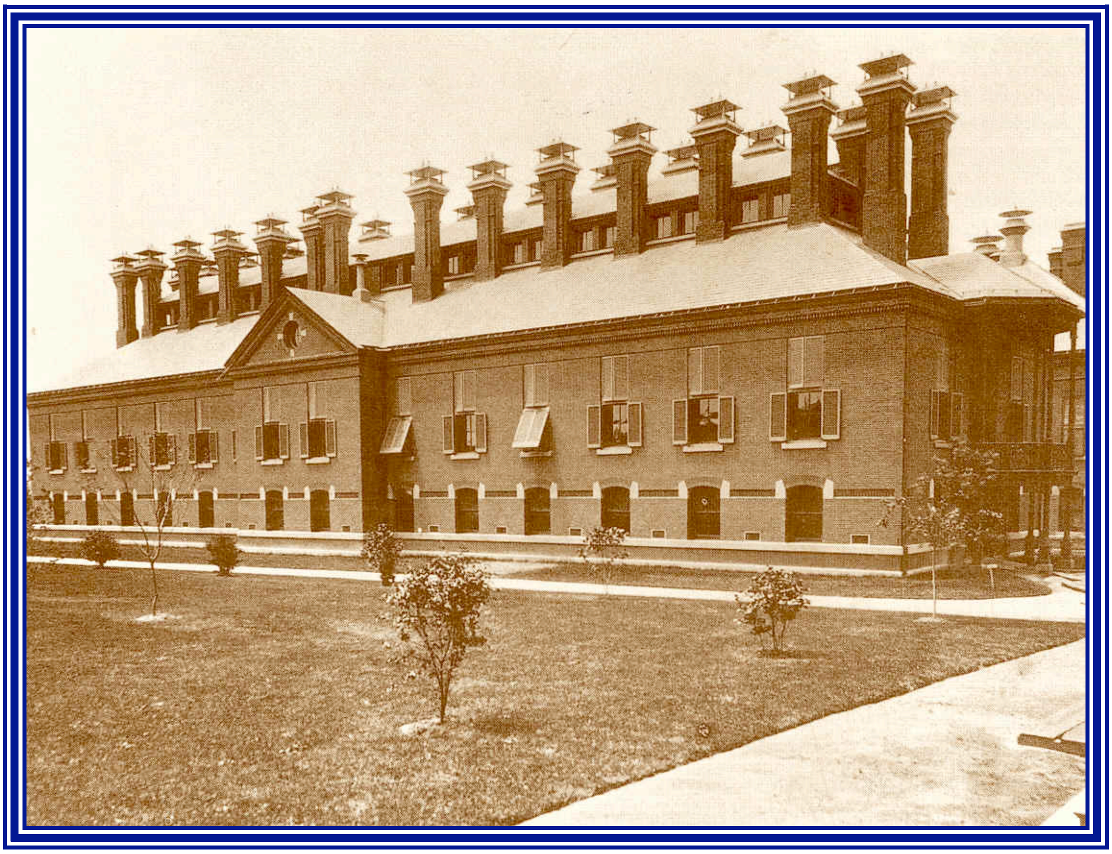

Natural ventilation towers, John Hopkins Hospital, Baltimore, 1885.

The Story of Comfort Air Conditioning

Part-1 Nineteenth Century Ventilation & Cooling

Text Section

Part-1
Nineteenth Century Ventilation & Cooling

"Pure air is the breath of life; foul air the angel of death."
Catalogue: "The 'Boyle' System of Ventilation," c.1900

1.1 Natural Ventilation

1851 Crystal Palace, Hyde Park, London

One of the largest and most impressive of the early iron and glass structures was the Building for the Exhibition of the Works of Industry of all Nations [Sir Joseph Paxton], better known as the Crystal Palace, erected in Hyde Park for the Great Exhibition of 1851. It was remarkable for its size, the speed of erection and being prefabricated in standardised parts.[1] It was 1848 ft (563 m) long by 408 ft (124 m) wide and the central transept was 108 ft (33 m) high. The enclosed volume was some 33 million cubic feet (940,000 m^3).

The structural design incorporated means of collecting and taking away both rainwater and internal condensation from a roof area of nearly 18 acres (7.3 ha). There was a major network of water mains with steam boilers, in their own miniature Crystal Palace boilerhouse, used to power the various engines and machinery on show. The building itself was unheated (it was after all conceived as a temporary structure). However, considerable thought was given to the provision of ventilating louvres and a system of solar blinds to reduce heat and glare. The natural ventilation scheme **[1.2]** was described as follows: [2]

"THE VENTILATION. Is obtained by means of louvres set in boxings, inserted behind the 'filling-in' frames of each of the three stories of the building- and in the dado, between the lower and upper cills on the ground floor. At the springing of the transept roof, a line of louvres is inserted on both sides, 3 feet 8 inches (1.12 m) high, running the whole length of the transept; and at the very summit of the curved roof, ventilation is obtained in the gables of the roofing, where it is interrupted by the narrow path of the upper lead flat. The total quantity of ventilating area in the louvres equals about 45,000 feet (4170 $m^{2)}$, in addition to which, large volumes of air will necessarily be introduced at the numerous doorways. The louvre frames on the ground floor consist of boxes, in which eight louvre blades of galvanised iron $6^1/_2$ inches (165 mm) wide, are fixed on pivots at 6 inches (152mm) from centre to centre, and so curved as to offer the minimum interruption to the ingress, or egress, of air when open, compatible with keeping them weathertight. Small iron brackets, attached to the centre of each blade, are furnished with eyes, through which are inserted pins, passing also through holes bored at equal distance from one another, in a species of rack: by drawing these racks up and down, the opening and closing of the ventilators is effected.

A number of these racks will, of course be attached to levers, and set in motion by rods and cranks; Mr Fox (of Fox Henderson & Co of Smethwick, the structural engineers and contractors) has designed an ingenious scheme of producing the simultaneous action of a considerable number, and at the same time of securing the uniform position of the louvre blades at any desired angle. Should it ever be found necessary to reduce, by artificial means, the internal temperature of the building below that of the exterior, Mr Paxton has proposed a system of cooling, applicable to these ventilators, somewhat on the principle of the Indian 'tatties'."

In 1852 the Hyde Park building was taken down and transported to Sydenham where a modified, larger building was re-erected. The Crystal Palace was totally destroyed by fire in 1936.

1867 Foreign & Commonwealth Office, Whitehall, London

Plans for a New Foreign Office [George Gilbert Scott & Sir Matthew Digby Wyatt] were commenced in 1858. Having won 3rd Prize in a competition for its design, Scott was originally appointed as architect. His commission was later extended to include the incorporation of a new India Office, but as Wyatt was already the India Office's Surveyor the two architects agreed to collaborate in the design of this project which has been called "quite gigantic...in comparison (with which) the Farnese Palace 'is a hut'." [3] However, following a change of Government, Scott was obliged to change his Gothic design to an Italianate style.

In the revised design, the large building of some 650,000 ft^2 (60,000 m$^{2)}$ was arranged as a number of smaller buildings, reminiscent of Italian villas with open courts, around a much larger open quadrangle **[1.3]**. Every office was provided with natural light and ventilation from a window with room depths limited to around 13 ft (4m) from the outside wall to the corridor. The storey heights are quite magnificent with the first floor (piano nobile) at almost 23 ft (7m) and even the lowest, on the third and fourth floors, around 11 ft (3.4m). Fireplaces were arranged back to back to heat every office with the dividing walls constructed from 9-inch (230 mm) brick to conceal the chimney flues.[4] The high ceilings and the large thermal mass of the building inevitably meant that the offices would be reasonably cool during the height of summer. Although the windows are large the thermal mass of the building restricts the rise in internal temperature. Early photographs show blinds on the outside of southerly facing windows. This may have been more fashion than need as the refurbished building [5] is still in use today without air conditioning.

1887 Old Pension Office, Washington, DC

This the oldest, and one of the largest, atrium buildings in the United States housed the Pension Bureau [General Montgomery C Meigs] which administered pension payments to 2.7 million veterans and their families for service in wars from the American Revolution to the Civil War. Meigs design was inspired by the Renaissance palaces of Rome, most notably the Palazzo Farnese and is said to have used 15.5 million red bricks. [6]

The Pension Office contained offices for 600 clerks located in galleries surrounding a 159 ft (49 m) tall interior court with an iron-trussed roof. A notable feature of the construction was the eight Corinthian columns 75 ft (23 m) tall and 8 ft (2.4 m) in diameter **[1.4]**. Meigs introduced a number of innovations to the building. Most corridors were eliminated. There was double-pane glass in the windows while a central clerestory admitted ample natural light and provided good natural ventilation. It was said, “One of Meig’s primary concerns was the welfare of the workers and the pensioners who visited on a monthly basis. He wanted a thoroughly ventilated building with no dark corners, passages or corners.” [7] Perhaps fittingly, the building now houses the National Building Museum.

1887 Dumbbell Tenements, New York

In 1878, the architect James E Ware won a competition sponsored by the journal *Plumber and Sanitary Engineer* to design an apartment block for workers to suit a site measuring 25 x 100 ft (7.6 x 30.5 m). Dumbbell tenements (named for their shape) were usually five to seven storeys high with fourteen rooms on each floor **[1.5]**. These rooms were arranged seven on each side from front to back, divided into 2 four-room apartments (front) and 2 three-room apartments (back). The four apartments shared two toilets. [8]

In 1879, New York State passed a Tenement House Law requiring a window in every bedroom. This obligation was met by providing a combined air and light shaft, measuring some 12 ft (3.7 m) at the widest point, but generally only a miserly 4 ft 8 in (1.4 m) wide, the main part being formed by the indented hallway sections of abutting tenements. These air shafts were notoriously dark and airless, frequently used as a rubbish dump, and thus a fire hazard. Their use to provide natural ventilation was not a success (but at least a place in musical history has been assured by Duke Ellington through his jazz recording Harlem Air Shaft in 1940.) Further construction of dumbbell tenements was banned in 1901, though by then they housed some 2.3 million New Yorkers, many continuing in use into the 1990s.

1890 Workhouse Infirmary, Newton Abbot

The ventilating engineers Robert Boyle Senior, and later his son Robert Boyle Junior, were vociferous advocates of the benefits of natural ventilation systems. Their company produced a series of publications extolling the virtues of the Boyle patented self-acting “air-pump” natural ventilator, scorning both hot air aspirating shafts or the use of fans. A typical publication[9] described ventilation requirements, gave numerous testimonials from the Royalty and Nobility, provided extensive lists of Public Buildings fitted with their system, included application drawings for many types of buildings, and provided a detailed catalogue and price list of ventilators and accessories.

Boyle's Rules for an Efficient System of Natural Ventilation include the following:

"Care should be taken in the employment of ventilators that both the outlets and inlets are sufficient in size and number, and so placed as to effectively accomplish the work they have to do. The outlet ventilators should be fixed on the highest part of the roof, clear of all obstructions, so that the wind can reach them freely from every quarter. The fresh air supply should be properly proportioned to the extraction. The combined area of the inlets, should, in all cases, be at least equal to that of the outlet shafts. Main exhaust shafts should be at least of equal area to the combined area of branch connections........ The vitiated air should be extracted at the ceiling, to where it naturally ascends. The fresh air should be admitted directly through the walls at a low velocity, in an upward direction, through a number of small inlet brackets or tubes distributed round the walls to secure more complete diffusion and an equable movement of the air in all parts of the building........."

The arrangement of air pumps, shafts and accessories, including ventilating radiators, provided for the Workhouse Infirmary at Newton Abbot, in Devon, is detailed on Boyle's scheme drawing **[1.6]**.

1.2 Heat-Assisted Ventilation

1850 Guy's Hospital, London

The original Guy's Hospital [Thomas Dance] was completed in 1725, being a three-storey building with basement and attic, designed to accommodate 400 patients: [10] "The wards were lit by opposed windows, but box-beds lined the walls with no regard to the fenestration, impairing the ventilation."

A drawing of 1850 **[1.7]** taken from a textbook by the French ventilation engineer General Morin shows, in section, the arrangements for ventilation of Guy's Hospital at that time.[11] Outside air is drawn in through the top of a fresh air intake tower (right) and into the basement, where it is heated in the annular space around a jacketted flue and rises up to be discharged at the top of the higher exhaust air tower (left). The heat-assisted rising column of air draws stale air out of the wards. The system was designed by John Sylvester, son of Charles Sylvester, the father having earlier worked with Wm Strutt on the warm air ventilating installation of 1807 at the Derby Infirmary. John's Company was later to become the well-known UK heating contractor, Rosser & Russell.

1870 Equitable Building, New York

The Equitable Life Assurance Society was founded in 1859. By 1867 it was one of the largest insurance companies in the United States and decided it must have a new headquarters building [Arthur Delevan Gilman & Richard Morris Hunt, then George B Post]. The building, now demolished, when first completed in 1870, had a height of around 140 ft (43 m) with 8-storeys and a basement. This is not apparent from contemporary photographs, since some levels were concealed by huge windows, nearly 9 ft wide x 17 ft high (2.7 x 5.2 m).[12]

Steam-powered lifts were installed at the insistence of Post and Henry Baldwin Hyde, the founder of Equitable. The lift shafts rose to 130 ft (40 m) said to be the highest of any at that time. The lifts were built by Otis Tufts (not to be confused with the Otis Elevator Co) and described as the "largest, most complete, and comfortable ever constructed...in constant but noiseless motion", leading the Equitable to be described as "the first business building in which the possibilities of the elevator were realised." It was also one of the earliest buildings to have electric lighting when, in 1878, arc lamps were introduced on an experimental basis in the corridors.

The building incorporated a system of forced draught ventilation designed by the Philadelphia engineer Lewis Leeds, who had earlier achieved a certain amount of fame through his 1866-67 series of lectures **[1.1]** on ventilation at the Franklin Institute: [13]

"Leeds illustrated his lectures using a magic lantern to show the way air currents behave with various arrangements of heating apparatus. In the little domestic scenes on the screen, the audience could observe how the people sat in clouds of purple air that had been vitiated while robust, pink, fresh warm air clung to the ceiling because of faulty design of the heating system."

Leeds's system for the Equitable incorporated a system of forced draught ventilation **[1.8]** which used a complex arrangement of flues to move the air by means of heated shafts, rather than the more usual steam-driven fans of the time. But the system was not a success. Post, in particular, was highly critical and said he thought not one of "the entire collection of shafts carried off one cubic foot of foul air per hour."[12]

1881 Natural History Museum, London

The design **[1.9]** for the Natural History Museum [Alfred Waterhouse], a large and complex building 680 ft (207 m) long x 130 ft (40 m) high to main roof level, is principally derived by the need for adequate daylighting, provided by a series of glass-roofed galleries. Additionally, the building incorporates a complex system of basement tunnels and vertical towers for the heat-assisted ventilation system the details of which have been researched in some detail in recent years. [14, 15, 16]

Fresh air was drawn in through six openings along the north wall at ground level. A detail of a typical basement air intake/supply tunnel **[1.10]** shows a double or stacked duct (one cold, one warmed) to provide local mixing control of temperature. The warmed air tunnel as shown was 5 ft (1.5 m) wide by 2 ft 6 in (0.76 m) high to the top of the shallow vault and contained a battery of 15 steam pipes. At this point, the separated cold (unheated) air supply beneath measured 5 ft (1.5 m) wide x 9 (0.23 m) in high. This air was supplied through small vertical risers connected to floor outlet grilles in the galleries. Further steam-pipe batteries in the tunnels "heated the air for tempering and to give it buoyancy." The exhaust air was discharged through six "Vent Towers." On the south main face there are four towers 193 ft (59 m) high: two flank the main entrance with a further two in corner pavilions. The north face has two towers 165 ft 6 in (50 m) high at the corners of the Great Hall. On opening day, the London Times reported:

"The towers on the north of the building have each a central smoke-shaft from the heating apparatus, the boilers of which are placed in the basement, immediately between the towers, while the space surrounding the smoke-shafts is used for drawing off the vitiated air from the various contiguous galleries. The front galleries are ventilated into the front towers, which form the crowning feature of the main front."

A report by Waterhouse[17] to The Right Hon. The First Commissioner of H M Works compares the proposals submitted by the ventilating engineer, Wilson Weatherley Phipson, with a competing tender submitted by Messrs Haden and recommends acceptance of the former, noting its advantages. Phipson's Tender amounted to £5115. 12s. 0d, while that of Haden came to £5242, but they also requested a price increase of 15 to 20% to cover the "Great Rise" in the cost of materials and labour.

Phipson's scheme provided an air change rate of 3 per hour and internal space temperatures in the range of 51 to 60°F (10.6 to 15.6° C). However, a modern evaluation[16] notes various deficiencies:

"Unfortunately, by having all the fresh air intakes on the north side, the symmetrical placement of the ventilation exhaust towers provided unbalance air paths, both in horizontal duct length, and in effective vertical stack height. The ventilation exhausts are also compromised by not being at the top of their towers, but on the sides."

But many of the system's features were innovative at the time and one conclusion is that,".....the Natural History Museum indeed may present both a monument of its time in its environmental control, and a model for a future of passive and low energy buildings."

1885 John Hopkins Hospital, Baltimore

When the Baltimore businessman John Hopkins left a large bequest to build a hospital based on the most up-to-date medical principles the United States Army physician John S Billings produced a plan, with the aid of the architect John R Niernsee, which "dramatically emphasised the layers of space around the patients." [18] Hopkins also decreed that his hospital was to be free of charge to people of any age, sex, or race or economic standing.

Billings adopted many of the principles of the ideal hospital set out by Florence Nightingale.[19] A Nightingale ward was long and narrow to isolate each bed from its neighbour and to allow the penetration of breezes. It was also high, with windows occupying around one-third of the wall area and extending close to the ceiling and floor to avoid trapping bad air in the ward. A contemporary Block Plan shows the hospital incorporated three Common Wards, an Isolation Ward and an Octagon Ward. Not withstanding Hopkins' decree, this plan also shows two Pay Wards.

Each Common Ward occupied a separate tall one-storey pavilion set on a raised basement devoted entirely to heating and ventilating purposes and forming a large, clean air chamber containing hot water coils for heating. Heated air from the basement or a separate supply of fresh air was drawn into the ward by an outlet under each bed, being controlled by a "switch-valve" arrangement. A lower foul-air duct ran longitudinally beneath the centre of the ward floor, extracting air from lateral ducts with openings beneath the foot of each bed. A similar, upper foul-air duct ran above the ward, having ceiling extract openings. Both foul-air ducts were connected to an aspirating chimney. The lower duct was used in winter, the upper duct in summer, an arrangement which allowed in theory, though not necessarily in practice, for each patient to be "surrounded by a cocoon of moving air." The main foul-air duct was made of wood, lined with galvanised iron, while the lateral connections were of galvanised iron and cylindrical in shape. A high-pressure steam coil was placed in the chimney, above the upper foul-air duct connection, to be used when "necessary to quicken the aspirating movement." Billings reported that a basement fan, installed in only one of the wards, was found to be unnecessary as "the aspirating chimney is sufficient to do all that is required." Service rooms were provided with independent vertical exhaust ducts of galvanised iron (referred to as "exit shafts"), passing through the roof and capped with "a modification of the Emerson ventilator." Billings' two-storey Octagon Ward made use of a foul-air aspirating chimney of 8 ft (2.4 m) internal diameter with an accelerating steam coil.

He also designed a special “Isolating” Ward having a number of separated rooms on either side of a corridor, the corridor being “freely open to the outer air.” Billings described the ventilation system **[1.11]** as follows:

“Each room has an open fireplace with a separate flue, placed in the centre of the inner wall of the room. On one side of this chimney is the entrance to the room from the corridor, closed by double doors; on the other side is a small closet containing a commode, the chamber from which can be removed through an opening in the wall, without entering the room. This closet is lined with galvanised iron and has a separate exit flue in which is an accelerating steam coil. The door of this closet does not come to the floor by 4 inches (100 mm) and the exit of the air, which enters the room through large openings in the outer wall, is mainly through this closet and up its special flue which is of iron so that the whole can be readily cleansed by flame.

.......Three of the rooms are larger than the rest, and in these the fresh air enters through the floor, which for a distance of 7 feet(2.1 m) from the outer wall is perforated with 1/4- inch (6 mm) holes, there being 5000 holes in each room.

It has been said these systems “applied a veneer of science to the passive ventilating techniques long used in vernacular hospitals.” [18] (The landmark ventilation installation for UK hospitals, because of the provision for humidification, is generally regarded as that for the **Royal Victoria Hospital, Belfast** in 1903, described by Reyner Banham in “The Architecture of the Well-Tempered Environment,” The Architectural Press, London, 1967, p.75/84 .)

1889 Liverpool Royal Infirmary

In 1882, the Trustees of the Liverpool Royal Infirmary decided that a new hospital, based on Florence Nightingale’s guiding principles, was badly needed. In 1885, Liverpool-born Sir Alfred Waterhouse was selected as the architect and was asked to provide for 290 beds in a very limited space:

“Florence Nightingale had already recommended the use of small “pavilion” wards -ideally 16 feet (4.8 m) high and no more than 30 feet (9.1 m) wide -to help prevent hospital diseases. These pavilion-style wards would be well ventilated and spacious; the window space would not be less than one-third of the total wall mass, and the windows would reach from two to three feet (0.6 to 0.9 m) from the floor, to one foot (0.3 m) from the ceiling.” [20]

Though Waterhouse made provision for Nightingale pavilion wards, he also incorporated two circular ward blocks in his design **[1.12]** an idea taken from the Antwerp Civil Hospital of 1884, and claimed to provide light and ventilation from all directions with extra headroom and floor space. While Florence Nightingale considered ventilation to be a key factor in the “healthy hospital”, she was not convinced that circular wards would provide adequate ventilation.

The heating, ventilation, steam and hot-water supply services are described in detail in a contemporary handwritten report.[21] The Ward ventilation, designed by Wilson Weatherley Phipson is described as follows:

"In the Wards the radiators are circular and are fixed in a central position. The heating in all cases is from the centre because it is found in practice that it causes less disturbance of the atmosphere in the Wards than when the radiators are placed against the external walls. The heating from the central position causes a current of warm air down the side walls. To all the circular radiators a direct supply of fresh air is provided and the heating power fixed upon has been calculated to ensure in conjunction with the open fire places during the winter months a mean temperature of 60^o Fahr (15.6^o C): with an amount of air admitted to the radiators and from other sources equal to the entire renewal of the atmosphere in the Wards four times in the hour. The fire places in the Wards are also central and constructed to form the main upcast shaft for the extraction of vitiated air. The flues from the fire places are carried up in iron pipes, quadruple on plan, each stack serving for four fireplaces and the extracting shaft.

By this means a simple system of extraction is obtained by utilizing the waste heat from the fires. The area of outlet for the smaller Wards being 6 square feet (0.55 m^2) and for the large Wards, through two central fireplaces, 12 square feet (1.1 m^2). In each outlet the gratings are provided with talc (mica) valves.

In other Departments of the Building inlets and outlets are constructed, but in these rooms the upcast flues are carried into the roofs, where they are collected and conveyed by means of a main trunk into the general extract shaft situated over the Central Block. In this shaft steam coils are fitted so as to ensure in all seasons a powerful upcast."

1.3 Natural Heated Inlet & Mechanical Exhaust Ventilation

1884 Mutual Life Insurance Company, New York

The new 8-storey office building for Mutual Life Insurance [Chas W Clinton] was designed with external offices and an inner court for natural lighting and ventilation.[22] Heating was accomplished by radiators below the windows with provision for fresh air inlet ventilation, the air being warmed by passing across the radiators. Air was exhausted by small vertical ducts located between windows on the external facade of the building, and in the main corridor partition wall, these being connected to roof fans **[1.13]**. The building was extended in 1888 and again in 1892, with a 15-storey rear addition [Clinton & Russell] in 1904 **[1.14]**.

1894 Manhattan Life Building, New York

The headquarters building of the Manhattan Life Assurance Company [Kimball & Thompson] at 66 Broadway was when opened the tallest building in the USA at 348 feet (106 m).[23] With 17 floors of offices, it was surmounted by a roof tower and cupola **[1.15]**. In plan the layout is U-shaped around an open court, with offices in the two legs and with stairs, a lift hall and a bank of 5 lifts in the connecting link. A contemporary photograph shows external blinds fitted at many of the windows.

A plan shows radiators under the external windows of the offices and 4 vertical ventilation shafts. Fresh air was admitted through sash ventilators and heated, when necessary, by passing across these radiators. The section shows drop ceilings in corridors, through which air was exhausted and passed through the vertical ventilation shafts to electric exhaust fans on the roof. [22] The ventilation engineers were Gillis & Geoghegan.

1.4 Cooling by Water Coils

1854 St George's Hall, Liverpool*

Although the ventilation scheme by Dr David Boswell Reid for the House of Commons failed due to a mutual lack of respect and understanding with the architect Sir Charles Barry, his collaboration with the architects on St George's Hall [Harvey Lonsdale Elmes, then Charles Robert Cockerell] was extremely successful. Elmes cleverly solved the difficult problem of combining a Great Hall, two Law Courts, a Concert Hall and various other rooms **[1.16]**. But it was possibly Liverpool's first Medical Officer of Health, Dr W H Duncan who, after recent cholera epidemics, concluded that lack of air movement contributed to the spread of infectious diseases, and was instrumental in securing Reid's appointment as ventilation engineer.

The Great Hall is 169 ft (52 m) long by 74 ft (29 m) wide, with an arched ceiling that is 84 ft (26 m) from the ground. The heating and ventilating system has been described in some detail by the 1912 President of the Institution of Heating & Ventilating Engineers, Charles Honiball: [24]

"Air entered at the bottom of the rooms and was exhausted through the ceiling, taking with it the heat and odours of gas lighting.........Fresh air was drawn into St George's Hall down two large shafts. Once it had reached the basement levels, the air was heated by warm-water coils and supplementary steam coils or it was cooled by running water from city mains through the coils. Moisture could be added to the air by sprays of steam, and the shafts that admitted fresh air held water sprays that cleared particles from the air."

Under the middle of the Great Hall, four ventilating fans (marked B on the drawing) distributed air through the building. Each fan was 10 ft (3 m) in diameter with blades $2^1/_2$ ft (0.76 m) wide, and when driven at up to 60 revolutions per minute by a 16 horsepower (12 kW) steam engine, could jointly deliver an air volume flow rate of some 50,000 ft^3/min (23.6 m^3/s).

*A recent addition to the CIBSE Heritage Group web site is the section on St Georges Hall at:

http://www.hevac-heritage.org/electronic_books/M&NW_anniversary/Section-2_StGeorgesHall.pdf

This is a detailed description of its history by Dr Neil Sturrock, Vice-Chairman Heritage Group.

1.5 Water-Spray Cooling

1864 Assize Courts, Manchester

The Manchester Assize Courts [Alfred Waterhouse], now demolished, were designed in the then fashionable Gothic style **[1.17]**. The ventilation installation by Haden is described in company documents.[25] The following notes were made by William Nelson Haden, probably c.1890, following discussions with his father, George Nelson Haden, on a variety of past installations in which George had been involved:

"I believe the first Installation for Air Washing was put in at the Manchester Assize Courts which were opened in 1863. The Air Washing was done by means of a film of water produced by a jet impinging on a small disc. In this case there were two, or I am not sure if there were not three Archways about 8 ft (2.4 m) square. The film filled the Archway and I have seen the water running away from them in a very dirty condition due to the smuts which have been eliminated by the passage of air through the film of water.

The Courts were opened in the Summer, and at the first Sitting the Judge complained of the heat as the weather was very hot and asked that the windows, all of which were closed, should be opened. Frederick Blake our Manager sent a note to him on the Bench to say that if the windows were opened the temperature would probably rise, but the Judge asked for the windows to be opened, which was done, and the temperature went up in a very short time 5^o (2.8^o C)."

1874 Grand Opera House, Vienna

The design for the Grand Opera House [Gottfried Semper, with Karl von Hasenauer], or Hofburgtheater, a building measuring 397 x 299 ft (121 x 91 m) in Vienna followed the same plan as Semper's second Dresden Opera House which was considered "an extremely grand architectural composition, deliberately challenging Garnier" [26] the architect of the famous Paris Opéra.

The ventilation system[19] **[1.18]** for the Vienna auditorium (capacity 2700 persons) employs two fans, *".......the lower one for propulsion, the upper for aspiration. The last is also aided by the heat produced by the great chandelier, which has 90 burners."*

In winter, air enters through the fresh air chamber A, drawn by a helical fan S [11.5 ft (3.5 m) diameter, capacity 55,000 ft3/min (25.9 m3/s) driven by a 16 hp (12 kW) steam engine] is discharged across the steam heating coils B,C,D & E, and enters the hall at 63/65^{o} F (17/18^{o} C) through floor outlets at an air velocity between 60 and 120 ft/minute (0.3 and 0.6 m/s). In summer, the fresh air is evaporatively cooled by water sprays. The exhaust fan U was said to be "a simple helix and of little use."

Some statistics of the ventilation system are interesting. The two fresh air shafts were each 254 ft^2 (23.5 m^2) feet. The main supply duct after the fan was 48$^1/_2$ ft^2 (4.5 m^2) and the foul air discharge shaft measured 13$^1/_2$ ft (4.1 m) in diameter giving an area of 143 ft^2 (13.2 m^2). The total area of the supply fresh-air inlets into the auditorium was 807 ft^2 (75 m^2). The air change rate was 7$^{1/}{}_4$ per hour. The heating coils comprised of 59,000 ft (15,240 m) of 1-inch (25 mm) tubing served by steam at a pressure of 5 atmospheres (5 bar).

The heating & ventilating engineer was Dr Böhm, medical director Hospital Rudolfsstiftung, and the fan was designed by Professor Heger of the Polytechnic School of Vienna. {The fan was said to be set up to normally deliver some 47,000 ft^3/min (22.1 m^3/s) which at around 1050 ft^3 (29.6 m^3) per hour per person is remarkably close to the statutory ventilation rate of 1000 ft^3/hr required by the former London County Council in places of public entertainment.}

Law Courts, London

These are thought to be the Law Courts in Whitehall, not the later [1882] Royal Courts of Justice [George Edmund Street], in the Strand. Like the Manchester Assize Courts, the Law Courts had an air washing installation, also reviewed by W N Haden: [25]

"The Law Courts in London were fitted with similar Air Washing Films. The fans were driven by Steam Engines. One of the Lancashire Boilers under the main Hall being a Steam Boiler. In this case the water was cooled by refrigerating apparatus. The

Refrigerator was supplied by Halls of Dartford. Had a capacity of two tons of ice per hour (54 TR or 190 kW), this from memory. The Engines were subsequently removed and replaced by electric motors. Later horsehair or coco-nut matting screens were used in place of the water screens, the water being charged down them from sparge pipe. This was done in many cases in several of the Board Schools in Birmingham. As the hair screen had to be removed for cleaning periodically we then introduced the glass screens. These were formed of strips of glass plain on one side and saw tooth section on the other, so arranged that the force of air caused the particles in the air to impinge against the teeth of the glass, which was kept clean by descending films of water so there was self-cleansing."

The installation is later than the Manchester Assize Court (1864) and before the building of the new Law Courts in the Strand (1882].[27]

1889 Auditorium Theatre, Chicago

The Auditorium Building [Dankmar Adler & Louis Sullivan] was conceived for multipurpose use, combining a theatre, a hotel and a block of offices under one roof. The Auditorium Theatre was among the largest ever erected (4237 seats). Adler was a brilliant innovator and an expert in acoustics, while Sullivan had experimented with the decorative use of electric lamps in the McVickers Theatre, Chicago in 1885. The steeply raked stalls were designed by Adler on a principle called the "isocoustic curve" and the ceiling shape was based on acoustic considerations; his calculations were ahead of his time, involving absorption, reflection and reverberation. The arches carried Sullivan's decorative lights and plaster air diffusers for the ventilation system. The number of electric lighting fixtures was unprecedented, with 5000 house lights, 150 footlights and all the stage lighting. In addition, elaborate hydraulic systems were provided to enlarge the proscenium opening, raise the main curtains, elevate or depress the stage floor and operate the scenery lifts.[28]

The central cooling system was constructed in a brick shaft that served as a fresh air intake and extended from the roof to the basement floor.[32] In the corners of this shaft, four cold water headers, each with a series of spray nozzles, were installed to clean and cool the air. It is thought that the sprays used mains water, running to waste, with no recirculation. Outside and return air were circulated through large brick tunnels to the supply fan. "Large hinged steel doors, resembling garage doors, served as (mixing) dampers or air diverting devices." These doors were chain operated. Similar doors were used to balance the air flow in the supply air distribution tunnels, which connected to sheet metal ducts running from the basement to plaster diffusers in the ceiling and balcony wall arches. These diffusers were pre-cast plaster hemispheres **[1.19]** designed by Sullivan as part of the theatre ornamentation and are said to have "efficiently performed their function as diffusers."

1.6 Ice-Block Cooling

1875 Houses of Parliament, London

The rebuilding of the Houses of Parliament [Sir Charles Barry with A W N Pugin] after the disastrous fire of 1834 led to many years of argument between the architect Barry and Dr David Boswell Reid who had been appointed to design a heating and ventilation system for the House of Commons, while Barry retained responsibility for the House of Lords.

Over the years, many eminent persons had tried to improve the ventilation.[29, 30] As early as 1660, Sir Christopher Wren installed a fire-assisted ventilation system. In 1734, Dr Desaguliers installed his mechanical “fanner” cranked by hand. Reid in his textbook on ventilation[30] also refers to the work of the Marquis of Chabannes, Mr Davies Gilbert and Sir Humphry Davy. After difficulties with Reid’s fire-assisted scheme for the Commons, the main airflow was reversed by Sir Goldsworthy Gurney. None of these systems proved satisfactory.

Gurney’s successor was Dr John Percy, who believed that fans could never successfully challenge the air-moving force of heated chimneys: [31]

“He maintained the ground level intakes installed by his predecessor and made the sensible recommendation that the courtyard from which air was taken should be kept free of horse dung. Percy’s principal changes were the addition of intakes on the side of the building towards the river and the installation of sprays of water and steam that could humidify, cool or heat the air as it entered the system.”

A drawing from Richardson’s Treatise of 1839 shows a “netting containing ice” located in the fresh air intake to provide cooling. A later drawing of 1875 in the magazine Harper’s Weekly illustrates the cooling of the House of Commons using ice and water sprays. The installation was continually being altered **[1.20]** in an effort to satisfy the complaints of the Members of Parliament. As recounted in the company papers of Haden: [25]

“At the Houses of Parliament at this time the refrigeration was done by placing blocks of ice in the air ducts, which involved a considerable amount of labour and my father thought that if we could use water at a temperature of 36^{o} (2.2 ^{o} C) in the Air Washing that this would reduce the temperature as well as the use of blocks of ice and, of course, could be done without any labour except passing water through the pump. No ice was made by the Refrigerating Plant but the water was kept in circulation at 36^{o} (2.2^{o} C) with a man in attendance to see that the temperature did not drop below this and freeze the whole up solid.”

1880 Madison Square Theatre, New York

The ventilation and cooling system for the Madison Square Theatre [remodelled by Francis H Kimball and Thomas Wisedell] was described in The Sanitary Engineer of 15 October, 1880.[19] Fresh air was drawn in through a roof cupola with rope-operated sliding shutters to provide openings to the prevailing wind. A pine-boarded shaft, 6 ft (1.8 m) square, extended down into the cellar and

"....suspended in it, point downward, is a conical-shaped cheese-cloth bag, about 40 feet (12 m) deep, through which the incoming air is filtered. A chamber at the bottom of the inlet is provided with a number of shelves inclined at an angle of about 45 degrees, upon which, in summer, ice is placed to chill the air. From this point, the main duct, diminished to a diameter of 4 feet (1.2 m), connects at the axis with a Sturtevant fan, 8 feet (2.4 m) in diameter, with blades 3 feet by 18 inches (0.9 x 0.45 m), and making 150 revolutions per minute. The periphery of this wheel, moving at a rate of about two-thirds of a mile per minute (18 m/s) , forces the air at a high velocity into the delivery duct, 5 x 3 feet (1.5 x 0.9 m), in which is placed another mass of ice. Four tons are used every night, two in the delivery and two in the inlet duct." (Some 24 TR, or 84 kW).

The main delivery duct was brick, branching into six sheet-iron ducts each of 2 ft (0.6 m) diameter. Every one of the 360 seats in the auditorium was individually supplied with cooled air "by 4-inch (100 mm) tin pipes." Separate ducts served the balcony, supplied air from the lower edge of the balcony and across the entire front of the stage so that, "in summer the cooled air is poured into the house to reduce the temperature and to furnish a supply for respiration." The boxes had their own separate inlets and outlets. The products of combustion from the dome gas chandelier and gas wall lamps were passed into separate flues connected, together with the main exhaust ducts, into another 8 ft (2.4 m) diameter Sturtevant fan, mounted on the roof.

1891 New York Music Hall (Carnegie Hall), New York

The heating, ventilation and cooling systems for the New York Music Hall [Wm B Tuthill], renamed shortly after its opening for its benefactor Andrew Carnegie, are described in The Engineering Record of 4 July, 1891 and 6 February, 1892. The Auditorium seated 3,000 persons, the Recital Hall below a further 1,200. Fresh air taken in from the roof through a 12 x 6 ft (3.7 x 1.8 m) vertical air shaft was supplied by two 7 ft (2.1 m) diameter Sturtevant fans, estimated as providing some 30,000 ft^3/min (14.1 m^3/s) through a perforated "ventilating" ceiling **[1.21]** into the Auditorium, being warmed in winter by some 6,600 ft^2 (611 m^2) of heating surface. Exhaust air was extracted beneath the seats into chambers under the Recital Hall and the Auditorium. The chambers were connected to a vertical foul air exhaust shaft of 16 x 6 ft (4.8 x 1.8 m) with roof exhaust fans. {This air distribution arrangement anticipated by some thirty years the "upside down" system (see Sect.2.4) devised by Logan Lewis to avoid cold draughts in movie theatres.}

In warm weather cooling could be accomplished by an ice-block system **[1.22]**. At the bottom of the fresh air shaft A, ice-racks OO were provided across the outlets branching from the base of the shaft with PP being iron drip pans, SS waste pipes and DD doors.[19] The ventilation system designer, Alfred R Wolff, was a leading figure in the early development of the scientific design of cooling, and later, air conditioning systems.

1.7 Mechanical Ventilation

Until the late 1880s, fans used for ventilating buildings were driven by heat-type engines.[32] These were mostly steam engines which seem to have been used for this purpose from around 1850 **[1.23]**. This continued until about 1920, by which time the wide scale distribution of electricity was in place, and reliable, commercial alternating current electric motors became available. At the turn of the century, the leading manufacturer of steam fans, including the driving engine **[1.24]** was undoubtedly B F Sturtevant of Boston.

Engine-driven fans were employed in many of the pioneering installations described in the early sections of this book: Liverpool's St George's Hall, Washington's Capitol, Vienna's Grand Opera House, New York's Madison Square Theatre and Carnegie Hall, the Pueblo Opera House, the Agassiz School in Boston, and Belfast's Royal Victoria Hospital (where the steam engine and one of the fans is still operable for demonstration purposes).

1884 Empire Theatre, Leicester Square, London.

The Empire Theatre [Thomas Verity] had no success as a theatre and was quickly turned into one of the more glamorous of the Victorian Music Halls **[1.25]**. The engineer responsible for the ventilation and heating was Wilson W Phipson, and a copy of his handwritten Operating Instructions survives.[33] These refer to the maintenance of the gas engine, fans and gearing, and recommend to the management how to operate the system in summer and ahead of occupancy by the public. Reference is also made to keeping a record of temperatures "at several points about the House on all levels," of using the gas-lighting to assist warming-up in cold weather (then later switching to the electric light) and using the Sunburners (a large ventilating gas light) in the foyer "at all times for carrying away the smoke." The Empire Theatre was demolished (1927) and the famous Empire, Leicester Square, cinema (Sect.2.4) built on the site.

1896 Carnegie House, Sunnyside Royal Hospital, Montrose, Scotland.

A mechanical ventilating system with humidity control **[1.26]** was built into the structure and gave excellent service for 73 years. [34] The installation consisted of a Sturtevant fan driven by a single-cylinder reciprocating steam engine, receiving its air supply via an air inlet chamber with baffle boards and water spray to control humidity, with a large heat exchanger, fed with exhaust steam, at fan discharge. Supply air passed through a rectangular underfloor tunnel, feeding vertical inlet pipes in the corners of the rooms served. The vertical pipes were standard 5-inch (130 mm) earthenware sewage pipes with cement joints and elbow outlets.

1907 Municipal Technical Institute, Belfast

Now known as the College of Technology, this building **[1.27]** when opened in 1907 was provided with a steam-driven system of mechanical ventilation.[35] Although an early 20th century installation, it has been included in this section due the remarkable fact that it is still capable of operation to the present day (2001).[36,37]

The 15 horsepower, single-cylinder steam engine, thought to have been manufactured by the installers of the mechanical heating and ventilation plenum system [Musgrave & Co, Belfast], drives two 11 ft (3.6 m) diameter centrifugal fans, one with the nameplate “The Ulster/Musgrave & Co Ltd/Belfast/No.566.” A filter bank, originally a water spray, and a gilled-tube steam heater are located at fan suction. Builders work chambers at 1st and 2nd floor levels mix return and fresh air, and are fitted with spinning disk humidifiers (driven off the steam engine, but no longer in use) which once provided winter humidification and a certain amount of spray-cooling in summer. Supply air is discharged by the fans into large walkway-size basement brickwork ducts. From these, small risers supply air to the upper floors, each being fitted with a hot water reheat coil and a canvas blind shutter for volume control. Extract air is routed back to the mixing chambers through the main corridors at each floor level.