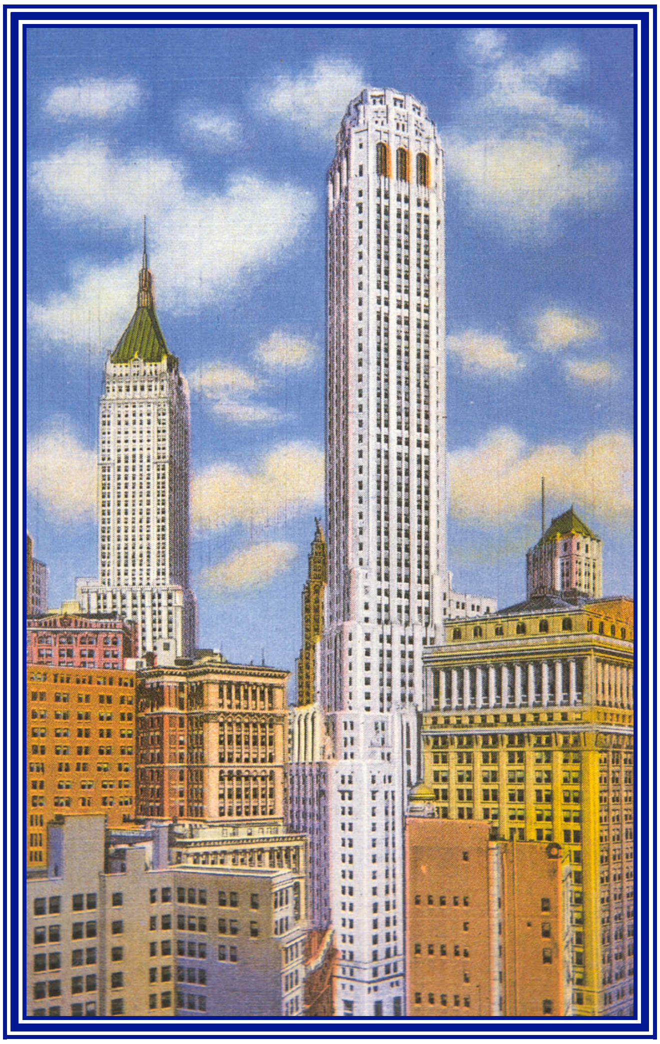

*City Bank Farmers Trust, New York, 1931.*

# The Story of Comfort Air Conditioning

## Part-2 The Air Conditioned Building, 1900-1939

### Text Section

### Part-2

# The Air Conditioned Building
# 1900-1939

**On one trip in the late fall of 1902, Carrier had to wait for a train in Pittsburgh. It was evening, the temperature was in the low thirties, and the railway platform was wrapped in a dense fog. As Carrier paced back and forth, waiting for his train, he began thinking about fog. As he thought he got the "flash of genius," as patent experts put it, that eventually resulted in "dew-point control," which became the fundamental concept of the entire air conditioning industry.**
*"Willis Haviland Carrier: Father of Air Conditioning," Margaret Ingels, 1952.*

## 2.1 Assorted Beginnings

Around the turn of the century ventilation the need for adequate supplies of fresh air were preoccupations of heating and ventilating engineers in the United States. As a result mechanical ventilation had been introduced into a number of the new larger and taller buildings. At a meeting in 1899 of the fledgling American Society of Heating and Ventilating Engineers (ASHVE founded in 1894) the author of a paper, "Some Points Regarding the Ventilation and the Heating of Tall Buildings"[1] described the mechanical ventilation systems then in use. Some systems relied solely on exhaust ducts and extract fans with natural inlets. Others had supply (blast) fans with natural exhaust. One plant, considered novel at the time, in Buffalo NY used the ventilation plant to entirely heat and ventilate the building without the use of radiators. A Sturtevant Company catalogue[2] of 1906 shows just such an arrangement used for the offices of the American Bell Telephone Company in Boston **[2.1]**. Another suggestion was that an ideal solution for such systems would be to have "double ducts", one hot and one cold. An early example, also shown in the Sturtevant catalogue, is the double-duct installation with mixing dampers **[2.2]** installed at Boston's Agassiz School.

Air conditioning was in its infancy and nearly all installations were for industrial and manufacturing applications. With a few exceptions comfort air conditioning was not to get under way until about 1920. For example, a book[3] issued by Carrier Engineering Corporation in 1919, refers to "Manufactured Weather" for textile mills and bakeries; for the manufacture of such diverse products as chocolate, rubber, chewing gum, aircraft, mattresses, car engines, rifles, electric insulators, explosives, paper, soap, pharmaceuticals; and for colour printing, laboratories and tobacco processing. By comparison, the comfort applications shown are for a motion-picture theatre, the Lord & Taylor department store in New York, a hotel dining room, and a hospital premature baby unit in Pittsburgh.

An article[4] written by the Editor of *Refrigerating Engineering* in 1934 recalled the state of that industry in 1904, the year of the founding of the American Society of Refrigerating Engineers (ASRE):

> *"The chief applications were ice making, brewing, meat packing and cold storage.*
> *In the domestic and commercial uses of refrigeration, and in air conditioning, most of what we have done now has come along since 1904 -though not all of it.....*
> *(Now) alphabetically, the leading application is to air conditioning or comfort cooling. This was not unknown, and by no means unthought-of in 1904, but aside from one or two installations for comfort, and a few more for the keeping of valuable records and manuscripts,the art was unheard of in actual practice."*

Meanwhile, Great Britain had seen the founding of The Institution of Heating & Ventilating Engineers (IHVE) in 1897, but cooling did not feature in their *Proceedings* until a first paper[5] in 1923, while the first article[6] on air conditioning was not presented until 1926. As in the United States, the first air conditioning was for industrial applications. Then came the cinemas, the public rooms of some hotels and a few restaurants. Office block air conditioning had to wait until after the Second World War, though in 1925 an attempt had been made to provide cooling at Bush House in the Aldwych, London[7] which was fitted with an embedded piping system for heating:

> *"Cold water was circulated in the heating piping with fairly satisfactory results. The system*
> *is somewhat unusual in design, which accounts for whatever success was attained. Instead of using standard radiators, grids of 1/2-in (12 mm) piping were built into the walls, just below the surface. This prevented the accumulation of frost on the coils and any discomfort that may have resulted. The first experiments were conducted from the city mains. This, however, was not cold enough, so water from Artesian wells was tried. This produced better results, but not what was desired. The next step was to cool the water by placing ice in the tank. The temperature immediately dropped from 84$^o$ (29$^o$ C) to 72$^o$ F (22$^o$ C )."*

It took until the 1920s for the comfort air conditioning industry took to become established in the United States.[8] In the preceding period installations were made for the public rooms of a number of hotels, some restaurants, a few department stores and a miscellaneous assortment of other buildings. The comfort industry was eventually launched by the demands of cinema owners and the film-going public. Movie theatres rapidly became the most important "comfort" market, until by 1938 an estimated 15,000 of the 16,251 theatres in operation were equipped with air conditioning.[9] Further impetus to the growth of comfort cooling and conditioning was due to the pioneering designs of Alfred Wolff[10], by the development of psychrometrics in 1911 and other advances[11,12] by Willis Carrier (The Father of Air Conditioning), by the development of direct-expansion washer systems and $CO_2$ refrigeration by Frederick Wittenmeier[13] from 1911, and by the introduction of the centrifugal refrigerating machine **[2.3, 2.4]**, also by Carrier[14,15,16] in 1922. The centrifugal machine was a major step forward: [8]

> *"The new chiller combined with the spray-type cooling and dehumidifying system proved to be.......a reliable and lower cost key to large air conditioning systems. This new use and improvement of existing technology allowed one company (Carrier) to greatly expand the application of air conditioning. The competitive threat also goaded other companies to improve their own equipment and designs, with the consumer being the ultimate winner."*

The later work of Carrier was crucial to the expansion of the comfort market. From 1927 he developed the Conduit Weathermaster (induction unit) system[11] specifically for the air conditioning of skyscraper offices, filing his first patent in 1939.

## 1901 Scranton High School, Pennsylvania

In June 1901, the Board of Directors of Scranton High School urgently sought a means of keeping the evening audience in their auditorium at a comfortable temperature. The auditorium was 80 x 80 x 20 ft high (about 24 x 24 x 6 m), with a seating capacity of 900, but often filled with up to 1400 persons. As reported by the designer John J Harris, [17] an ice rack system **[2.5]** was devised:

> *"Time being short, the only resource left was by the use of ice. A rack was constructed in the fresh air inlet large enough to hold about 8 tons (tonnes) of ice......at 6 o' clock in the evening the ice was placed in the rack and staggered in such a way that the air was compelled to pass around and between the cakes of ice until discharged by the fan through the flues into the auditorium above, to mingle with the sultry atmosphere: tempering, diffusing and maintaining a temperature that was most invigorating."*

The fans delivered 12,800 $ft^3$/min (6 $m^3$/s) and required the melting of some 5600 lb/h (2450 kg/h) of ice, calculated by Harris as equivalent to 85 TR (300 kW). At a discussion on the paper it was stated that in June 1902, when the outside temperature was 90$^o$F (32 $^o$C), the inside was kept at 72$^o$F (21$^o$C) with some 1600 people in the auditorium, and that adding 5% of salt to the ice helped in lowering the temperature and reducing the melting of the ice. A further comment was: *"It seems to me that it is good deal easier to design an apparatus that will cool a room, than it is to design a school board that will pay the bill."*

## 1903 Stock Exchange, New York

Although the design by Willis Carrier for the Sackett-Wilhelms Lithographing and Printing Works in Brooklyn, installed in 1902, has been described[18] as *"the first scientifically engineered air conditioning system"* (an industrial application), it has recently been revealed that it was not a success, [19] though the reasons for this appear to be more to do with lack of funds rather than anything else. Like the Sackett-Wilhelms installation, that for the Stock Exchange [G B Post, 1903] was scientifically designed, but was much larger and operated satisfactorily for some twenty years.[10,19,20]

The designer was Alfred Wolff, who with Henry Torrance Jr. a well respected refrigeration engineer, devised a mechanical cooling system for the trading area, known as the Board Room **[2.6]**. He used four high-pressure steam boilers to feed three steam-engine driven dc generators of 750 kW. Exhaust steam from the generator engines, supplemented by live steam, provided winter heating using a mix of direct and indirect radiation. In summer, steam powered three absorption refrigerating brine chillers with a total cooling capacity of 450 TR (1580 kW); *"chilled brine (was) stored in a subterranean tank, allowing night-time operation in anticipation of the daytime hours of frenzied trading in the Board Room."* The Board Room cooling used a plenum supply system of 40,000 ft$^3$/min (18.8 m$^3$/s) and 300 TR (1050 kW) capacity combined with mechanical extract. Wolff, in a letter of 1901 to the architect had confidently described the benefits of his proposed design: [21]

> *"What this means in comfort, in ability to transact business, the health and well-being of the members, can scarcely be realised by a mere recital....of figures, but must be experienced to be fully appreciated.....If the refrigeration plant is instituted for the boardroom and the entering air is cooled....and the percentage of moisture lowered, the result will be that this room will be superior in atmospheric conditions to anything that exists elsewhere. It will mark a new era in the comforts of habitation."*

## 1904 State of Missouri Auditorium, St Louis

The engineer, Gardner T Voorhees, was initially in charge of the refrigeration plans for the Louisiana Purchase Exposition, the St Louis World's Fair of 1904/05. He proposed an ambitious programme which envisaged the comfort cooling of the many exhibitions, restaurants and theatres by connecting local plant to the fair's central refrigerating system.[21] The organisers turned down his proposals. However, one building, sponsored by the State of Missouri, was comfort cooled. Its rotunda and 1000 seat auditorium was supplied with some 35,000 ft$^3$/min (16.6 m$^3$/s) of *"partially recirculated air, cooled by direct expansion...delivered through mid-height wall registers."* This installation, probably the public debut of air conditioning, introduced many thousands of visitors to the delights of comfort cooling.

## 1906 Kuhn, Loeb & Co Bank, New York

In a design by the New York consulting engineer, Arthur Feldman, the banking offices of Kuhn, Loeb at William & Pine Streets were cooled by a 20 TR (70 kW) ammonia refrigerating system delivering calcium chloride brine into a tank, another early example of stored cooling[21]. The supply air was passed over pipe banks through which the brine was circulated. Finned tube coils had yet to be developed.

## 1921 Council Chamber, County Hall, London

A booklet[22] issued by the consortium of contractors responsible for the installation of mechanical services at County Hall [Knott & Collins, 1921] notes that the that the plenum supply and extract ventilation moved 468 tons of air in an hour, or 236,000 ft$^3$/min (111 m$^3$/s), and used 1450 plenum/extract registers. The Council Chamber Suite was air conditioned by Carrier Engineering[23] . An illustration **[2.7]** of the comfort cooling installation in *Scientific American* [24] shows an air washer system where the spray water is cooled in hot weather by the use of an ice tank. The American author was most impressed by,

> *"..the individual atmosphere control at each desk in the council hall.......The normal supply of fresh air, which is supplied automatically and without individual control, comes through the outlet at the end just below the seat, while the vitiated air is withdrawn through a register below the front end of the seat"* (An arrangement not unlike that used some 60 years later in some modern financial dealing rooms.)
> *"...the English installation is more elaborate than anything that has yet come to our attention."*

## 1927 Minneapolis Auditorium

This huge auditorium building [Croft & Boerner, 1927] **[2.8]** was considered *"as a land mark in the progress of the cooling and ventilating art"* and *"The first municipal auditorium in which adequate provision has been made for the comfort of its occupants in hot weather."* Its statistics are impressive.[25] The structure measured 564 x 233 x 140 ft high (199 x 71 x 43 m) with a total seating capacity of 18,100. The main central arena had a seating capacity of 11,000; the Orchestra Hall to one side a further 3,600; a small hall wing to the other side, a further 3,500. The basement of the entire building was available as an Exhibition Hall. The total building cost including land and fees was $5,000,000. The mechanical equipment cost $1,169, 690, or 23.4% of total.

Heating was provided by steam using direct radiation. The entire building was ventilated by ten separate air supply fan systems, eight of which were equipped for cooling. The total air supply to the building was 413,000 $ft^3$/min (194 $m^3$/s), the Main Arena taking 223,000 $ft^3$/min (105 $m^3$/s) of this. Cooling was accomplished by air washers supplied with 3,000,000 US gallons (about 11,300 $m^3$) per day of well water at 49.5$^o$ F (4$^o$ C) equivalent to a refrigerating capacity of some 1000 TR (3500 kW).

An unusual feature was the form of Performance Guarantee required to be given by the contractor. The systems *"shall have cooling capacity to maintain in the respective spaces when fully occupied an effective temperature within 1$^o$ (F) of the <u>mean</u> between 66$^o$ effective temperature and the effective temperature then prevailing in the outdoor air whenever same exceeds 66$^o$."* (This was based on the ASHVE Research Laboratory Thermometric, or Comfort Chart, of 1925). What the Guarantee meant in practice was maintaining an indoor condition of 81.4$^o$ F (27.4$^o$ C) dry bulb, 54.6 % relative humidity at an outdoor of 100$^o$ F (38.3$^o$ C) dry bulb, 78$^o$ F (25.6$^o$ C) wet bulb, under full-load conditions.

# 2.2 Hotels and Restaurants

## 1903 Midland Hotel, Manchester

The warming and ventilation of the Midland Hotel [Charles Trubshaw, 1903] **[2.9]** in Manchester was probably the largest comfort installation carried out for a British hotel up to that time. A brochure issued by the contractor, Ashwell & Nesbit, describes the systems: [26]

> *"..the corridors, entrances and a few of the principal bed and sitting rooms are warmed by direct radiators; but the main portions of the building, embracing the smoking room, billiard room, lounge, coffee room, reading room, ball room, etc., is supplied with fresh warmed air from the battery chambers situated in the sub-basement under the centre of the hotel. The fresh air is derived from two air shafts in the main wall which constitutes the centre of the building, extending from a height of about 70 feet (21 m) to the sub-basement and conveyed by a short horizontal duct to the eight groups of batteries supplying the above rooms with fresh warmed air, a by-pass being provided with a suitable damper, so that a variable volume of cool air may pass directly to the fans."*

Two types of system, later used in air conditioning applications, can be identified: dual-duct and zone reheat. The brochure also refers to the air filtration or cleansing screen made from wooden frames covered with a fine cloth, followed by a coke screen *"which eliminates the particles of smut and dust from incoming air,"* and notes the two fans are driven by 20 brake horsepower (15 kW) motors. An interesting fact about the boiler plant is that it comprised three large steam Locomotive boilers supplied by the Midland Railway Company. A sticker attached to the brochure refers to a test made on 5th September, 1903 which showed:

> *"..that our Ventilating Apparatus was delivering SIX MILLION CUBIC FEET OF AIR PER HOUR (100,000 $ft^3$ /min, or 47.2 $m^3$ /s) into the Hotel, which means that with air at 62$^o$ Fahr. (16$^o$ C)= 203 TONS WEIGHT."*

## 1902-1906 New York Hotels

Before the advent of comfort air conditioning, affluent New Yorkers *"desperate to cool off after sundown during their city's notoriously heavy and humid summers"* [27] sought refuge on the famous Roof Garden of the Astor Hotel [Clinton & Russell, 1904] on Times Square. Not far away, the 18-storey St Regis Hotel [Trowbridge & Livingston, 1904] on the southeast corner of Fifth Avenue and Fifty-fourth Street was described as *"fitted with the latest and best of mechanical utilities, especially its heating and ventilating system,"*[28] but apparently this did not include cooling. Contemporary drawings of mechanical plant rooms in New York, from the magazine *Engineering Record,* for the Beaux-Arts Ansonia Apartment Hotel [W E D Stokes and Graves & Duboy, 1902], and the Hotel Belmont [Warren & Wetmore, 1906] show complex services, including an ice-tank and refrigerating machinery respectively, but no evidence of air conditioning.[29]

## 1907 Congress Hotel, Chicago

Hotel restaurants and public rooms were among the very early applications of comfort air conditioning. Perhaps the first was the installation by Andrews & Johnson Co[30] in 1907 for the Pompeian Room and Banquet Hall in the Congress Hotel in Chicago [Clinton J Warren, Holabird & Roche, 1893] and extended in 1902 and 1907. The refrigerating system[31] was designed by Frederick Wittenmeier of Kroeschell Bros Ice Machine Co, and had a cooling capacity of 140 TR (492 kW). He conceived the idea of cooling the air by placing direct-expansion $CO_2$ coils in an air washer spray chamber which he claimed did away with the expense of pumping large quantities of brine. Wittenmeier also refers to the use of steam coils *"to reheat the air when necessary to obtain the desired temperature and humidity,"* a system he used for the main restaurant (French Room) of the Congress to keep the room at 72$^o$ F (22$^o$ C) with a relative humidity of 72%.

## From 1911 Wittenmeier & Carrier

Wittenmeier also installed air-cooling systems in the Blackstone Hotel [Marshall & Fox, 1911] and Hotel Planters [J E O Pridmore], both in Chicago[32] and in the Rogers Hotel in Minneapolis.[11] The Blackstone system used $CO_2$ coils placed in air washers to cool the banquet hall, restaurant, grill, café and barbershop.[33] In 1913, Carrier Air Conditioning Co (then a subsidiary of Buffalo Forge) installed a central station, spray-type air conditioning system for the dining rooms of the Wisconsin Hotel, Milwaukee **[2.10]**. The refrigeration plant was provided by the Vilter Manufacturing Co.[11]

Meanwhile Wittenmeier, now running his own company, continued to install his so-called "Vitolysed-Air"systems. A 1927 advertisement in the July issue of *The Heating and Ventilating Magazine* for "Complete Air Conditioning Installations: Cooling -Refrigerating -Washing" cites a number of completed hotel installations: Weylin Hotel, New York; Montauk Point Hotel, New York State; Ritz-Carlton Hotel, Boston; and the famous Ambassador Hotel [Schimdt, Garden & Martin, 1919] and also the Windermere Hotel, both in Chicago.

## 1921-1933 London Hotels & Restaurants

Contemporary magazines or historical articles barely mention hotel air conditioning between the Wars. During this period, the air conditioning of hotels in the UK was rare. What little there was appears to have been confined to luxury hotels in London and is believed to have been limited to public rooms. A Carrier air conditioning brochure[23] mentions only the **Cumberland Hotel** [F J Wills, 1933] at Marble Arch **[2.11]** and the Ballroom of the **Dorchester Hotel** [Curtis Greene & Partners] in Park Lane. Another Carrier brochure[34] contains photographs [**2.12**] of the installation at the Cumberland which comprised two centrifugal chillers with a total cooling capacity of 500 TR (1755 kW). One machine was electrically-driven and the other, unusually for the UK, was driven by a steam turbine. Papers from Carrier Engineering[35] list also the Regent Palace Hotel c.1928, and Strand Palace Hotel 1928, as being provided with air conditioning.

A number of large restaurants were air conditioned during the period 1921/29: in Paris, the Tavern Olympia; in London, the Trocadero, Lyons' Olympia and Lyons' Corner Houses. The **Oxford Street Corner House** for J Lyons was provided with three evaporative cooling systems, each of about 22,500 $ft^3$/min (11.8 $m^3$/s), in 1926/27 and later in 1936, a 250 TR (880 kW) centrifugal chiller was installed[36] .

### 1931 Waldorf-Astoria, New York

A cut-away detail drawing of one of New York's most famous hotels of this period, the Waldorf-Astoria [Schultze & Weaver, 1931] is interesting. The massive building was described as making *"a quantum jump in scale beyond that of the typical skyscraper*".[37] The drawing shows the enormous size and number of public rooms and indicates services plant rooms for heating, lighting and ventilation at the lowest basement level. No mention of air conditioning. Ironically, the $42 million contract for the project was signed on the day of the stock market crash, 29 October, 1929.

## 2.3 Department Stores

Architecturally, major department stores are generally characterised by having a large internal volume, with high ceilings (particularly on the ground floor), often with atriums, often with ornate external facades and display windows, sometimes external blinds, and with internal gains (display lighting and customers), plus fresh air, constituting the bulk of the cooling load. Most of the famous department stores in London, Paris, Berlin, New York and Philadelphia were originally constructed before the advent of comfort air conditioning.

### 1903 Robinson & Cleaver, London

Robinson & Cleaver, a firm of Belfast linen-drapers, opened a store in London's Regent Street in 1894. It may have been the Irish connection that convinced them in 1903 to have a *"forced air heating humidifying, ventilating system, including ice, for air cooling"* installed by Thomas Chester, Davidson & Co.[11] The link with Belfast is the factory of Samuel Cleland Davidson, designer of possibly the best-known of all centrifugal fans, the *"Sirocco",* which he developed in 1900. The system for the store included a Davidson fan and a washer.

### 1900-1911 Wanamakers, Philadelphia

One of the most famous department stores in the USA is Wanamakers in Philadelphia which first opened in 1877 in the Grand Depot, a former railway freight station. As the business grew, a new 12-storey building **[2.13]** which took nine years to build, was opened in 1911. At that time it was said to be the largest retail store in the world. A series of drawings in the magazine *Engineering Record* from 1902 & 1905 show the extensive mechanical engineering plant and systems serving Wanamakers[29] . While some mechanical ventilation, ammonia refrigeration and brine piping can be identified, there is no evidence of air conditioning for sales areas. However, the biography of John

Wanamaker[38], apparently referring to additions to his original store, possibly around the turn of the century states:

> *"Other major developments included the addition of a basement and galleries, increasing total floor space to eight acres (3.2 ha), and a fresh air ventilating system (cool air that had been passed through sprays of water) that lowered the air-store temperature by ten or twelve degrees (about $6^o$ C) during hot summer months."*

No other information has been uncovered.

## 1912 Eatons, Toronto

A pioneering air cooling installation[39] was that installed for Eaton's Department store **[2.14]** in Toronto, to achieve cleanliness, less depreciation of stock, and comfort of patrons and employees. The system consisted of nine ventilating units circulating a total air volume of 225,000 $ft^3$/min (106 $m^3$/s) with preheaters, Webster air washers and reheating coils, providing a measure of evaporative cooling in summer. There was no refrigerating plant. The majority of the air from the seven units located in the basements was discharged into the open basement space which served as a supply plenum. One of the other two units was located on the third floor serving offices on the floor below, the other on the fourth floor serving a "special department".

## 1924 J L Hudson, Detroit

In the USA, Carrier Corporation opened the door to the comfort air conditioning market when in 1924 Irvine Lyle made the first "comfort" sale of Willis Carrier's new centrifugal chiller to the J L Hudson Company department store in Detroit: [11]

> *This store had found that on bargain days the ventilating system in its basement was of little help. Temperatures soared; customers fainted. The manager feared he would have to discontinue bargain sales when the crowds poured in. Lyle persuaded him to install an air conditioning system using three centrifugal machines, each of 195 TR capacity (a total of 2060 kW). The result was a cool basement, increased sales, and in a few years the extension of air conditiong to other floors. This was the first air conditioning installation in the department store field....."*

Meanwhile, after developing the centrifugal chiller, Willis Carrier began pioneering work on unit air conditioners, seeing a market for small retail shops that wanted to compete on comfort terms with the larger department stores. Accordingly, in 1928, Carrier Corp established a Standard Products Division to handle this business sector.

## 1929 Abraham & Straus, New York

Abraham & Straus was founded in 1865 as Wechsler & Abraham and by 1889 was the largest dry goods store in New York State.[40] A drawing of 1904 **[2.15]** shows outside blinds shading the display windows at street level. Extending the store commenced in 1929, and air conditioning was progressively added to the design of the consultant, Edward E Ashley. A contemporary photograph shows outside blinds in full use. The air conditioning was claimed to be the world's largest privately owned system and the only store in the New York metropolitan area to have cooling above the first floor.[41] The air conditioning included both central and unit systems. The central refrigeration plant was 1200 TR (4220 kW) composed of three unusually large reciprocating machines. The air plants circulated 405,000 $ft^3/min$ (190 $m^3/s$) of conditioned air and incorporated air washers. The store area served was 355,000 $ft^2$ (some 33,000 $m^2$).

## Stores Postscript

A number of major air conditioned department stores were completed towards the end of this inter-war period.

In 1935, air conditioning was installed to serve the first floor and the two basements of two New York stores: **Gimbels** on 6th Avenue and Saks in Herald Square.[42] The combined conditioned area was 221,000 $ft^2$ (about 20,500 $m^2$). The common refrigerating equipment capacity was 800 TR (2812 kW).

In 1936, air conditioning was installed in the new Loveman, Joseph & Loeb store in Birmingham, Alabama.[43]

The building had 175,000 ft3 (16,200 m2) of floor space, serv4ed by a single centrifugal chiller of 350 TR (1230 kW) cooling capacity. The air conditioning consultant was Charles S Leopold of Philadelphia:

When the Gimbel Store in Philadelphia was air conditioned the consulting engineer was again Charles S Leopold.[44] The air conditioning system comprised of eight dehumidifiers (air handling plants) with a total of 365,000 $ft^3/min$ (172 $m^3/s$) of supply air operating with two centrifugal water chillers totalling 1200 TR (4220 kW) and using a large chilled water storage tank.

No air conditioning installations for UK department stores during the 1920s or 30s have been identified. Investigations in the USA, relating to the provision of air conditioning in so-called *"Limited Price Variety Chain Stores",* also popularly called *"Five and Tens"* (5 & 10 cents per item), found in a survey of 10,253 stores that at the end of 1941 some 11% (about 1130) of these stores were equipped with air conditioning.[44]

## 2.4 Movie Theatres

**Progress was the addition of sound to movies and the installation of air conditioning in movie theatres.**
*Russell Baker, quoted in The Movies: Between Vitaphone and Video,* 1972.

The potential benefits of air conditioning appear to have been realised when cooling was installed in a number of theatres and cinemas in the early years of the century. It is generally accepted that it was the demands of the American movie theatre industry that laid the foundations for the later comfort air conditioning of office buildings. However, while by 1938 it was estimated that some 15,000 American movie theatres had air conditioning the number of similarly equipped major office blocks was little more than a handful. The widespread adoption of office air conditioning had to wait until after the Second World War

In America the pioneers of cooling for movie theatres had to deal with ventilation regulations which specified minimum fresh air quantities per person. They had to convince theatre owners that the increase in customers would more than pay for the capital and operating costs of the system. In some cases they had to demonstrate that the refrigerants in use were safe. Initially obsessed with maintaining low internal temperatures they had to learn the importance of humidity control. Some of the early pioneers failed to grasp the fundamentals of air distribution and the avoidance of cold draughts. But they also began to understand the principles of reheat and return air bypass, and of separate control of temperature and humidity. This story has been told elsewhere.[9]

It was also the advertising campaigns put out by American theatres that raised public awareness of air conditioning, though owners generally preferred to decorate their buildings with terms such as:

*"Cooling Plant"*
*"Refrigerating Plant"*
*"Refrigerated Washed Air"*
*"Cooled by Refrigeration"*

Other slogans, almost always accompanied by pictures of snow, icicles and blocks of ice[45] included:

*"Never Over Seventy Degrees"*
*"Artic Breezes"*
*"Cool and Comfortable"*
*" $20^o$ Cooler Inside"*
*"Refreshingly Cool".*

The theatre owners deliberately wasted cold air to pull in their audiences,[9]

*"Many theatres were designed with a system that provided a positive pressure in the auditorium, forcing cold air out through the lobby and onto the street to tempt passers-by. Engineers called this advertising air."*

In addition, it was the large comfort market provided by the movie theatres that helped many air conditioning manufacturers, including Carrier Corporation to survive the Depression, and go on later to develop the widespread air conditioning of offices and other commercial premises. Two early pioneers of theatre air conditioning were Logan Lewis (a Vice-President of Carrier Corporation) who wrote on the technical and commercial aspects[46] and Otto W Armspach (Chief Engineer of the Theatre Division of Carrier Corporation) who wrote about the factors affecting human comfort.[47] But it was Frederick Wittenmeier in Chicago, as will be explained later, who was responsible for opening up the market.

## 1903 Germany

A few early attempts in theatres at Weisbaden and Frankfurt am Main, Germany used air washers[48] but are said to have been unsuccessful, presumably because of the lack of humidity control. Possibly the first attempt to incorporate refrigeration was the combination well water/ammonia brine chiller used to cool the air for a theatre in Cologne, Germany:[49]

> *"The cooling system, installed in 1903, provided for coils to cool 47,000 cfm (22.1 $m^3$ /s) of fresh air. A steam driven ammonia machine of about 16 tons (56 kW) operated 15 to 16 hr per day and stored the cold in a brine storage tank, and the stored up cooling effect was used during the performance of three to four hours. Preliminary cooling was accomplished by well water cooling coils, which water was then used for the condensers of the refrigerating machine, and the final cooling by the brine coils."*

The question of the best means of air supply (floor versus ceiling outlets) to avoid cold draughts on the seated audience was to provoke much controversy in the 1920s in the USA when the comfort air conditioning of cinemas became a major industry. In light of the later conflicting opinions on the subject, the Cologne system was notable in that it distributed the supply air from overhead and returned it through multiple openings in the floor.

## 1909 Rio de Janiero, Brazil

Another early comfort cooling installation was for the City Theatre in Rio de Janeiro, Brazil in 1909, which like the Cologne plant employed off-peak storage, using some 50,000 US gallons (190 $m^3$) of refrigerated brine.[50]

## 1907-1917 The Unites States: Ventilation and Cooling

About 1907 a theatre in Evansville, Indiana, USA is reported to have cooled its ventilating air in summer by melting crushed ice in baskets placed in the fresh air inlets.[8] In 1911 the Folies-Bergere Theatre in New York installed an air cooling system designed by Walter Fleisher.[51] There was no mechanical refrigeration. The system used a Thomas air washer but the results were poor. As Fleisher admitted *"We were able to cool about 7 degrees (nearly 4 $^{o}$ C) below outdoors, but only the inefficiency of the apparatus saved the installation from being unbearable."*

An alternative solution to keeping cinema audiences comfortable was the so-called *"Airdome Theatre"* as the one at Danville, Illinois, built in 1910.[52] This style was a roofless structure that from the exterior resembled a traditional American movie theatre:

> *"This relaxed structure catered to summertime entertainment much like the rooftop gardens, restaurants and theatres found in some of the larger vaudeville theatres in New York, Stale air, produced by hot machinery and warm bodies was always a problem in the unventilated storefronts. Open to the sky, the air-dome structure was economical, requiring only an open lot with a high fence, and less of a fire hazard than enclosed theatres."*

But before the adoption of cooling systems many cinemas got by, or tried to get by, with mechanical ventilation systems.[9] Examples include the Ziegfeld Picture Playhouse in Chicago where a 1914 advertisement declared it to be *"sumptuously outfitted and scientifically ventilated"*, and the Robin Hood Theatre in Grand Haven Michigan where in 1917 the management claimed that *"a system of perfect ventilation makes the theatre one of the coolest in the locality. Exhaust fans in the ceiling and numerous electric wall fans keep the temperature several degrees below that of the street."* The rebuilt Poplar Theatre of 1917 in Philadelphia boasted of *"perfect ventilation"* using two large exhaust fans and twenty smaller fans. Another example is shown in a postcard of 1916 featuring the **Butterfly Theatre in Milwaukee [2.17]**, Wiscosin where the caption reads *"Perfect Ventilation. Change of Program Daily. Complete Change of Air Every 3 Minutes"*.[53]

In an effort to overcome the problem of draughts caused by using fans only for exhaust and drawing fresh air in through doors and windows the Typhoon Fan Company of New York reversed this arrangement and used fans to force in fresh air without any system of exhaust. This was apparently a low cost solution that attracted many takers, such that by 1923 the company had equipped some 1500 movie theatres.[9] This system was used in 1917 at the luxury Rivoli Theatre [Thomas Lamb] in New York, which *"was equipped with a perfume system that operated in conjunction with its ventilation."*

## 1917 Montgomery, Alabama

The first American movie theatre to use mechanical refrigeration seems to have been the New Empire Theatre in Montgomery (900 seats) which in 1917 had an air washer system with a 12 TR (42 kW) capacity refrigeration plant said to have been installed by the American Blower Corporation.[9,11] Although probably catering only for some 25% of the actual cooling load the addition of refrigeration would have produced better internal conditions than using evaporative air washer cooling alone in Alabama's hot, humid summers.

## 1917- 1930 Chicago[9]

About 1917, it was Frederick Wittenmeier who was quick to recognise the business opportunities if he could convince the owners of Chicago movie-theatres that air conditioning would attract a larger summer audience and avoid the traditional seasonal turndown in hot weather. He had already successfully developed a safe and economical solution to overcome the potential risks of using toxic refrigerants, such as ammonia or methyl chloride, in direct expansion systems for comfort applications, by leading the commercial development of $CO_2$ refrigeration in the United States.[13] (The usual alternative at this time was a brine cooling system.)

When the B & K (Balaban & Katz) **Central Park Theatre [2.18]** opened in Chicago in 1917 its air conditioning system attracted both local and national attention. It was such a commercial success that B & K soon made it a standard requirement in their theatres and similarly equipped the **Riviera [2.19]** in 1919, and the Tivoli and Chicago, both in 1921, followed later by the Roosevelt [Rapp & Rapp]. The Wittenmeier Machine Company advertised, *"Cooling and dehumidifying the air during the summer makes a theatre equipped with a Wittenmeier System a profit producer."*

Competitors of B & K also installed air conditioning, when the new (2260 seats) State-Lake Theatre [Rapp & Rapp, 1919], part of the Orpheum Chain, installed a 250 TR (880 kW) $CO_2$ system. Thus Chicago has a good claim to being the place where the comfort air conditioning industry was really born. However, the Wittenmeier systems had their faults, particularly with air distribution and humidity levels, and it was Carrier Corporation, starting in Los Angeles, who took a more scientific approach.

## 1917-1931 Los Angeles

The first of the legendary Sid Grauman's movie-theatres was **The Million Dollar [2.20]** [Albert C Martin & William Lee Woollett, 1917], followed by the Rialto [1918] and then by his first in Hollywood, **The Egyptian [2.22]** [Meyer & Holler, 1922]. These were all equipped with evaporative cooling system, having air washers without refrigeration, but the operating engineers at the Million Dollar Theatre are said to have increased the cooling during hot weather by depositing cakes of ice in the washer tank.[9]

While Grauman was planning his next venture, the Metropolitan, the engineers at Carrier Corporation were looking for ways to break into the theatre air conditioning market. The upward air distribution systems used by Wittenmeier, combined with high levels of humidity, led to complaints of discomfort **[2.17]** as Logan Lewis of Carrier later recalled:[54]

> *"The relative humidity was so high that the atmosphere was uncomfortably clammy. All patrons suffered from cold feet and dozens in every audience resorted to wrapping them in newspapers to protect them from the cold. If, as an alternative, the air was cooled to a lower temperature for the purpose of reducing humidity, cold feet were made colder still. As the audience and its body heat thinned out, conditions became progressively worse.*
>
> *We tried, time and again, to sell systems that met our own standards of quality, but always lost out on prohibitive price -until two radical concepts in engineering were developed. The newly invented bypass made it possible not only to maintain low humidities with less refrigeration but also practical to control temperature and humidity independently of each other. The trick was to cool only one-third of the air about twice as much and then to mix it with warm bypass air coming back from the theatre.*

*Experience in the suppression of dust in a tobacco stemery, prompted a reversal of air circulation -so shockingly different that it was, until proven, widely ridiculed in theatre circles as the upside-down system. With it tempered air of much lower dewpoint was delivered through overhead outlets and taken out through mushrooms at the floor level."*

The opportunity to put these ideas into practice came when Carrier secured the order for the air conditioning of the spectacular (3485 seats) **Grauman's Metropolitan Theatre** [William Lee Woollett, 1922] which *"epitomised the combination of innovative engineering and extravagant architecture"*. The down-draught air distribution arrangement **[2.23]** was not a complete success and it was only later when architects agreed to forsake decorative grilles for properly engineered pan outlets (a panel hung below the discharge over which the cold air diffused) that the draught problem was solved. This system was installed before the Carrier centrifugal refrigeration machine became available. According to Ingels[11] (and much quoted) the refrigerating plant was a $CO_2$ type supplied by the Carbondale Machine Co. However, Grant[18] states it was an ammonia compressor. Grauman went on to open his most famous theatre of all, **The Chinese** in Hollywood [Meyer & Holler, 1927] but no record of how it was (or if) cooled has been located by the author.

More of a mystery is the Orpheum Theatre. Confusion seems to have been brought about by two theatres of the same name, designed by the same architect, some 15 years apart. The first Orpheum [G Albert Lansburgh, 1911] was a vaudeville theatre on the Orpheum circuit in 1911 and some sources[19] refer to it having been cooled by a $CO_2$ direct expansion system installed by Kroeschell Bros Ice Machine Co, though it is not listed by Ingels[11]. Wittenmeier was employed by Kroeschell Bros at this time but established his own company in 1915. His paper of 1922 makes no reference to the Orpheum though his early hotel work when working for Kroeschell and the installations by his own company for the Balaban & Katz Chicago theatres are discussed.[31] The larger (2190 seats) better known Orpheum Theatre [also by Landsburgh, 1926] was claimed to have the rarity of an air conditioned lounge and *"usurped the preeminent position for top bookings from the nearby 1250-seat Palace (also designed by G Albert Lansburgh, and also at first named the Orpheum)."*[55]

Around this time a Los Angeles engineer reported *"we have two houses -the Orpheum and the Metropolitan -that have adequate refrigerating systems, and as an index of the prevailing trend, three more are in course of construction."*[9] These may have included the **Tower [2.24]** and the **Los Angeles Theatres [2.25]**, for one theatre owner certainly believed in the commercial benefits of air conditioning. The de luxe Tower Theatre [S Charles Lee, 1927] the first designed for talking pictures (906 seats), was a bold scheme on a very small site. An advertisement,[52] in the year of its opening, read:

*"Leave Your Fan at Home!*

*Manufactured Weather makes every day a good day at the Tower Theatre. When you enter, you will realise that H L Gumbiner has fulfilled one more great ambition to his public. He has included in this theatre the marvel of manufactured Weather. This is a Carrier Conditioned Theatre providing to the* *patrons a copious supply of air that is washed and purified, air that is warmed and humidified for ideal comfort in Winter, air that is cooled and dehumidified for invigorating comfort in Summer, air that is greatly diffused throughout the theatre without the slightest draught."*

Gumbiner went on to build the much larger (2190 seats) Los Angeles Theatre [S Charles Lee, 1931] in the French Renaissance style with ideas borrowed from the Hall of Mirrors at Versailles and from the Paris Opera. The theatre included an enormous lobby with a grand staircase, a lounge/ballroom, smoking room, nursery, restaurant, elaborate restrooms and a magnificent auditorium. There was *"a window installed on the landing between the first floor and the restrooms from which patrons could view the weather machinery."* In addition *"One of the exterior poster cases.....contained a recording apparatus that continuously compared the temperature inside and outside."* Unfortunately, Gumbiner was a showman not a businessman. His independent cinemas failed to break the studio-chain monopoly and soon, in spite of air conditioning, he went bankrupt.

## 1924 Texas

Carrier first used their new centrifugal refrigerating machine in theatre applications when they secured orders to air condition the **Palace in Dallas [2.26]**, and the Texan and Iris in Houston, all owned by Will Horwitz Jr.[11] The first installation at the Palace was combined with Lewis's bypass downdraught system. In Houston the two theatres were cooled by one centrifugal machine located in the Texan with chilled water pumped across the street to a storage tank in the Iris. Horwitz wrote:

> *"The cooling plant is revolutionising picture show attendance in Houston. Each patron exclaims with delight when he gets inside the doorway. The plant is working perfectly. Our engineer says he has nothing to do on the job but loaf."*

## 1920-1927 New York

Completed in a style described as Adam and Empire, the Capitol Theatre [Thomas Lamb, 1919] on the corner of Broadway and 51st Street was intended to be the largest in the world (5300 seats). Neither the public nor customers took to the building or its stage shows. After a brief closure in 1920 it reopened, when an advertisement proudly proclaimed,[56] *"TRIUMPHAL RE-OPENING -The Capitol -The World's Largest, Coolest, Most Beautiful Theatre..."* A contemporary photograph shows a series of hoardings on the front of the theatre with the message, *"Largest Theatre Cooling Plant in the World. Now Fitted"*

For Carrier Corporation the breakthrough into the New York theatre cooling market came when the **Rivoli** [Thomas Lamb, 1917] decided to replace its existing ventilation with a new air conditioning system **[2.27].** Opened in 1925 the installation used a 133 TR (470 kW) centrifugal, but only after some anxious moments when Willis Carrier had to drop a lighted match into a container of the refrigerant (dielene) to convince the safety chief to grant an operating permit.[11]

In the opening night audience was Adolph Zukor, a founder of Paramount Pictures, and it was almost certainly his approval that led to the adoption of air conditioning of new Paramount theatres, both in the United States and in Great Britain. Wittenmeier was also busy and air conditioned one of the flagship theatres of a rival chain, **Warner's Theatre, New York**, [Thomas Lamb, 1926]. **[2.28]**

Carrier's new centrifugal machine found rapid acceptance and was used in the **Paramount Theatre, New York [2.29]** [Rapp & Rapp, 1926] and then in New York's giant (6214 seats) **Roxy** [Walter Ahlschlager, 1927] **[2.30]**. The Roxy used two centrifugals with a total capacity of 420 TR (1474 kW) and now using a different refrigerant, Carrene-1, safety was no longer an issue.

## 1921-1939 Great Britain

The pioneering company in the design and installation of comfort air conditioning in Great Britain, through its application to theatres and cinemas, was the Carrier Engineering Co of London founded in 1921.

At the time of its opening The Broadway cinema [George Coles, 1927] at Stratford in East London, owned by H & G Kinemas, was the largest (2768 seats) designed by Coles, a versatile cinema architect described as the English Thomas Lamb. The unpublished memoirs[35] of the late J A E (Archie) Heard, a director of Carrier, record that the *"super-cinemas"* of the 1920s, with their *"enormous, lavishly decorated auditoriums, required very specialised and quite complex air conditioning systems, providing both winter humidification and dehumidification in summer using refrigeration".* He continues *"The first air-conditioned cinema was the Stratford, Broadway which had a simple air conditioning system..."* In Heard's terminology, only *"full air conditioning"* included refrigeration.

Heard's memoirs cite the **Carlton Theatre** **[2.31]** [Frank Verity, 1927] in London's Haymarket as the first fully air conditioned cinema in Britain. The Carlton was designed for use either as a cinema, or as a live theatre (1159 seats). It opened with a stage production, but began showing silent films in March 1928. In 1929 it was wired for sound and became a cinema permanently. The Carrier centrifugal refrigeration machine is stated as being the fourth to be installed in Britain.

Next, Carrier Engineering installed air conditioning in London's **Empire** **[2.32]** [Thomas Lamb with the Practice of the late Frank Matcham, 1928] in Leicester Square. Owned by Jury-Metro-Goldwyn (later MGM) the Empire super-cinema was built on the site of the Empire Music Hall which in 1896 had served as home to the moving pictures of Lumière's Cinématographe. Lamb's design for the facade was said to be based on his Albee cinema in Cincinnati while the lobby echoed his design for the air conditioned Capitol Theatre of 1920 in New York City. The original auditorium (3226 seats) was the largest of any in London's West End. Luxuriously decorated throughout in High Renaissance style, it came complete with a Wurlitzer organ and an elevating orchestra pit. The air conditioning of the auditorium was carried out by Carrier[34] who also provided the centrifugal refrigerating machine **[2.33]** which had *"a capacity of 250 ice-melting tons (880 kW)"*

Other Carrier Engineering installations followed, though not all had refrigeration: [35]

Astoria, Finsbury Park, London **[2.34]** [Edward Stone, 1930]
Cambridge Theatre, London [Wimperis, Simpson & Guthrie, 1930], 1305 seats
Paramount, Manchester [Verity and Beverley, 1930]
**Westminster Theatre**, London [A Dunbar Smith, 1931] 660 seats
Paramount, Leeds [Frank Verity, 1932] 2500 seats
Paramount, Liverpool [1932] 2500 seats

The decision by the Paramount chain to include air conditioning in their British cinemas was no doubt influenced by the earlier success of the Carrier Corporation in providing air conditioning for a number of their New York movie theatres. Other cinema chains were less convinced of the benefits and generally continued to use plenum ventilation systems with an air washer, a typical example being the installation[57] for the **Gaumont Palace** [Trent & Tulley, 1936] in London's Chelsea (2700 seats) **[2.35]**.

Then another major London cinema, The **Warner** [Edward a Stone & T R Somerford, 1938] opened in, Leicester Square. Built on the site of the famous Daly's Theatre, the striking frontage **[2.36]** was faced in marble blocks with sculptured figures representing sight and sound placed high on the facade at either end. The design of the auditorium (1789 seats) was described as simple, with the side walls and the front of the circle covered with an acoustic quilting to absorb sound, while air conditioning was provided by a Carrier system using a chilled water spray washer.

## 1927-1939 France and Belgium

In Paris, Carrier Engineering Co of London[23] equipped the **Paramount Theatre [2.37**] [Frank Verity & Auguste Bluysen, 1929] with air conditioning and provided a centrifugal water chiller having a capacity of *"150 ice-making tons (527 kW)."*[34] Other early theatres and cinemas air conditioned by Carrier[35] include the Paris-Plaza; the Beaux-Arts in Nice; the Rex in Paris, and the Metropole in Brussels.

## 1925-1938 Northern India

At this time, India was still the jewel in the crown of the British Empire. Carrier Engineering of London was among the British firms working on the sub-continent. Initially, equipment and ductwork was shipped from England. Later, financial considerations led to ductwork being manufactured locally and major items of refrigerating equipment being imported from the USA.[58] Early systems used spray washers for evaporative cooling. This was employed at the Regal Cinema, Lahore (c.1931) and probably at the Plaza in New Delhi and for the Empire, Calcutta (c.1929).[59] {Other comfort installations[59] included the Government Secretariat Buildings & Legislative Assembly in New Delhi (Sir Herbert Baker & Sir Edwin Landseer Lutyens, 1912-31), and the Khasbagh Palace in Rampur.[60] The latter used chilled water in the washers, generated by ammonia compressors of Vilter manufacture, employing Baudelot coolers, where the water trickles down the <u>outside</u> of the coil type evaporators. Carrier drawings (1932)[61] also show the air conditioning systems for the Palace at Jodhpur which included large chilled water storage tanks. About this time, the Palace at Jaipur was also air conditioned.} However, the most prestigious movie theatre air conditioning installation prior to the Second World War was probably that provided for the **Metro Cinema, Bombay [2.38]** [Thomas Lamb with D W Ditchburn, 1938] described as "India's largest cinema" (1500 seats). The Inaugural Programme states [62]

> *"In every detail, your comfort and enjoyment are considered. The air is purified and cooled by a Carrier weather-conditioning plant which controls both temperature and humidity."*

## 2.5 Landmark Skyscraper Offices without Air Conditioning

In the United States, around the turn of the century, opening windows for natural ventilation with radiators for heating was still the generally accepted norm. In some offices, the lower floor levels were mechanically ventilated. The rationale was that lower floors suffered from the noise and smell of the streets and that the occupants could not open windows for relief. In the taller office blocks, most of the upper floors still relied on opening windows, a practice that continued into the late 1920s and 1930s. British offices similarly relied on opening windows, though there were a few exceptions.

### 1911 Royal Liver Building, Liverpool

The Royal Liver Building [W Aubrey Thomas, 1911] which has been "*described as a towering mass that dominates the whole river front*" is one of the best known landmarks of the City of Liverpool **[2.39]**. *"The dimensions of the building are 301 ft (92 m) long by 177 ft 6 in (54 m) wide, the height from basement level to the main roof being about 170 ft (52 m) and to the top of the towers approximately 300 ft (92 m)......The structure comprises a basement with ten upper floors, while in the two towers are six storeys above roof level."*[63] Well known to all Liverpudlians are the 25 ft (7.6 m) diameter clock and the two 17 ft (5.2 m) high bronze Liver birds which crown the two main towers.

The main features of the building upon completion, taken from a contemporary description, are as follows. The building skeleton is of monolithic reinforced concrete ("Hennebique" system), the floors are of hollow fireclay blocks covered with concrete, with the corridor and tenancy walls being of fireproof hollow bricks. The outer walls are of grey granite with steel casement windows. There were 15 high-speed electric passenger lifts, 2 electric goods lifts and a large hydraulic goods lift from basement to ground floor. Though not air conditioned, the heating and ventilation services by Richard Crittall & Co were advanced and unusual for that time. The building is one of the first major mechanically ventilated office buildings in the UK. The heating was described as a "*hot panel*" system [64]

> *" ...the heating is accomplished by means of hot water supplied from a great boiler house in the basement (housing 4 boilers with Bennis stokers), circulating through a network of small pipes fixed under the Durato (asbestos composition) flooring and in wall panels, and radiating warmth at the discretion of the occupants. As the fresh air enters a room, whether through the door, or through the adjustable inlet gratings under every window, it acquires the desired temperature from the radiation of hot water pipes, the strength of which may be regulated with nicety."*

The mechanical exhaust ventilation arrangements were also described:

> *" Closely connected with the heating are of course the ventilating arrangements, which are such as to ensure a free and safe circulation of pure air throughout the vast structure. Every corridor has a double ceiling and into the cavity thus formed the foul air is admitted through gratings in the upper parts of the office walls, and thence drawn up and ejected by powerful revolving ("centrifugal cased fans") through three great upright rectangular vent shafts, measuring ten feet by ten feet ( 3 m square). Two of these shafts serve the offices, boardrooms &c., and the other the lavatories, bathrooms &c., so that all possibility of objectionable back draughts is avoided."*

It would appear that the exhaust air volume was in the region of 240,000 $ft^3$/min (113 $m^3$/s). A rough estimate suggests this was equivalent to some 1.5 to 2 air changes per hour.

It was to be another 50 years before the first air conditioned office buildings rose in the UK.

## 1908-1915 New York

In the first wave of really tall New York office buildings were the French Beaux-Arts style **Singer Building [2.40]** [Ernest Flagg, 1908] at 612 ft (187 m), followed by the **Metropolitan Life Tower [2.41]** [Pierre LeBrun, 1909] at 700 ft (213 m), and then surpassed by the **Woolworth Building** **[2.42]** [Cass Gilbert, 1913] at a towering 792 ft (241 m).

Another landmark office, because of its sheer size, was the **Equitable Building [2.43]** [Ernest Graham, 1915]. This 39-storey "giant box" provided 1.2 million $ft^2$ (115,000 $m^2$) of floor area and has the dubious distinction of being largely responsible for the introduction in 1916 of zoning laws to limit skyscrapers to not more than 12 times the size of the plot. The Equitable was nearly three times this. In none of these buildings was the office space air conditioned or even cooled.

## 1921-1926 Chicago

There are two very famous Chicago tower buildings of this period **[2.44, 2.45]**. The first to be built was the **Wrigley Building** [Graham, Anderson, Probst & White, 1921] with a 17-storey base, topped by a 11-storey clock tower. The second is the Gothic-styled **Tribune Tower** [Raymond Hood & John L Howells, 1925] rising to a height of 462 ft (141 m). Neither was air conditioned, though in an advertisement in *The Heating & Ventilating Magazine* of July 1927, p.181, both the Wrigley and Tribune Buildings are listed as having installations by the Wittenmeier Company (possibly air washers and probably of a minor nature in the lower levels of the building.)

In 1923 Chicago had abandoned its limit on building height and passed a zoning law that permitted skyscrapers. The **Straus Building [2.46]** [Graham, Anderson, Probst & White, 1924] was one of the first major structures to take advantage of this change in the regulations. The result was a 9-storey tower, rising to 475 ft (145 m), on top of a 21-storey main base with a conventional interior central court. After occupation by the bank of some 20% of the building the remaining 440,000ft2 (40,740 $m^2$) was marketed to tenants as *"Chicago's Finest Office Building"* achieving record rental incomes, with no call for air conditioning. By 1930, more than twenty buildings had exceeded the old 260 ft (79 m) height limit.

## 1926-1932 New York

The second wave of skyscraper offices, in the period spanning the mid-the 1920s to the early 1930s, saw the construction of more very large and very tall office skyscrapers. By 1930 comfort air conditioning was almost a standard requirement in the better movie theatres, and was being introduced into some hotels and department stores. But it was also the time of the Depression. Whether the reasons were purely financial or otherwise, air conditioning was not installed in these landmark office skyscrapers, though in some cases it has now been retrofitted.

The first building to fully exploit the zoning laws was the **New York Telephone Company** (Barclay-Vesey) Building [McKenzie, Voorhees & Gmelin, 1926] **[2.47]** built in American Art-Deco style to a height of 498 ft (152 m). Its massive bulk, surmounted by a 32-storey tower, was possible because many of the internal operations of the telephone company required only artificial light, eliminating the need for an interior light court.

Shortly after there was a competition to be the world's tallest between the Bank of Manhattan Trust Building and the **Chrysler Building**. The Bank of Manhattan [H Craig Severance with Yasuo Matsui, 1930] was 72-storeys, 927 ft high (283 m) with a floor area of 903,000 $ft^2$ (83,600 $m^2$). The massing of the building took full advantage of the setback regulations in New York's zoning law of 1916. An ornate pyramidal crown and Gothic spire was added by the architects in an effort to be taller than the Chrysler Building [William Van Alen, 1930]. However, in what is now architectural legend, Alen added a 185-ft (65 m) spire to his design, which was secretly assembled within the top floors of the building and raised in to place just as the building was finished .[65] At 1,046 ft high (319 m), with 77-storeys and a floor area of 1.04 million $ft^2$ (96,300 $m^2$) the Art Deco Chrysler won the contest. Neither building was air conditioned. One report[66] talks of *"two independent air conditioning systems"* being provided in the Chrysler Building, but this appears to be unsubstantiated and there is no evidence to support this, at least on plans of the office floors. The Manhattan Trust (now 40 Wall Street) had a new refrigeration plant of 2600 TR (9140 kW) installed in 1996. Another famous office skyscraper was the City Bank Farmers Trust Building [Cross & Cross, 1931] once the fourth tallest in the world at 741 ft (226 m) with 57-storeys and an area of 500,000 $ft^2$ (46,300 $m^2$). Originally with recessed radiator heating, it was fitted with air conditioning at a later date.

The height record was soon claimed by the **Empire State** [Shreve, Lamb & Harmon, 1931] at 1250 ft (381 m) with 102-storeys (equivalent) and an area of 2.2 million $ft^2$ (203,700 $m^2$) a record it was to hold for 41 years, until overtaken by the **World Trade Centre**. The Empire State had 6400 windows and, without air conditioning, the windows had to be openable for natural ventilation. By 1961 some 80% of the Empire State had been air conditioned and in a modernisation programme, commencing in 1990, the heating and air conditioning systems were renewed.[67]

Soon after, came the completion of the Art Deco Cities Services Building [Clinton & Russell with Holton & George, 1932], then the third tallest in the world at 952 ft (290 m), 67-storeys and 865,000 $ft^2$ (80,100 $m^2$). This building had the first double-deck lifts (by Otis), but was not air conditioned.

So the interior standards of radiator heating and natural ventilation acceptable to the tenants of speculative offices in New York in the 1930s were not good enough in the post-war years. Many of these renowned and architecturally first-class buildings have now been successfully upgraded with air conditioning, new lifts, fire alarms and computerised building control systems added.

## 2.6 Some Skyscraper Offices with Partial Air Conditioning

The term "partial air conditioning" means different things to different people. In contemporary accounts it may mean that not all of the building is air conditioned. It can also mean that not all the functions of full air conditioning are provided, in that there is no refrigerating plant (perhaps only evaporative or well-water cooling) or that heating and ventilation with humidification is classed as partial air conditioning.

### 1929 Union Trust Building, Detroit

The first example is the **Union Trust Building in Detroit [2.48]** [Wirt Rowland with Smith Hinchman & Grylls, 1929] where only the lower half of the office tower was conditioned. In this 40-storey office building, built in the "monumental" style with relatively small windows the lower 16-storeys and 2 basements were *"heated and ventilated throughout by a combined air conditioning and heating system."* [68] The solution adopted employed low velocity all-systems with central spray chambers and direct-expansion cooling coils, with local zone reheaters **[2.49]**. One plant of 69,000 $ft^3$/min (32.5 $m^3$/s) served the Lower Bank, two plants of 74,000 $ft^3$/min total (34.8 $m^3$/s) catered for the Main Bank, and a further two for the Office, floors 7-16 supplied 150,000 $ft^3$/min (70.7 $m^3$/s). The occupancy of these areas was 450, 410 and 2610 people respectively. Refrigeration with a capacity 600 TR (2110 kW) was provided by $CO_2$ compressors from the American Carbonic Machinery Co. Investment studies suggested that providing air conditioning was not cost-effective, but the Bank and Trust Company decided that the advertising value and the improvement in staff working conditions outweighed these considerations.

## 1932 Louisiana State Capitol, Baton Rouge

Another example is the Louisiana State Capitol [Weiss, Dreyfous & Seifferth, 1932] in Baton Rouge. This impressive 34-storey structure **[2.50]** built in the Art Deco style, with a 450 ft (137 m) high observation tower, was not originally provided with air conditioning, perhaps a surprising decision considering the hot and humid local climate of this part of the deep south with summer design conditions of 95°F dry bulb, 81°F wet bulb (35/27.2°C) The building includes two large Assembly Chambers on the ground floor (Senate and Representatives) and some 19 floors of offices. While steam heating was provided in the offices, reliance was placed on opening windows to achieve natural ventilation. Original mechanical services drawings exist, dated November 1930, and show elaborate mechanical ventilation plant serving the Assembly Chambers, but no trace of cooling or air conditioning at this time.[69] But a major service provided throughout the building was an "ice water" system to the drinking fountains The drinking water was cooled by a refrigeration system with two $CO_2$ reciprocating compressors, one with a 50 hp (37 kW) motor, the other unknown. However, some air conditioning was added as an afterthought. Cooling was added to the ventilation systems serving two restaurants on the ground floor and to systems supplying air to the Judge's Reception Rooms on the 22nd & 23rd floors. All these systems were fresh air supply and the cooling coils were fed with chilled water from the oversized ice water system, before passing to the fountains for drinking. This scheme is possibly unique in the annals of air conditioning!

## 1933 Gulf Building, Pittsburgh

A building with an interesting system is that of the Gulf Refining Co in Pittsburgh. At 40-storeys high the building is 195 x 135 ft (64 x 44 m) in plan at street level and above the 7th floor where the main set-back occurs, 108 x 108 ft (35 x 35 m). It has stores at street level, upper floors of offices and three basement levels. Although described as *"partially air conditioned"* there was no mechanical cooling.[70] The reasoning for this decision stated:

> *"In the modern large building, supplying or conditioning air are major problems which must be studied not only from the standpoint of the comfort and satisfaction of the tenants but also for the economical and flexible operation of the heating system. The local atmospheric conditions during the entire year, the size of the floors or rooms, all have a bearing on this study and the final conclusions. The question of air conditioning -whether complete with refrigeration or partial with air washing and tempering -is important."*

While these considerations may have been taken into account in the USA during the 1930s, when deciding whether or not to provide air conditioning in office buildings, the fact is that most buildings, including some of the most famous early skyscrapers, were not so equipped. In the case of the Gulf Building, it was the architectural design that lead to the omission of full air conditioning:

> *"In the upper floors, above the setback, the elevators and stairways, together with spacious halls, occupy the centre of the building. This provides all offices with direct outside light and window ventilation. In studying the problem of heating and ventilating it was found these offices were of a size in which natural ventilation could be controlled by the occupant to give a reasonably satisfactory air condition throughout the room. Steam radiators, located under the window are hand-controlled. The conditions of heat and air for each room are therefore within the control of the occupant and are not the responsibility of the engineer or building superintendent."*

Whether or not this proved to be sound reasoning is unknown. A cynic might view it as an attempt to justify a cheap installation. However, the designers still opted to provide a humidified air supply to the lower floors, providing three such systems: 1st to 4th floors; basement & basement mezzanine; sub-basement. Numerous other warm air supply and exhaust systems served toilets and miscellaneous areas. A feature of all these systems was the provision for speed control of the alternating current electric fan motors using a Westinghouse *"manual adjustable resistance-type secondary-speed controller for 50-per cent speed adjustment and a primary magnetic panel";* an early example of variable volume.

## 2.7 The First Air Conditioned Office Buildings

### 1906 Larkin Administration Building, Buffalo

The design that broke the mould of opening windows was that for the Larkin Building [Frank Lloyd Wright, 1906] which housed a mail-order business with some 1800 employees. The brief from the client required a sealed building with mechanical ventilation.[71] This was largely dictated by the industrial nature of the site and the proximity of the New York Central Railroad, emitting fumes and noise. Wright's solution was a large, sealed inwards-looking box, dependent on mechanical ventilation and overhead daylighting **[2.51]**. Though the brief made no mention of cooling, Wright specified a refrigeration plant that distributed chilled water at 50°F (10°C) to Acme washers, by Thomas & Smith of Chicago, in the air handling plants.[72]

The external appearance, form and massing of the building was dramatically different from architectural fashion at the time. Most American architects were still designing offices with heavily ornamented facades in the Beaux-Arts style. The Larkin Building was large and relatively squat. In terms of mass, it resembled one of Chicago's "Quarter-Block" buildings that Wright was involved with when he worked in Louis Sullivan's architectural office during the 1890s. It had a basement, five floors above ground, electric lighting throughout, but no sun shading, in contrast to most buildings of the period. Wright described it as *"a simple cliff of brick hermetically sealed (one of the first 'air-conditioned' buildings in the country),"* and wrote [73]

> *"The machinery of the various appurtenance systems, pipe shafts incidental thereto, the heating and ventilating air intakes, and the stairways which serve also as fire escapes, are quartered in plan and placed outside the main building at the four outer corners, so that the entire area might be free for working purposes. These stair chambers are top-lighted. The interior of the main building thus forms a large single room in which the main floors are galleries open to a large central court (atrium), which is also lighted from above. All the windows of the various storeys (galleries) are 7 feet (2.1 m) above the floor, the space beneath being utilised for steel filing cabinets. The window sashes are double, and the building practically sealed to dirt, odour and noise, fresh air being taken high above the ground in shafts extending above the roof surfaces."*

The mechanical ventilation system **[2.52]** provided heating and cooling by 4 to 5 changes per hour of full fresh air treated in the basement air handling plants. Air was exhausted from the offices at floor line in winter and from the ceiling in summer, presumably to maximise the respective heating and cooling effect. Ingels[11] states that refrigeration was added in 1909 when a Kroeschell Bros $CO_2$ plant was provided but it now appears that mechanical cooling was in place in 1907.[71] Although the cooling power was not great, by comparison with more recent systems, one can speculate that that intrinsic features of the building would have meant that it was cool and comfortable in summer. These features that contribute to cool comfort include: the generous floor-to-ceiling height of 13 ft (4 m); the "thermal-mass" of the walls and ceiling; the recessed windows; and the "stack-effect" of the atrium. The only area where there was likely to be a lack of comfort was on the west side where clerks would have been in direct sunshine on summer afternoons. Later photographs show that blinds were eventually installed, presumably to minimise overheating.

The Larkin offices were probably the first designed to accommodate all the hardware associated with modern air conditioning. Service ducts running from basement to roof were sited adjacent to staircases and expressed on the outside of the building, an early example of the integrated design of architecture and air conditioning. As Wright recalled, [72]

> *"I took the next train to Buffalo to try and get the Larkin Company to see that it was worth thirty thousand dollars more to build the stair towers free of the central block, not only as independent stair towers for communication and escape but also as air intakes for the ventilating system. It would require this sum to individualise and properly articulate these features as I saw them."*

The ducts handled air drawn in and exhausted at roof level. Columns were extended with false sections to house steel supply ducts. Large areas of the basement were allocated to water storage and to air handling plants drawing air from the top of the building. Although Wright specified a refrigeration machine, space was not allocated to it on the basement plan. Therefore, he may have been the first of many architects to underprovide space for the air conditioning equipment. It is said Wright used the Chicago National Bank [Jenney & Mundie, 1901] as a model for the heating and ventilation system.

From the perspective of the history of comfort air conditioning, this building is unique. Wright's design included working drawings of the ducting and plant and resolved many of the major issues decades ahead of other architects. Although the Larkin Building was well received, the development of air conditioning in offices languished for the next 20 years. As for the building, unfortunately it was demolished in 1950.

## 1928 Milam Building, San Antonio

A Carrier advertisement[74] states that the 8-storey T W Patterson Building in Fresno, California was the first office block to be air conditioned. The year was 1926 and the system was added into existing, occupied premises. However, the same advertisement also claims that the 21-storey Milam Building holds a special place in air conditioning history, *"Because the Milam Building was the world's tallest concrete-framed structure at the time, it represents a real milestone in climate control in commercial buildings."*

The year 1929, saw the launch of the American trade magazine *Heating, Piping and Air Conditioning*, and indicates that the term "air conditioning" was coming into common use. The lead article in the July issue[75] proclaimed that the Milam Building **[2.53]** [George Willis, 1928] was the *"first in the country completely equipped for air conditioning to provide year-'round comfort."* However, the building form, fenestration and floor plan layout belong to the pre-air conditioning era.

The air conditioning system used 11 air handling units which served a basement cafeteria, ground floor shops and some 750 offices on the floors above, delivering a total air quantity of "*8 tons/min,"* or 240,000 ft$^3$/min (113 m$^3$/s). The basement refrigeration plant comprised two centrifugal water chillers with a capacity of 375 TR (1300 kW), which related to the floor area of 220,000 ft$^2$ (20,000 m$^2$) gives a cooling rate of only 1.7 TR/1000 ft$^2$ (65 W/m$^2$) which is about half that expected for a typical office building of the 1960s. The floor duct distribution to offices **[2.54]** was housed in a false ceiling that formed a bulkhead in the main corridor, lower than the ceilings in the offices. Conditioned air was supplied from side-wall grilles at a high level and returned to the fan room through transfer grilles and along corridors. The amount of fresh air make-up could be adjusted by hand. The all air system was used also to heat the building by warm air.

The air conditioning system had several interesting features. Condenser cooling water was provided from the adjacent river, a chilled-water storage tank was charged overnight and chilled water spray washers were used to cool and dehumidify the air during the following day. In addition, occupants of offices could choose to open the window, or the air conditioning register, or both. This was perhaps a very early form of "mixed-mode."

Taking into account the outdoor design condition of 96.8$^{o}$ F (36$^{o}$ C) dry bulb and 73.4$^{o}$ F (23$^{o}$ C) wet bulb, the design of the ductwork, the relatively poor air distribution and the minimal refrigerating capacity, it is unlikely that the occupants of the offices in the south-west corner enjoyed the benefits of a fully air conditioned environment. Perhaps the ability to open windows was a significant factor, for despite these criticisms, the Milam Building has always enjoyed the reputation of being recognised as the first properly comfort air conditioned office building in the world.

## 1931 Broadcasting House, London

Public service broadcasting in Britain began in October 1922, but the facilities quickly proved inadequate. The Portland Place site at the top of Regent Street was acquired and a dedicated broadcast building was planned. It had to incorporate all the latest radio technology yet harmonise with its Regency environment. The challenge was to combine 22 studios, which had to be acoustically treated and air conditioned, with administrative offices which needed maximum daylight.

The design of the new Broadcasting House [G Val Myers, 1931]**[2.31]** dispensed with the then usual inner light well. The studios were placed in the core of the building, acoustically protected by the outer shell of offices. The largest studio, the concert hall, occupied a volume of 37,300 ft$^3$ (3450 m$^3$) on three levels. The air conditioning **[2.55]** while serving studios not offices, represents a notable landmark in the development of comfort air conditioning in Britain. Nothing to equal it appeared until some 30 years later.

The air conditioning was designed and installed by Carrier Engineering [76]

> *"There are 32 fans handling 614 tons of air per hour (310,000 ft$^3$ /min, or 146 m$^3$ /s), 16 pumps delivering 641 tons of water per hour under pressure (180 kg/s), 54 electric motors having a combined capacity of 504 hp (376 kW), sheet steel ducting weighing 120 tons (122 tonnes), and 60 independent automatic controls."*

Water for the spray washers was cooled by a 200 TR (700 kW) centrifugal refrigerating machine **[2.56]** operating with an evaporative condenser. Carrier advertised the project with the slogan, *"Perfect atmosphere makes Perfect broadcasting possible."*

## 1932 Philadelphia Saving Fund Society, Philadelphia

**Sniff the bracing atmosphere. When you've done all this, then celebrate, in your own way, the modern office building!**
*Philadelphia Inquirer advertisement, 14 July 1932.*

The PSFS Building [George Howe and William Lescaze, 1932] broke new ground in its architectural style and concept of air conditioning. It consists of a tower of 491 ft (150 m), T-shaped in plan, rising from a base containing shops and a banking hall, with banks of lifts grouped at the rear **[2.57]**. The appearance was considered modern and distinctly different from any other in the United States. The design reflected the "International Style"[77] with such features as an absence of external ornamentation, cubic shapes and a relatively large area of metal-framed, ribbon windows, this style of window having been previously exploited by Le Corbusier.

At this time, office buildings were very rarely air conditioned. Why the PSFS was a notable exception is not clear. The manager of the PSFS, writing in 1937, claimed the reason was the prospect of increased rental income.[78] However, the difference might have been that the PSFS was built for a prosperous savings fund society that had the funds available. It was a period of severe recession in the United States, and property developers had still not identified any financial gain from air conditioning.

The design of the engineering systems at the PSFS Building included several innovations that pioneered the approach to servicing tall buildings. One of the more significant was the introduction of an intermediate level mechanical plant room on the 21st floor, in addition to the plant at roof level and in the basement. The concept reduced the space required for the vertical ducts by distributing them down from the roof, up from the basement, and both up and down from the 21st floor. This division of the supply air plant dramatically reduced the floor space for vertical ducts.

Fresh and possibly recirculated air was supplied to floor fan rooms at each level. Each fan room had two fans, one serving the east side of the building, the other the west. The fresh air was mixed with air drawn back through the corridors and recirculated to the offices. The intermediate plant room at the 21st floor also housed water tanks and reduced pressure on the distribution pipes at lower floor levels. These techniques have been extensively employed in tall buildings since.

One can speculate whether the architects demanded air conditioning to counteract the heat gain from the relatively large windows even though venetian blinds were an integral element of the design concept. This would make the PSFS Building the earliest where the air conditioning was installed to allow greater architectural freedom.

However, what is certain is that they used a novel architectural technique to conceal some of the air conditioning paraphernalia. The large "PSFS" sign on the top of the building, lit by red neon, is a Philadelphia landmark. It was designed to conceal the cooling towers.

## 1933 Cité de Refuge (Salvation Army Hostel), Paris

The new Salvation Army Hostel [Le Corbusier with Gustave Lyon, 1933] was planned to provide significant advances in building environmental control. Lyon developed air conditioning in Europe independent of "experiments" in the Unites States, [79] and completed the air conditioning for a 3000-seat auditorium, the Salle Pleyel, with his system called "l'air poncteul", which loosely translates as "regulated air".

Le Corbusier claimed to have devised two master concepts for a new approach to environmental management, the first being "la respiration exacte," or controlled mechanical ventilation, based on Lyon's experiences. His second idea was to circulate air at 64.4 $^{o}$F (18 $^{o}$C) between the panes of double glazed windows to create a thermal barrier or neutralising wall, "le mur neutralisant" **[2.58]** between the external and internal environments.

The opportunity to use these ideas came with the Salvation Army project where Le Corbusier conceived the idea to hermetically seal the south face of the building from floor to ceiling and from wall to wall with 11,000 ft$^2$ (1000 m$^2$) of glass [80]

> *"We gave them freely (the six hundred poor souls who live there) the ineffable joy of full sunlight ....the glass was hermetically sealed, because warmed and filtered air circulates constantly inside, controlled by the heaters and fans."*

The building opened late and over budget on 7 December, 1933, in one of the coldest periods in memory. The temperature inside on that cold, sunny day was perfect. Unfortunately, the same could not be said in summer. Although the designers had intended to provide their version of air conditioning, the budget did not provide for the refrigerating plant, and the neutralising wall had been omitted,[80] *"The sealed glass wall with its southerly aspect made the interior an intolerable glasshouse..."* Sealed windows did not comply with regulations and ultimately, much to Le Corbusier's displeasure, the windows were changed to opening. It appears that this experience changed Le Corbusier's ideas about glazing. His subsequent buildings featured shading (which was eventually fitted by others to the hostel) and led him to invent the external egg-crate of vertical and horizontal shades, the "brise-soleil"...... *"..one of his most masterly inventions, one of the few last 'structural' innovations in the field of environmental management that we have seen."*

## 1933-1935 British Empire & International Buildings, Rockefeller Centre, New York

**Rockefeller Centre** **[2.59]** [Reinhard & Hofmeister, Hood & Fouilhoux & Corbeth, and Harrison & MacMurray], now comprising an enormous complex of nineteen commercial buildings covering 22 acres (9 ha) in midtown Manhattan, was commenced in 1929. Originally covering 12 acres (5 ha), the most famous of the first buildings are the 850 ft (259 m) high RCA, now GE, tower of 70-storeys with 2,100,000 ft$^2$ floor area (194,400 m$^2$), and **Radio City Music Hall** (5874 seats). The RCA building marked the emergence of a new form of office skyscraper and was nicknamed “the slab”, because the thin slab layout was based on the principle of 27 ft (8.2 m) of lighting depth to give optimum conditions around the central lift core. These office floors were not air conditioned. In fact, a number of references give the impression that none of the buildings in the original complex was air conditioned, but this is not the case. Some department stores and other areas at the lower levels of the RCA and the 38-storey International Building were provided with “summer cooling” by centrifugal water chillers. Part of the office accommodation in the latter was served by a mix of central and unit systems connected to the landlord’s chilled water distribution system, to which a tenant could connect on payment of an increased rent.[81]

The British Empire Building (Building No.3), was built as a 6-storey block, with a basement and sub-basement, and comprised a total of some 112,000 $ft^2$ ($10,370\ m^2$). There were three air conditioning systems, serving basement shops, ground floor shops and offices above. Cooling was accomplished by chilled water spray washers, but an usual feature was the refrigerating plant, a 300 TR (1053 kW) steam-jet unit, normally
only found in industrial or marine applications, and even then not that common.[82] The air conditioning consultant was Clyde R Place, the contractor Baker, Smith, Inc.

## 1933 The Metropolitan Life Insurance Company, New York.

From their original headquarters building of 1892, the offices of Metropolitan Life expanded to the designs of architect Napolean LeBrun, continuing to grow until it occupied the an entire city block, culminating in 1909 with the famous Metropolitan Life Tower at 700 ft (213 m) high, the tallest building in the world until completion of the Woolworth Building in 1913.

Expansion and changes continued over the years, but in 1929 the company proposed the construction of massive new office building **[2.60]** alongside LeBrun’s Tower. The architects, Harvey Wiley Corbett with D Everett Waid, prepared drawings for various versions of a “telescoping tower,” the height of which ranged from 80 to 100 storeys. This tower, described as Corbett’s most visionary design was meant to be the world’s tallest [37]

> *“The walls folded rhythmically into triangular bays, which Corbett hoped to realise in metal and glass, despite the city building code’s insistence on masonry construction.......Escalators would have provided access to the first sixteen floors, thus reducing the size of the elevator cores without sacrificing the quality of service on the upper floors......Eighty-foot-deep floors were made possible by full air conditioning, and indirect lighting increased in intensity with the distance from windows. The acoustic-tile ceiling stepped up in six-inch increments from a low point near the core to just above the windows, providing ample duct space with minimum loss of natural light.”*

The design was ahead of its time. It proposed a form of curtain-wall construction with full air conditioning. It included a then novel combination of escalators and passenger lifts. An integrated design considered the requirements of daylighting, artificial lighting, acoustics and accommodation for services.

According to Corbett, the proposal was for *"a highly specialised building designed primarily as a machine."*

However, the Depression forced the company to scale down its plans and the resulting alternative building, **[2.61]** was essentially the base of the tower only. It was constructed in three stages, the first of which was completed in 1933. The 30 storey-building, with an additional 4 basement levels, had 25 office floors (including ground level). The building was fully air conditioned with the refrigerating plant located in the lowest basement. [84, 85,] A description of the system **[2.62]** states [86]

> *"The fresh air is taken from outside at the fifteenth floor, where it is warmed or cooled, according to the season, and conveyed upward and downward to the other floors. At each floors are fans that mix the fresh air with a larger quantity of recirculating air and distribute the mixture locally. Cooling and filtering apparatus are provided for each fan unit.*
>
> *Figure [xiii] shows the distribution ducts of a typical floor. The air is introduced into the horizontally through grilles near the ceiling, which is stepped at the grille faces so that its height is increased toward the outer wall. This feature is unique.*
>
> *Figure [not included here] shows the exhaust system. It is necessary to remove and discharge to the outdoors a quantity of air equal to the amount of fresh air introduced. This quantity can largely be made up of exhaust from toilet rooms, restaurants ,etc., which should not be recirculated."*

Surprisingly, no mention is made of slightly pressurising the building with fresh air to minimise infiltration.

From the drawings and descriptions: [85] the first basement is a kitchen area, the second and third sub-basements are air conditioned lunch rooms; the fourth houses the refrigeration plant. The fifteenth floor plant room houses eight dehumidified fresh air fan systems (humidified in winter) with four large spray washers. These distribute air to fifty booster fan recirculating units (two per floor) fitted with reheat coils to temper the supply air to 70$^{o}$F In winter, the office heat loss is offset by under-window radiators. Return air is taken through ceiling exhaust grilles (about ten per floor) virtually eliminating a return air duct system.

The refrigeration plant consists of four centrifugal water chillers. Basement primary pumps deliver chilled water to the 15th floor where booster pumps deliver it to the washer sprays, before it drains by gravity to an 11,000 US gallon surge tank on the 13th floor, which in turn is connected to the suction side of the basement primary pumps

A review [85] of the air conditioning system's performance during the first summer of operation (1933) provides the following information:

| | |
|---|---|
| *"Air supplied* | *540,000 cfm* |
| *Square feet floor area conditioned* | *650,000* |
| *Refrigeration* | *1,350 tons* |
| *Cold water circulated* | *3,400 (US) gpm* |
| *People* | *6,500* |
| *Seating capacity restaurants* | *2,500* |
| *Lunches served per day* | *7,800* |
| *Electrical power connected* | *2,170 hp* |
| *Fans (number)* | *71* |
| *Dehumidifiers* | *7* |
| *Pumps* | *10"* |

The system was placed in operation in December 1932. Tests during the following summer note that indoor temperatures were maintained between 74 and 70°F dry bulb, with a range of relative humidity between 43 and 53% with outside conditions peaking at over 90°F dry bulb and around 74°F wet bulb temperatures.

## 1939 Johnson Wax Administration Building, Racine

A building that really took advantage of the opportunities that air conditioning offered before the Second World War was the Johnson Wax Administration Building [Frank Lloyd Wright, 1939] at Racine in Wisconsin. Like the Larkin Building, the site was in an industrial zone so Wright again decided to create an enclosed, sealed space and light it from above **[2.63]**. He promised to give his client, [87]

> *"..a beautiful building in which a person could 'feel as though he were among pine trees breathing fresh air and sunlight.' In the Administration Building Wright created a private, air conditioned working area nestled within a man-made forest (the striking reinforced concrete columns of the Great Workroom and Lobby), and though he screened out the surrounding environment, one element of the universe outside entered his forest - light which poured in..."*

Wright included several innovative features in this sealed building. Apart from air conditioning, it had underfloor hot water heating, and clerestory windows and skylights constructed from bundles of glass tubes to produce diffuse light. The air handling units were at roof level and resembled "nostrils" and carried out a similar function. In Wright's plan, [87]

> *"The fans, compressors and filters would be located at the base of the nostrils, and plenums within the mezzanine floor would spread the conditioned air through the Great Workroom. The use of integral plenums would almost eliminate the need to use sheet metal in the building. Ceiling ducts would circulate the air through the penthouse level."*

Although Carrier Corporation were consulted over these proposals, the air conditioning contract went to the York Company.

The new building created a sensation. The 8 May, 1939 issue of *Life* magazine described it as

> *"Spectacular as the showiest Hollywood set, it represents simply the result of creative genius applied to the problem of designing the most efficient and comfortable, as well as beautiful, place in which Johnson Wax executives and clerks could do their work."*

Comfort air conditioning for offices had been recognised.

## Postscript

With the exception of the Milam Building, the PSFS Building, the lesser-known Metropolitan Life, Frank Lloyd Wright's Larkin and Johnson Wax Buildings, and Le Corbusier's ill-fated "Cité de Refuge," comfort air conditioning made very little impact on the appearance of buildings up to the mid-1930s.

Strangely, one of the few that did was an office building for the Hershey chocolate company. The company decided to build a windowless air conditioned building in the *"very clean and beautiful country (side) of Pennsylvania"* [88] Another was a new office building for the Detroit Edison Company that avoided the need for 'U', 'H', or 'E' floor plans and constructed one of the first deep-plan buildings without light courts.[89]

In tall buildings, the amount of space required for vertical ducts remained a major drawback, even when intermediate floor plantrooms were utilised. Property developers found the large amount of space sacrificed to these ducts a major disincentive as they attempted to maximise their profit on every square foot. The era of the deep-plan office had not arrived, while most architects could not be bothered to take advantage of the design opportunities available by using air conditioning.

A textbook of 1933 sums up the then generally prevailing view relating to the air conditioning of office buildings [90]

> *"Before authorizing the expenditure of a large sum of money for the installation of air-conditioning equipment in a building and additional money for operating charges, the owner must know that there will be a reasonable financial return on the money invested. Comfort of employees or tenants is not usually considered a sufficient justification for the expense involved. In some types of office building, for example, the advantages are likely to justify the extra expense for the following reasons: (1) Comfortable conditions in parts of the building used by the public are a valuable asset to the business; (2) street noises are greatly reduced with constantly closed and locked windows; (3) dust (ordinarily disagreeably prevalent on the lower floors of buildings) can be kept out of the building; (4) number of employees can be greater in a given number of square feet of floor space; (5) constant control of temperature and humidity (during both summer and winter seasons) increases the efficiency of the employees because of constant comfort temperature and humidity, as well as also on account of the absence of distraction due to the manual adjustment of radiators, windows, and desk fans."*

In 1934 and 1935, 13 office blocks in Washington had air conditioning installed.[91] In 1936, Congress authorised that the Capitol, Old Senate Office Building (Russell) and the two House Office Buildings (Cannon and Longworth) were to be completely air conditioned (The Senate and House Chambers of the Capitol had been air conditioned in 1928). The Capitol power plant was provided with six 800 TR refrigerating machines
(a total of 16,800 kW)[92]

> *"Chilled water was generated at 40$^o$ F and was supplied to the four buildings on Capitol Hill through underground supply and return mains varying in size from 24-in to 12-in for a distance of more than 3/4 mile each way and experienced a temperature rise of approximately 12$^o$ F."*

The facilities were put into operation in 1938 and were, at the time, the largest central water chilling plant constructed in the USA for office building use. {By 1965, the total installed refrigerating capacity had grown to 15,400 TR (54,000 kW).}

A Chicago survey[91] of 1935 notes more than 900 air conditioning installations, of which 136 were in movie theatres (about half of the theatres in the city), 143 in restaurants and 171 in private offices (the last two categories were probably made up of mainly unit installations). Office buildings accounted for 83 installations. Details of the rest are not given, but may have been residential applications.

However, as the economy of the United States recovered from the Depression, in the late 1930s, air conditioning equipment sales doubled in one year, rising to more than $30 million in the first five months of 1937.[93] All of the major manufacturers -General Electric, Frigidaire, Carrier, York, Westinghouse, etc., produced room air conditioners which were mostly installed in offices. However, despite the availability of these room conditioners and of fan-coil units, which had been patented by Reuben Trane in 1933, [94] the technology was largely unchanged from the earliest installations by Alfred Wolff and Willis Carrier. In most air conditioned buildings of this period, before the Second World War, the systems were of the all-air type. The technology for terminal systems was known and published, [95, 96] but hardly applied. However, change was imminent.

Since the 1920s Willis Carrier had, from time to time, looked for a solution to the problems of air conditioning tall multi-room buildings. Carrier thought the answer to reducing the floor area occupied by vertical ducts lay in using high duct velocities. He then had to find a way of dealing with the energy of the high-velocity air when it reached the room outlets. The answer was to use the principle of the ejector nozzle which the Carrier Corp had used for many years in industrial drying applications. Fortunately, the nozzle design had been patented by Dr Albert Klein, the Carrier representative in Germany, who had sold them to Buffalo Forge, where Willis Carrier has started his career. He devised what was to be the forerunner of the room induction unit, starting in 1928 with an experimental system in the company's own offices in Newark. Other early systems were installed in offices in New York, Virginia, Ohio and in the Pentagon Building in Washington.[11] The first sill-height low pressure "Weathermaster" induction units were sold in 1930 to the Super-heater Co of East Chicago, Indiana. In the same year, Weathermasters were used in the

Phoenix Title & Trust Co Building and in the California Bank of Los Angeles. By the end of 1934 twenty-three buildings were using Weathermaster units. The problem of large air risers was not overcome until 1938, after much practical work on the development of circular high pressure ducting. By the end of 1939 Carrier had successfully developed a complete high velocity Weathermaster induction system, filing his patent application on 12 August, 1939. From now on it would be possible to air conditioning both new and existing skyscrapers by the space-saving “water-air” induction unit system.