 1990.

In 1926, the T.W. Patterson Building in Fresno, California, installed a comfort air system throughout six of its floors. Eighteen months later, the 21-story Milam Building in San Antonio, Texas, became the first high-rise office building to have central air conditioning installed during construction. A rule of thumb emerged over the next generation: whenever 20% of the office buildings in a city offered air conditioning, all others were forced to upgrade to remain competitive. New York City and Philadelphia would reach this threshold by about 1953.

By 1937, the air-conditioning industry's gross revenue had climbed to $90 million. Fortune magazine reported that air conditioning "has broken into office buildings, hotels, homes. It is almost taken for granted on Pullman cars. Ships, government buildings, hospitals have come to use it."

Arthur D. Little's *Industrial Bulletin* called air conditioning the "lustiest and liveliest of the present-day infant industries," having been installed "in the Senate Chamber and House of Representatives; the White House executive offices; the ape-house of The Bronx Zoo; Atlantic City's convention hall; the London Daily Mail; the Secretariate in Delhi, India; Manhattan's RCA Building; San Francisco's Stock Exchanges." Without the centrifugal chiller, none of this success would have been possible.

Thanks to continuous innovation, process air kept pace with this dramatic growth in comfort air. Textile mill output had shown substantial increases, Carrier told an audience at the Conference of Air Conditioning and Automatic Heat at the University of Wisconsin. New synthetics such as rayon were "wholly dependent" on air conditioning. Process air permitted factories to be built in any climate and operated in any season, he added, allowing companies to exploit geographic advantage.

In less than a decade, centrifugal refrigeration had driven process air into more than 200 industries. Its versatility was demonstrated during World War II when Tiffany & Co., Macy's, Sears, Roebuck & Co., Marshall Field's, and other department stores sacrificed their installations to the war effort. Nearly 7,000 tons of comfort air conditioning were relocated to support process air installations at manufacturers such as B.F. Goodrich in Texas and Pratt & Whitney in Kansas City.

Going Global

The global community embraced centrifugal chilling after WWII. The Reid Rubber Mills of Auckland, New Zealand, acquired a centrifugal refrigeration machine for use in chilling water for processing rubber. India installed centrifugal chillers in three new rayon plants, Puerto Rico in a "modern, windowless textile mill," Mexico in a cracker factory, El Salvador in a brewery, and Venezuela in a confectionary plant. Two of the largest centrifugal refrigeration machines built to that time were placed at Polymer Corporation Ltd. in Ontario, Canada, while centrifugal chillers were installed at the Laboratori Palma in Rome to help control temperatures for the production of penicillin and streptomycin.

In 1934, engineers redesigned the centrifugal chiller to use new refrigerants, permitting capabilities as low as minus 100°F (minus 73.3°C) and opening up fields such as meatpacking and industrial process work.

Comfort air kept pace with this extraordinary innovation and growth. In 1931, Japan's *Koan Maru* became the first merchant ship to be fully air conditioned. In 1934, the first apartments in Buenos Aires were comfort cooled, followed by the Chittar Palace in India in 1936, Egypt's Hall of Parliament in 1937, and City Hall in Oslo, Norway, in 1939.

By the mid-1930s, centrifugal chilling had also begun to improve the lives of patients and healthcare workers, from cooling hospitals and clinics in Mexico, Cairo and today's Pakistan, to supporting the recovery of cancer patients in New York City.

By the end of 1940, after thousands of U.S. and international guests had experienced comfort cooling for the first time in Carrier's igloo at the New York World's Fair, the company sold its 1,000th centrifugal chiller.

In 1955, the centrifugal chiller met the future when two 163-ton machines were installed at the Bell System exchange in Canada to cool sensitive relay switches. By providing precise temperature and humidity, centrifugal chillers would one day support the infrastructure of the modern digital age, including electronics of every type, semiconductor chips, data centers and robotics.

In 1960, the Federal Aviation Agency ordered a centrifugal chiller installed in the new Dulles International Airport terminal building. This installation required half the footprint and delivered 15 times the cooling capacity of the first centrifugal chiller placed at Onondaga Pottery Company.

By 1964, the combined capacity of all centrifugal chillers produced since 1922 totaled almost 5 million tons, or enough capacity to air condition 2 million single-family homes. And demand had accelerated, with more than 90% produced since WWII. Meanwhile, the machine installed in the J. L. Hudson Store in Detroit completed its 40th year of reliable service.

This 1960 photograph displays two Carrier centrifugal chillers, 38 years and 5,000 machines apart. The world's first would soon be displayed in the permanent collections of the Smithsonian Institution in Washington, D.C. Carrier's 5,000th centrifugal chiller was destined for the new Dulles International Airport. By 1980, Carrier had manufactured 40,000 centrifugal chillers. Today, centrifugal chilling is a multibillion dollar global industry and still growing.

Evolving the Essential

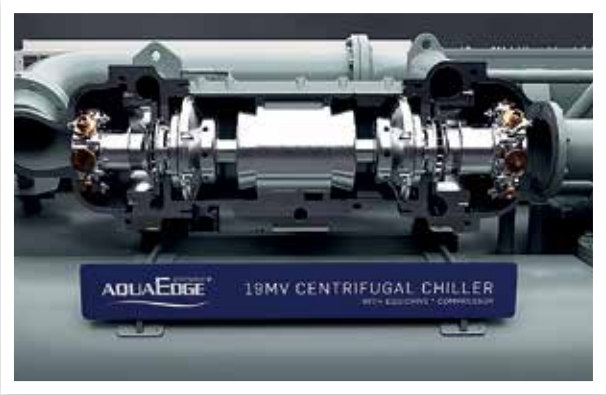
The centrifugal chiller became a workhorse of comfort and process applications worldwide. While its fundamental physics have not changed in a century, the chiller's major components have been adapted and improved over time by a legion of innovative Carrier engineers.

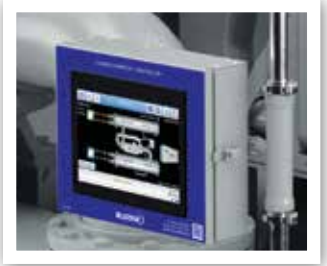
For example, motors driving the chiller's compressor have evolved from induction to permanent magnet and drives from open to semi-hermetic. Aerodynamic components have been optimized for new refrigerants and improvements in operating range. Bearing technology has progressed from traditional oiled journal and roller bearings to magnetic and ceramic.
Tubes for the heat exchanger, typically made from copper (though other materials are used such as a copper-nickel mix and titanium), were initially manufactured to be smooth on both the inside (water side) and outside (refrigerant side). Over time, significant research and development has resulted in mechanical enhancements on both sides, sometimes on the microscopic level, to substantially increase heat transfer capability while improving efficiency and cost.

Starters have changed from styles such as across the line, wye-delta and solid state to the modern variable frequency drive (VFD) that allows the speed to vary, substantially improving efficiency and operating range. Controls have evolved from simple analog gauges to full-color, graphical displays with software that can determine the optimal operating conditions, and to AI that can diagnose potential machine service issues well before a catastrophic event occurs. These functions link to a central building management system that can be accessed remotely.

Some of the most significant improvements to the centrifugal chiller have been in its refrigerant. From dielene and Carrene (methylene chloride), the industry moved to chlorofluorocarbons (CFCs), all eventually banned by the Montreal Protocol, to hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs), and now to advanced refrigerants such as hydrofluoroolefins (HFOs). This transition has steadily shifted refrigerants away from chlorine and toward materials with lower global warming potential (GWP).

Carrier's proven EquiDrive™ two-stage back-to-back compressor technology – which increases pressure with each of its two impellers – provides more operating range and efficiency at design conditions.





Connected touch-screen control panels allow for easier operation, tracking and analysis of operational data.

Carrying Chiller Technology Into The Future

Carrier once again took centrifugal chiller technology to a new level with its AquaEdge® 19DV and 19MV chillers, introduced in 2018 and 2021 respectively. Each utilizes EquiDrive two-stage back-to-back compressor technology which substantially improves efficiency and operating range. The 19DV specifically offers unique energy-saving options such as free cooling and heat recovery all while operating with ultra-low GWP R-1234zd(E).

At the same time, digital enablement is having a tremendous impact on the industry and on professionals' ability to design and maintain their equipment and cooling systems with confidence. Today, advanced software tools like Carrier's PLV Pro™ provide consulting engineers with detailed energy analyses that can help them make objective and informed decisions when it comes to chiller selection. And with solutions like the BluEdge® service platform and the SmartVu™ control panel, facility engineers and building owners can use intuitive, connected technology to improve the way they monitor and interact with their HVAC equipment.

Through these enhancements to equipment, software and service, Carrier continues to inspire confidence in centrifugal chiller technology to empower customers to create healthy, safe, sustainable and intelligent indoor environments.

The Carrier Commercial Service team developed a chiller modernization solution for the One Court Square Tower in Long Island City, New York, that incorporates innovation in every aspect of its design including compression, heat exchange and controls technology, enabling improved cooling efficiency.

The AquaEdge 19DV claims several global awards for innovation in cooling and heating technology as well as achievements in environmental sustainability.

BUILDINGS MONEY-SAVING PRODUCTS WINNER

engineer 2019 PRODUCT OF THE YEAR Gold

AWARDS 2019 WINNER

SINGAPORE ENVIRONMENTAL ACHIEVEMENT AWARDS

2019 MENA Green Building AWARDS WINNER

KBC COOLING INDUSTRY AWARDS 19 WINNER

H&V news AWARDS 2020 WINNER

Making Modern Life Possible

In the last century, few venues have been untouched by Willis Carrier's invention of centrifugal chiller technology, from skyscrapers to apartment buildings, hotels to hospitals, airports and cruise lines to subway stations, and sporting venues to museums. Likewise, centrifugal chilling has made life more comfortable and productive from the deserts of Las Vegas and Dubai to the tropics of Florida and Singapore. And, centrifugal chillers have made possible countless manufacturing processes that improve all facets of our lives, from medicines, automotive products, plastics, chemicals, textiles and mining applications, to many aspects of our modern digital age, including electronics, semiconductor chips and data centers.

What began as a memo drafted by an engineer frustrated by the pace of change, the centrifugal chiller is today celebrating a century of innovation and evolution. Launched in 1922, the product has grown into a multibillion dollar industry that supports global health and productivity, making modern life possible.

On the same day in 1950 that Carrier Corporation completed its 2,000th centrifugal chiller, Willis H. Carrier, chairman emeritus, visited the Onondaga Pottery Company in Syracuse, New York, to inspect his first centrifugal chiller, completed in 1922. The Chief found it in perfect working condition. This picture is thought to be among the last taken of Carrier.

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This booklet is an overview of the 100th Anniversary of Willis Carrier's invention of centrifugal chilling technology. The historic information contained in this booklet, including any description of events, people, and historical content, is based on sources believed to be reliable and accurate. This historical review was compiled from a collection of personal narratives and correspondence, newspaper and magazine archives, trade publications, company annual reports and archives, books and verbal interviews. To the best of our knowledge of all parties involved in the information gathering, all content was accurate at the time of press. Carrier does not accept liability for any new information contrary to that contained in this publication.

Carrier

CENTRIFUGAL CHILLERS

INVENTED 1922

100 years

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