Chicago, Bird’s-Eye view, 1893.

The Story of Comfort Air Conditioning

An Introductory Essay
The Evolution of Office Buildings and Air Conditioning

Text Section
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It is considered that 10 cubic feet per minute should be provided for each individual. This estimate is given with much diffidence and only as an approximation.

“Illustrations of Ventilation,” Dr David Boswell Reid, 1844.

Buildings featured in the main body of the book are shown in **bold**.

Names of architects and construction dates for buildings referred to in this essay are given in brackets.

A short biography of those engineers and architects whose names are underlined is given in Appendix-1.

A list of the principal buildings referred to in the main body of the book, with construction dates and names of the architects and ventilation or air conditioning engineers (where known) are given in Appendix-2.

References are given in Appendix-3.

Building names in **blue** have been visited by the author, the Heritage Group or colleagues.

**E1. Early Ventilation and Cooling**

Over the centuries man developed first buildings and then engineering services\(^1\)\(^,\)\(^2\)\(^,\)\(^3\) in attempts to stay cool indoors when space temperature and relative humidity would otherwise rise to uncomfortable levels as a result of climate, unwanted solar radiation or internal gains from people, lights and equipment.

In very hot and dry tropical climates, traditional styles of architecture have been developed to give the best possible protection from the climate. The thick-walled buildings of the Sahara are particularly efficacious in maintaining equable temperatures inside. The white exteriors reflect sunlight; the narrow streets give maximum shade; the small windows exclude solar heat and the courtyards trap the cold night air. Rather similar characteristics typify the architecture of those European countries bordering the Mediterranean. In warm and wet or humid climates, where diurnal temperature changes are slight, native architecture uses light buildings with opportunity for copious or cross-ventilation.
Harnessing the prevailing wind to improve natural ventilation has been practised since very early times [E.1]: “The earliest known reference to (the) use of ventilators to convey cooling breezes down into a room is an 8th-century BC Assyrian inscription”. But architecture [E.2, E.3] gives only limited protection against the climate.

Wind-ventilation structures include the unidirectional wind-scoop [E.4] and the multidirectional wind-tower [E.5] with inlets high above the roof, where wind speed is greater and the air less laden with dust. Wind-scoops are to be seen in Baghdad, Pakistan, Afghanistan and in Cairo, where they are called “malqaf”:

“The wind-catcher consists of a fixed inlet made of brick, timber or metal, and inclined at about 45° to the prevailing wind, which it deflects into a channel built into the wall of the building. The conduits are preferably interior walls, not subject to direct solar radiation. After passing through the rooms, the air disperses into the courtyard, pushing warm air upwards.”

In central and southern Iran (Persia), high multidirectional wind-towers, or “badjeer” are a characteristic architectural feature. Such tower systems [E.6] often operate with a domed-roof building (to take advantage of warm air stratification) and an air vent (to maintain a circulation of air through the occupied room). More sophisticated versions may work with underground tunnels (earth cooling), fountains or underground streams (evaporative cooling), and cisterns of cold water.5

Marco Polo, who visited the city of Hormoz in the Persian Gulf in the late 13th century, commented: 4

“The climate is excessively hot -so hot that the houses are fitted with ventilators to catch the wind. The ventilators are set to face the quarter from which the wind blows and let it blow into the house. This they do because they cannot endure the overpowering heat.”

The Persians also used a passive ice-maker (though not for cooling the air supply to buildings), taking advantage of the near-freezing temperatures of winter nights in the desert.5

A drawing [E.7] of a three-storey town house of a notable of Thebes in Ancient Egypt, c.1550 BC, shows private apartments on the first floor and offices on the second. Ducts were built into these ceilings to enable air to circulate and reduce the rise in internal temperature. This may be the earliest drawing of a ventilated office.
It was the Romans from about 80 BC, in their quest to colonise the temperate areas of central and western Europe, who became pre-eminent in the development of heating and ventilation using the “hypocaust” in both their large public baths and in their villas.\textsuperscript{6} The hypocaust was a warm air heating and ventilation system which used an underground furnace with hot gases circulating through the space below the floors of the living area, which were raised on pillars. Other hypocaust systems used wall heating and direct warm air supply. Later still (c.2nd century AD), the hypocaust pillars were abandoned and instead smoke-ducts were formed in the sub-floor and connected to wall flues, providing a system that could be adapted for ventilation.

The Roman Emperor Varius Avitis is said to have ordered that mountain snow be brought and formed in mounds in his garden so that the natural breezes might be cooled.\textsuperscript{7} It has also been reported that around 775 AD Caliph Mahdi of Baghdad built a summer residence with hollow walls into which snow was packed and about the same time, a magician in the service of another Caliph, “.....devised the first real forced-air cooling and dehumidifying system [E.8]. He had slaves fanning air over cakes of snow and down through a hole in the ceiling.....”\textsuperscript{8}

The Alhambra in Spain (begun 1230), the palace of the rulers of Granada, is the most famous of the works of Moslem architecture in that country. In the Halls of Baths,

“.....the roof is perforated with ventilation openings, and it is not only of the best form for the purpose of ventilation, but the openings themselves are of the best possible shape, being wider at the lower extremity than at the upper; and in order that these openings may present the least possible amount of friction to the outgoing air, they are provided with short tubes of baked earth, covered with a green vitreous glazing.”\textsuperscript{9}

It is claimed that the chimney was invented in Italy, the earliest account being in 1347. By Henry VIII’s time their use was quite common. Later, the possibilities of using chimneys for heat-assisted ventilation would be realised. However, “ventilating machines” seem to have been first described by Agricola in his textbook\textsuperscript{10} on mining of 1556. Woodcut illustrations depict simple wind-towers, bellows operated by men or horses, and primitive wooden fans [E.9] with hand-cranks for manual operation connected to windmills or through gearing to water-wheels.

At the city of Jaisalmer (mainly developed during the years 1750-1850) on the Indian sub-continent, the town and its buildings overcame the problem of the severe desert summer by special passive design features: dense clustering of buildings, sun control through orientation and structural projections, cooling of sunlit faces by use of fins, massive construction for roofs and walls, and the use of courtyards and other air ducts for ventilation.\textsuperscript{11}
It was for London’s Houses of Parliament that the first serious attempts at providing ventilation were made, beginning with a system designed by Sir Christopher Wren in the 1660s. In 1723, a system using ventilating fires was tried by Dr Desaguliers but proved unsuccessful after housekeeping staff refused to light the fires. In 1736, Desaguliers installed his 7 ft (2.1 m) diameter mechanical fan, or “fanner” [E.10], to serve the Commons. This was cranked by hand by a man called the “ventilator” and remained in use until 1817. Meanwhile, Stephen Hales wrote his Treatise on Ventilators (1758) and used a bellows ventilator at a hospital in Winchester, England. In 1834, the Houses of Parliament were destroyed by fire. The rebuilding, the acrimonious disputes between the architect Sir Charles Barry and the ventilation engineer Dr David Boswell Reid, details of the heat-assisted ventilation schemes and the on-going problems have been extensively documented.12,13,14,15

Another famous government building, the United States Capitol [Thomas U Walter, from 1851] in Washington, DC was provided with an elaborate system of plenum ventilation using two large supply fans, one 16 ft (4.9 m), the other 12 ft (3.7 m) in the basement [E.11] with natural exhaust through roof louvres.15 Beginning in 1855, the work was directed by Captain Montgomery Meigs who employed the services of Robert Briggs, a consulting engineer from Boston, and Joseph Nason, a New York manufacturer, and has been described “...as the first really scientific and complete job of its kind done in the country.”

It was also in the 19th century that a number of innovative ventilation schemes were installed. One of the first, which has been described as “a landmark in the technology” was the design [E.12] for Pentonville Prison, London [Major Joshua Jebb RE (Royal Engineers), 1840]. Underground cold air flues delivered fresh air to heating coils from where it ascended in vertical risers with a branch to each cell. Vitiated air was drawn via low level extract grilles from each cell into a common air shaft, joining the boiler flues at attic level, an attic fireplace providing the power for foul air extraction in summer.16 Another notable prison heating and ventilating design was that provided for London’s Wormwood Scrubs Prison [Major General Sir Edmund Frederick Du Cane RE, 1885].17 The ventilating system [E.13] installed at the Pueblo Opera House, Colorado [Adler & Sullivan, 1891] used a hot and tempered air mixing device to regulate supply air temperature.15

It has been said that around 1842, Dr John Gorrie of Apalachicola, Florida, devised an air-cooling system to treat fever-stricken sailors by blowing air over buckets of imported ice. But no description of his air-blowing mechanism has thus far been discovered.18 However, Gorrie did go on to invent and patent a cold-air refrigerating machine in 1851. In 1861, George Knight of Cincinnati wrote an article for Scientific American, proposing a hospital cooling system.7 Shortly thereafter in 1865, Nathaniel Shaler of Newport, Kentucky proposed an improved air cooling apparatus [E.14], having a heat exchanger made with “ice-holders” placed in a “tortuous passage” through which room air is blown to cool it.7 Shaler also suggested placing a dessicant in the airstream.
Possibly the most famous early ice-cooling system was that devised by Naval engineers to relieve the suffering of US President James Garfield in 1881 as he lay dying from an assassin’s bullet. Air was passed, “.....through dozens of thin cotton screens onto which dripped the cold meltage from a salt-ice mixture contained in a tank above. The cooled air was ducted into the President’s bedroom, resulting in as much as a 20° F (11° C) temperature drop.”

However, the earliest cooling and air conditioning systems were largely for industrial or manufacturing applications, though comfort cooling using ice-blocks or water sprays can be traced back to the second half of the 19th century. Ice-bunker air conditioning systems [E.15] were still in use in the 1930s.

Particularly active around the turn of the century in promoting the benefits of ventilation were John Billings and Benjamin Sturtevant in the USA and Robert Boyle Jr in Great Britain. Also in Britain, William Key obtained a patent for cooling (1890) and is believed to have influenced Henry Lea’s design for the air conditioning at the Royal Victoria Hospital, Belfast [E.16] [William Henman, 1903], installed by Samuel Davidson (who designed the “Sirocco” fan). William Key also designed the air treatment plant for the Glasgow School of Art [Charles Rennie Mackintosh, 1904].

A pioneer of industrial air conditioning was Stuart Cramer who is generally credited with coining the term “air conditioning.” Many early comfort systems were for theatres and concert halls. The first major comfort installation using mechanical refrigeration, designed by Alfred Wolff (probably based on the work of the German engineer, Hermann Rietschel), appears to have been the Stock Exchange in New York in 1903. By the 1920s a small number of comfort cooling systems had been installed in hotel public rooms and in department stores. But comfort air conditioning was to become a major industry in the USA with the boom in the building of movie theatres, largely brought about by the introduction of the “talkies.” It was provided in many thousands of theatres, being largely pioneered by Frederick Wittenmeier in Chicago, and by Willis Carrier in New York. Though on a much smaller scale, and a few years later, the same pattern was repeated in the UK. The widespread provision of air conditioning for offices came much later.

**E2. Development of the Office Building**

The Greeks, the Romans, and later the important trading cities of medieval Europe had buildings for conducting business. In Rome (1st century BC), the Tabularium, or Public Record Office was both an office building and a repository of official records. The Uffizi in Florence, now a famous museum and art gallery, originally included municipal offices with council chambers, courts and public spaces. While other earlier buildings had some office accommodation, the eminent architectural historian, Nicolas Pevsner, puts the Uffizi [Giorgio Vasari, 1560-71] forward as the first office building (Ufficio is Italian for office). It was built in the centre of the old city and designed for the Medici duke, Cosimo I, to provide government offices for the new state of Tuscany. It appears the architect encountered many similar difficulties to his counterparts today. Some of the great medieval town halls were to a large extent office buildings -Antwerp (1565), Amsterdam (1655).
During the 19th century, the growth of insurance companies meant large buildings were needed to house the rapidly increasing numbers of clerical and administrative workers. Arguably, the first example of a commercial office building [E.17] is the County Fire Office [Robert Abraham, 1819] in Regent Street, London; many others followed. The first so-called office described in the magazine *The Builder* (founded in 1844) is the New Imperial Insurance Office [John Gibson, 1848] in Threadneedle Street in the City of London, described as “an early office block with fireproofing features.” 20 How, or if, these buildings were heated and ventilated has not been established. However, an early important commercial building is the National Provincial Bank of England [also by Gibson, 1865] at 15 Bishopsgate, London. Here, the ventilation was provided by the pioneer ventilating engineer Wilson Weatherley Phipson using the “System Van Hecke” described as a steam-powered system.20 (Phipson had served as a Dr Hecke's assistant for the heating and ventilation of numerous hospitals in France and Belgium. 21)

It is claimed that New York's first building to be constructed solely for use as office space was the 5-storey Trinity Building at 111 Broadway [Richard Upjohn, 1840s], built by the Trinity Church as a speculative venture. The potential of the elevator in office building was first realised with the 130 feet (40 m) *Equitable Life Assurance Building* at 120 Broadway, New York (1870), which had a heat-assisted ventilation system designed by the Philadelphia engineer Lewis Leeds.

A wave of government ministries offices erupted in and around Whitehall in London during the 17th century. The first proper government office is often regarded as Somerset House [Sir William Chambers, begun 1776], having a river frontage of 800 ft (244 m), a huge inner courtyard of 350 ft x 310 ft (106 m x 95 m) and offices arranged “on the left and right of long spinal corridors.” 19 Many other government ministries were provided with large purpose-built office buildings following the establishment of the Office of Works in 1851. Prior to this, many government departments were housed wholly or in part in rented houses originally built for family living and, before replaced, scathingly referred to as “rabbit warrens.” These new offices were built to house the administration for Britain's powerful navy and for the expanding British Empire. A notable example is the huge Foreign & Commonwealth Office, completed in 1867, and heated by fireplaces with opening windows for ventilation. In the United States, an important government building was Washington's *Old Pension Office* of 1887 which, though innovative in many ways, relied on natural ventilation.

Most of the large offices built up to and around the end of the 19th century reflect the styles of classical architecture. The internal environment provided for the workers in the offices of this period was determined largely by building features such as structure, fenestration, plan form and storey height. These were based on designs that can be traced back to antiquity and share characteristics with Italian palaces of the Renaissance and the Roman houses described in Vitruvius's *The Ten Books of Architecture*. Protection from extremes of climate was often restricted to passive measures such as opening windows, using external shading devices [E.18] and lowering internal shades when it was hot: using coal fires or stoves, circulating fireplaces [E.19] to promote ventilation, and eventually radiators when it was cold. These features
were also determined by other factors including finance, function, location, current technology and architectural fashion.

The earliest office buildings were of load-bearing masonry construction. The 9 1/2 storey Mills Building [G B Post, 1883] at the corner of Broad Street and Exchange Place, New York, with a floor area of 200,000 square feet (18,500 m²), was described as “the first modern office building.” This is said to have been the first office building in the world to have had its own electricity generating plant, powering 5588 lights. [London’s Prudential Assurance Office in High Holborn [Alfred Waterhouse, 1878-1905] was provided with its own electrical generating plant in 1886 as part of a combined heat and power installation, possibly the first ever example of such, to a design outlined by Wilson Phipson].

In New York: “In the business section on the Battery, entire blocks were soon filled by nine- and ten storey office buildings, but because of the inherent structural problems of masonry-bearing wall construction above that height, few buildings rose higher than this new limit.” The limit on height with this form of construction was reached by Chicago’s 16-storey Monadnock Building [Burnham & Root, 1891] which required walls 6 feet thick (1.8 m) at the base.

The cost of land, the perfection of the elevator [E.20], the introduction of the telephone, the development of effective fireproofing [E.21], improved techniques for the building of foundations, and the potential profits to be made by building to rent, all led to the development of the first skyscrapers. But the technological breakthrough that made tall office blocks a reality was the development of the steel-skeleton frame [E.22] as first used in the 9-storey Home Insurance Building, Chicago [E.23] [William Le Baron Jenney, 1885].

The new technology was rapidly exploited. In Chicago, the Masonic Temple office building [Burnham & Root, 1892] at 20 storeys and 302 feet (100 m) was briefly the tallest building in the world. Although electricity was common by this time, the high cost and low output of the lamps meant that office work was still carried out by daylight. Gas lighting for offices was not popular due to the heat, the smell, and the need for ventilation. The ability to illuminate the full depth of an office by daylight was an important consideration. Although it limited the maximum depth of the office between the outside wall and the internal corridor, it also meant that natural ventilation was available from opening windows. The provision of adequate daylight, and the consequent requirements of window size and limitations on depth of offices, was a major problem to architects attempting to provide the maximum floor space (and potential profit) from building plots. Architects of this period generally adopted European classical styles and quickly realised the advantages to be gained by the use of internal light courts. This allowed the use of both perimeter and internal offices, the latter overlooking a court extending the full height of the building [E.24] as in the Chamber of Commerce Building, Chicago [Baumann and Huehl, 1889]. Here, the 200 feet (61 m) high space was described as “admitting a perfect flood of light (that) penetrates the central court so that the interior of the building is almost as brightly illuminated as the exterior during the day.” The additional daylight and ventilation provided by this type of layout allowed property investors to obtain the best ratio of lucrative office floor area to plot size.
Nowhere is this better demonstrated than in Chicago where a colossal office building boom followed in the aftermath of the Great Fire of 1871. However, the imposition of a 130 feet (40 m) height restriction in 1893, due to overbuilding and a real-estate recession, led to the adoption of a monumental style of office buildings named the “Chicago Quarter Blocks,” because they just filled the width of the blocks between streets [E.25]. In the absence of air conditioning and effective electric lighting, an almost standard form of Chicago office block developed: a large square in plan with two rings of offices, perimeter and inner court. The hollow square plan was often replaced by the U-shaped plan (as used at the Uffizi), which improved the daylighting of the court. The result was that “the skyline of Chicago was relatively low, flat-topped and homogeneous.” [23]

Another important innovation was the “Chicago window,” developed to improve daylighting and facilitate natural ventilation: “a broad expanse of glass that featured a large fixed centre-pane with movable sashes on either side,” [24] its advantages demonstrated in the early type of curtain wall [E.26] used in the steel-framed Studebaker Building [S S Beman, 1895]. [25] The basic need to provide daylight in offices was a constraint of every office building and was common to all styles of building evolving in major North American cities. The Chicago style was used elsewhere, a well-known example being the reputed model office building of its time, the Wainwright Building [E.27] in St Louis [Louis Sullivan, 1891]. The U-shaped court provided interior daylighting, but early photographs [E.28] show that external shades were a necessity for exterior sunlit offices.

A different solution to the design of office buildings was followed in New York from around the beginning of the 20th century. Cass Gilbert, later the architect of New York’s Woolworth Building (1913) defined a skyscraper as “a machine that makes the land pay,” [26] for in Manhattan building plots tended to be relatively small and very expensive. Thus, in New York the tower style of office building proliferated and “offices could be arranged in a shallow ring of rentable space surrounded by a central core of circulation and mechanical services.” [23] The provision for heating and ventilation for these offices was rudimentary. For example, the Mutual Life Building (1884) had radiators, natural fresh air inlet through sash inlets and mechanical extract [E.29]. Nearly thirty years later, The Woolworth Building was provided with a Dunham system of vacuum steam heating with radiators, allied to a mechanical fresh air ventilation plant. [26] The number and bulk of skyscraper offices led in 1916 to the introduction of the zoning ordinance which limited the maximum volume allowed for the lot, producing the distinctive style of “wedding-cake” setbacks. Though later buildings increased in size and height, for example the Chrysler [E.30], the Empire State [E.31] and Rockefeller Centre [E.32], the office areas were still not provided with air conditioning. Office air conditioning was pioneered neither in Chicago nor in New York. [27]
E3. The Growth of Office Air Conditioning

Frank Lloyd Wright's Larkin Building at Buffalo had refrigeration added into the ventilation system, either in 1907 or 1909 (sources conflict). Another existing office block to which air conditioning was added was the T W Patterson building in Fresno, California in 1926.

The first major office building to have air conditioning provided when built is generally accepted as the Milam Building in San Antonio, Texas, in 1928. Other early air conditioned offices are few, but probably most notable are the PSFS Building in Philadelphia (1932), Metropolitan Life, New York (1933), and the Johnson Wax Administration Building in Racine, Wisconsin (1939). In the UK, one major building to be comfort air conditioned before the World War II was London’s Broadcasting House for the BBC (1931) where the cooling was for internal radio studios. In Europe, Le Corbusier sought to develop architectural solutions to environmental control, as at the Salvation Army Refuge in Paris (1933). From 1900 to 1939 may be considered the period of the rise of air conditioning, when pioneer manufacturers like Reuben Trane developed new equipment.

Major strides in the air conditioning of offices blocks in the USA had to wait until after the end of World War II. One of the most significant is the Equitable Building in Portland, Oregon (1948). Numerous major air conditioned office blocks followed, including, in New York: the UN (1950), Lever House (1952) and the Seagram (1958). In Europe, after the War, an early major air conditioning scheme was for the trading areas of Lloyds of London (1957). On the continent, air conditioning was provided for the Mannesmann (1958) and Phönix-Rheinrohr (1959) buildings, both in Düsseldorf, and the Pirelli Office Tower (1959) in Milan. The first rush of UK air conditioned office blocks came in 1962: E S & A Robinson, Bristol; the CIS, Manchester; Shell Centre and Millbank Development in London. In France, the first air conditioned skyscraper in Paris, La Tour Main-Montparnasse, did not appear until 1974.

The period after World War II, up to around 1978, may be considered the boom years of air conditioning, but the 1970s saw the first major world energy crisis and spiralling energy costs. Air conditioning designers developed many forms of heat recovery system and apparatus, which were often omitted at the last minute on grounds of capital cost. However, the profligate use of energy became less and less acceptable. Lessons and ideas from the past were incorporated into new buildings: passive architecture, thermal storage, natural and nocturnal ventilation, reduced artificial lighting and better use of daylighting. Conventional comfort air conditioning for offices entered a period of decline. With increasing concerns over the ozone layer and global warming, it may yet give way to alternative environmental control solutions.