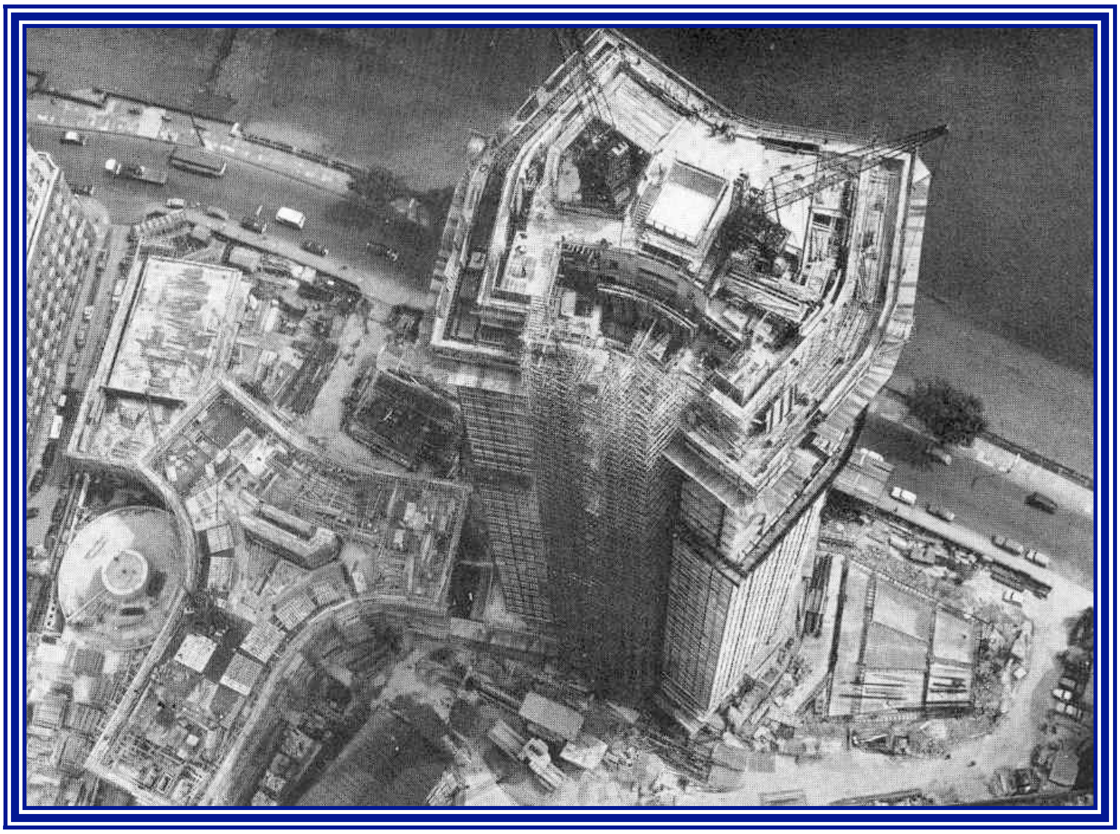

Millbank Tower (Vickers Building), London, 1959-62.

The Story of Comfort Air Conditioning

Part-3 Air Conditioned Office Buildings, 1940-1978

Text Section

Part-3
Air Conditioned Office Buildings 1940-1978

Yes sir, that's the city of the future! Two-hundred storey skyscrapers! Air pumped in from the country. Every cubic foot of space used day and night. Mechanically perfect! Magnificent! Will any one *live* there?
[3.1] *"Sketch of the City of the Future," Lewis Mumford, 1925.*

3.1 The Forties: getting started

Most of the air conditioned buildings constructed before the Second World War had all-air systems. By the end of 1939 the recently patented high-velocity Carrier Weathermaster induction unit system was complete. Here, at last, was an air conditioning system suitable for multi-storey, multi-room buildings. The concept of using fresh air for ventilation and humidity control, and handling the sensible cooling or heating load by water overcame many of the distribution problems associated with the space requirements for ductwork in all-air systems.

In 1940, the first sales of the new Weathermaster system were made,[1] and included installations for the Bankers Life Building in Macon, Georgia, the Durham Life Building in Raleigh, North Carolina, and the United Carbon Building in Charleston, West Virginia. Others followed before the United States went to war in 1941, the most notable being the Statler Hotel in Washington, DC.

In the absence of new projects during the war moratorium on civilian buildings, one of the leading American magazines, *Architectural Forum*, ran a special issue on post-war trends.[2] The editor, Howard Myers, invited a number of leading architects including Louis Kahn, William Lescaze, Mies van der Rohe and a lesser known Italian architect from Portland, Oregon, Pietro Belluschi, to produce designs for a range of projects that might be built in a medium size town after war-time planning restrictions were lifted. Myers stipulated that the architects' design "*show an advanced but not stratospheri*c" approach to planning construction and equipment and that they draw upon technology that was currently available but not in common use.

Myers selected Belluschi to produce an office building design. Belluschi wrote:

"Our assumptions were affected by the peculiar circumstances found in our north-west region -cheap power and a tremendously expanded production of light metals for war use, which will beg for utilisation after the emergency."

Apparently, he intended to air condition the building, using aluminium extensively for cladding, wall-panel frames, external air inlets, internal louvre blinds and even as trays for ceiling tiles. He proposed to maintain internal comfort with unit air conditioners, individual local air inlets, and radiant heating panels in the ceiling.[3]

1948 Equitable Building, Portland, Oregon

Belluschi put his ideas into practice before the war ended. The Equitable Savings and Loan Association decided to build a new headquarters in Portland.[4] Although superficially the design was similar to the *Forum* project, Belluschi introduced a number of significant changes that impacted the internal environment as much as the appearance **[3.2, 3.3]** .[5]

The building was heralded by the *Architectural Forum*[6] as the first and long overdue *"crystal and metal tower,"* one of its most spectacular aspects being *"its huge area of sea green glass."* The glass was sealed double-glazing with the outer pane made of heat-absorbing glass that provided a 40% reduction in solar transmission. Belluschi had satisfied himself that the solar-treated glazing would not only reduce the solar heat load but also reduce sky glare to the point where blinds or shades would not be needed for comfort. Apparently, *"some of the tenants expressed alarm at the lack of shading, but after several months of satisfactory conditions few of them had installed blinds."*

The air conditioning designer, J Donald Kroeker, was as innovative as the architect. The building was one of the first to be entirely heated and cooled using water from wells via a heat pump. The air conditioning systems were controlled automatically and local air handling plants located on each floor had separate ducts serving different faces of the building and interior zones, and included the option of 100% outside air. Kroeker claimed a reduction in operating costs of between 10% and 25% in comparison with heating and ventilating only.

Now called the Commonwealth Building, it is the prototype of the modern fully air conditioned office block. The air conditioning was installed to counteract the heat gain from the large sealed windows without the need for blinds or shading. Ultimately this may have been an unfortunate precedent in terms of energy and the environment. However, the building and systems have been monitored closely since 1948 and are still performing well and economically.[7,8] Despite its location and lack of publicity, it is a seminal building in the development of air conditioned offices.

3.2 The Fifties: American and European high-rise

1950 United Nations Secretariat, New York

The UN Secretariat [Wallace K Harrison et al, 1950] was the first major international building to be constructed after the war. A multi-national advisory committee was established for the design of these tower offices **[3.4]** (the low-rise General Assembly Building was constructed alongside and completed in 1952). The team was composed of a number of leading architects with Le Corbusier acting in an advisory capacity. The Director of Planning was W K Harrison, who helped design tall buildings such as Rockefeller Centre before the war.[9]

During the development of the scheme, Harrison was involved in a number of conflicts with Le Corbusier, who later protested at not being asked to supervise the construction, claiming the plans were mainly his work. One such argument involved the protection of the offices in the tower against excessive solar heat gain and glare. Le Corbusier wanted stone facades, but the board preferred to maximise sun and natural daylighting using overall glazing. They decided this could be best achieved with curtain walling, even though at this time it was an unusual solution for a skyscraper.

At this time the Equitable Building was the only modern example of a continuous glazed curtain wall in the country (the first glass curtain wall is generally accepted as the 1918 Hallidie Building in San Francisco, now demolished.). In the case of the Equitable, *"even in those energy-rich days this much glass raised the question of heat gain and loss."* For the UN the designers considered four glazing options in conjunction with internal venetian blinds, these being single and double glazing, with and without tinted glass. However, Le Corbusier thought the building should be protected from the sun by brise-soleil.[9] (No doubt the bad experiences with his design for the Salvation Army Hostel in Paris, described in Sect.2.7 influenced his thinking.) The brise-soleil were eliminated because snow and ice collecting on them in a New York winter was considered a hazard.

To select the best of the glazing options, the air conditioning designers [Syska & Hennessey] conducted an experiment placing recording thermometers in front of two windows, one with tinted glazing, one without, oriented as they would be in the building. After two weeks the thermometer behind the tinted glass had consistently recorded a temperature 5 to 10^{o}F (5.5/8.5^{o}C) lower. This convinced Harrison that tinted glass without brise-soleil could moderate the heat and justify its extra cost. In hindsight this appears to be a huge leap in logic. However, the internal environment did not rely on tinted glass alone. The windows had venetian blinds on the inside and some 4000 of the new Carrier Weathermaster induction units beneath the sills.

Finally, the 39-storey glazed slab, 544 ft (166 m) high, 287 ft (88 m) wide and 72 ft (22 m) thick, with 5400 operable windows was complete.[10] One report[11] states, "*Its green-glazed long walls facing east and west proved incompatible with the air conditioning -but they still set a trend. Gone was the world of expressionism and Art Deco. These towers marked the beginning (more precisely the wider recognition) of the International style -clean, simple volumetric forms; regular repeated units giving order to the elevations; restrained detailing; and an absence of decoration."*

Yet despite problems with the curtain walling,[12] the combination of tinted glass, venetian blinds and a high velocity induction system must have worked reasonably well, as it was repeated on numerous buildings for the next 20 or 30 years. The UN Secretariat, and the even larger Gateway Centre group of office buildings in Pittsburgh, with 6000 induction units and 4500 TR (15,800 kW) of refrigeration,[1] heralded a new era in comfort air conditioning.

1952 Lever House, New York

Considered by many to be *"a key monument in the American evolution of the International Style,"*[13] Lever House [Gordon Bunshaft of Skidmore, Owings & Merrill, generally known as SOM, 1952] *"barely qualifies as a skyscraper."* The 24-storey tower, rising to 302 ft (92 m), sits on a 1-storey podium that itself sits on columns **[3.5]**. It was the first New York building to take advantage of a new zoning provision that permitted a building to rise with no setbacks, provided it covered only 25% of the site. Unlike the UN building, it is totally curtain walled on all four sides, being sheathed in blue-green glass. In elevation, each bay comprises a tinted window, above an opaque glass panel, and below that a third panel concealing the structural depth of the floor slab, the horizontal services distribution and the high-velocity air conditioning. The 18 floors of offices **[3.6]**, with 8700 ft^2 (805 m^2) per floor, met the standards of office accommodation developed for Rockefeller Centre in the era before air conditioning, where every desk was to be no more than 25 ft (7.6 m) from a window.[10]

Taking advantage of the air conditioning (by Carrier), the windows were fixed, and since they could be cleaned only from the outside, SOM devised an exterior cleaning gondola that moved up and down the facade on cables suspended from a roof hoist that ran round the building's perimeter on rails. This cleaning machine would become a standard feature of curtain-wall buildings. Lewis Mumford could not resist extolling the ingenuity of the window-washing machine, [10]

"For a company whose main products are soap and detergents, that little handicap of sealed windows is a heaven sent opportunity, for what could better dramatise its business than a squad of cleaners operating in their chariot..."

Although it had been Mies van der Rohe who, in 1919, had developed sketches for a 20-storey all-glass office tower in Berlin[14] *"sheathed from street-level to the roof-line with an uninterrupted skin of glass,"* it was Lever House that was more influential in the development of the curtain-walled office tower than any other. Its light, almost transparent appearance became very popular during the 1950s and 60s, both in the Unites States and later in Europe. Air conditioning is so fundamental to the design of this style of building that the internal environment cannot be said to be satisfactory without it.

1953 Alcoa Building, Pittsburgh

The arrangement of Lever House, a thin slab on a massive base, was presaged by the design for the Alcoa Building **[3.7]** [Harrison, Abramovitz & Wiggins, 1946] in New York, but it was never built.[10] When it came to the design of a headquarters for the Aluminium Company of America, the Alcoa Building in Pittsburgh [Harrison & Abramovitz, 1953] in Pittsburgh, the result was innovative in the extreme, [13]

"The Alcoa's faceted metal wall bucked the trend towards glass, notwithstanding Harrison's chairing the design committee for the all-glass secretariat of the UN around the same time. The exterior walls consist of 1/8-inch (3 mm) thick aluminium panels that are bolted to angles on the building's structure and backed with four inches (100 mm) of perlite concrete sprayed on aluminium lathe and reinforcing bars."

The result a lightweight economical structure, 410 ft (125 m) high, where the principal weight saving is found in the thin curtain wall. Alcoa required maximum use of aluminium, almost regardless of cost. The electrical system, wiring, cooling tower and plumbing were all manufactured from aluminium, as was every conceivable finish -from lift doors to window sills. As for window-cleaning, there were experimental rubber-rimmed windows that pivoted right round to permit washing from the inside.

A radiant heating and cooling system was contained in the ceiling structure, freeing the window space under the exterior walls from radiators or air conditioning units, and providing an additional 15,000 ft^2 (1400 m^2) of rentable space. When opened in 1962, London's Shell Centre had possibly the largest ever radiant cooling ceiling system. This and the Alcoa system may be considered forerunners of the chilled beam and chilled ceiling air conditioning systems that gained popularity in the 1990s.

1956 Price Tower, Bartlesville, Oklahoma

Another building that broke away from the glass-sheathed curtain wall concept was the Price Tower **[3.8]** [Frank Lloyd Wright, 1956] a 19-storey multi-cellular tower 186 ft (57 m) high using a reinforced concrete structure,[13]

"conceived of as an enormous tree whose branches are broadly cantilevered floors emanating from a cross-shaped supporting spine. The hollow concrete spine contains the building's plumbing, elevator and air conditioning systems and breaks the structure into four quadrants -three for plumbing and one for duplex apartments."

Price Tower was thus an early example of the multiuse building, catering for living and working, a style later exemplified in Chicago's John Hancock Centre with its condominiums, offices, stores and a hotel.

Wright's design for the Price Tower exploited the *"jewel-like"* properties of glass and copper. The gold-tinted windows were protected from the sun by external wide projecting fins made of copper, vertical over the apartment windows, horizontal elsewhere. The building was not a success. Originally conceived in the late 1930s for Manhattan, by the 1950s both the world and the form of the skyscraper had changed.[11] The building's impractical layout never worked well, *"the apartments were too small; and the office quadrants too tight and inflexible. The magnificent copper louvres did little to stop the fierce sun hitting the two-storey glass walls, and the cooling plant, unable to cope with the heat gain, had to be replaced and relocated in an adjacent parking lot."*

Both surprising and sad for Wright, who had been involved in two of the most important of the early air conditioned office buildings -the Larkin in 1906 and Johnson Wax in 1939.

1957 Lloyd's New Building, London

Meanwhile, comfort air conditioning was beginning to take shape in some of Europe's post-war buildings. One of the first examples is that installed for Lloyd's of London.

Lloyd's, started in 1688 in a coffee tavern of that name, is a household name for insurance throughout the world. In 1928, the *"Old Lloyd's Building"* in Leadenhall Street with its large Underwriting Room was opened. Construction of Lloyd's New Building [Sir Edwin Cooper & Partners, 1957] in Lime Street, with an Underwriting Room twice the size of the original, commenced in 1952. The Committee directed that the item of first importance was an efficient system of air conditioning and *"that any architectural or other requirements must be subservient to this."* However, in practice the constraints imposed by architecture, internal decor and use of the Room for evening functions posed severe problems for the air conditioning consultants, Oscar Faber & Partners. A description of the old building[15] explains some of the problems to be faced in the new:

"The old Underwriting Room at Lloyd's was equipped with a ventilating system originally, but it was not satisfactory and had been altered under two schemes of reorganisation. Under the last of these (date unknown), refrigeration plant had been added.

As it finally existed, the air inlet was by means of high-level grilles on the side walls, and the extract was by means of grilles in the underwriters' boxes (a hard wooden seat, a desk in front, and a rack for books; all in a space some 6 ft(1.8 m) square, where the underwriter and his clerk sat, surrounded by brokers' clerks waiting to do business).....In 1928 the Old Room contained about eighty-two boxes, seating 520 persons.

However, the atmospheric conditions in the Room of the old building, even with the refrigerating plant in use, were never considered satisfactory, and were the source of constant complaints of stuffiness and oppressiveness, causing tiredness and headaches.

The air-conditioning plant itself comprised an oil-coated filter, a spray-type air washer, steam heater batteries and reciprocating refrigerating plant of 220 hp (164 kW) in two sets."

In the new Underwriting Room **[3.9]** the problem was greater. Now 175 underwriters' boxes, seating about 1250 persons, some on the ground-floor level and some in a gallery, had to be accommodated. The air conditioning, installed by G N Haden, was required to cope with a maximum occupancy of 5000 persons and handle solar gains through a large roof light and side windows. The building cooling load (fabric, solar, people, lights and infiltration) was calculated as 535 TR (1880 kW); fresh air 77,600 ft^3/min (36.5 m^3/s) as 285 TR (1000 kW); which with allowance for reheat and plant gains, gave a total of 1006 TR (3540 kW). The decision to use a low velocity all-air system required a supply air volume of 327,000 ft^3/min (154 m^3/s) and posed severe difficulties in housing the ductwork and plant as the latter had to be kept out of the Room. The final design used a main fresh air plant with a spray washer, connected to six large recirculating air plants, each with an electrostatic filter and cooling coil. To provide standby capacity, the refrigeration selected was three centrifugal water chillers each 650 TR (2280 kW) driven by 3.3 kV electric motors. A central control room with extensive mimic diagrams was provided.

The role of the plant engineer was paraphrased in verse in the discussion following presentation of the technical paper: [15]

The underwriters in the Room
Have found their comfort such a boon,
Their metabolic rates are gauged
By subtle and unusual ways
For in his room of Eau de nil,
Not one complaint can be concealed
From flashing lights both red and green
As though upon a vision screen.

An interesting comparison may be made with Alfred Wolff's pioneering design of 1901 for the New York Stock Exchange (in Sect.2.10, where in the Board Room (trading floor), in spite of extremely large windows and a skylight, the major part of the cooling load was due to the heat gain and fresh air requirements of about 1000 workers. The air conditioning for the Board Room supplied 40,000 ft^3/min (18.8 m^3/s) and provided 300 TR (1050 kW) of cooling.

In 1985, Lloyd's moved once again, this time into Richard Roger's controversial building with its 200 ft (61 m) high glass-roofed atrium and with lifts and air conditioning ducts on the outside of the building.

1958 Seagram Building, New York

Along with Lever House, the Seagram Building **[3.10]** [Mies van der Rohe, 1958] is often regarded as the zenith of the International Style. The 39-storey rectangular tower, 525 ft (160 m) high, sheathed in a bronze and topaz-tinted glass curtain wall, revealed new possibilities in skyscraper office design. In an example of the integration of architecture and engineering, the high velocity air conditioning units were recessed into the floor with floor supply outlets, while the inside venetian blinds were designed to assume only three positions: all the way up, all the way down, or at half-mast.[14] The client spared no expense, the Seagram Building being,[16] *"At the time of its completion......the most expensive skyscraper per square foot of floor space ever built in Manhattan, and the most universally admired."* However, [13] *"The deceptive simplicity* *of Mies's designs and the economy of their prefabricated parts.... resulted in innumerable banal glass boxes now commonplace on city skylines."*

1958 Mannesmann Building, Düsseldorf

The Mannesmann Building **[3.11]** [Paul Scheider-Eslenben & Herbert Knothe, 1958] was one of Europe's earliest post-war air conditioned office blocks. It sits on the bank of the Rhine and is unusual in that its major axis (east-west) is at right angles to the river. The curtain wall, with blue and white vitreous enamel panels set in an aluminium frame, is suspended in front of the structural framework. There is a ground floor, a mezzanine and 22 office floors. Building statistics are: height 97 m, volume 51,540 m^3, heating capacity 4360 kW, cooling capacity 1105 kW, total power installed 1830 kVA.[17,18] The air conditioning was all-air type, with one fresh air central plant for every four floors, and with a local plant at each floor level. Air supply was through a perforated ceiling and over windows; return air being extracted below windows and above doors before being returned through a corridor ceiling void. Radiant panels below windows provided additional heating.

1958 UK Atomic Energy Authority, London

This medium size building for the UKAEA [Treaherne & Norman, Preston & Partners and Leslie C Norton, 1959] in Charles II Street, was possibly the first fully air conditioned office block in the UK. The 8-storey building employs steel frame construction, precast concrete floor slabs, brick external walls with facings of Portland stone, and double-glazed window taking up about 60% of the wall area. The air conditioning by Carrier was of the high velocity Weathermaster type, employing some 217 induction units on a two-pipe system and operating on a changeover control cycle, ie. chilled water for cooling or hot water for heating.[19] The refrigerating plant used a 140 TR (490 kW) absorption type water chiller taking low pressure steam from the boiler plant, an arrangement not usually found in London commercial buildings (where there is no demand for steam), and operated with a roof cooling tower.

1959 Phönix-Rheinrohr Building, Düsseldorf,

Another of Europe's early post-war air conditioned office blocks of curtain wall construction, the Phönix-Rheinrohr Building **[3.12]** [Helmut Hentrich & Hubert Petschnigg, 1959] has a "triple-zone" layout with services and lifts within a central core. There are 20 office floors above a double-height ground floor and 3 basements. The air conditioning plant is located on the topmost floors. Building statistics include: height 105 m, volume 138,550 m^3, heating capacity 9300 kW, cooling capacity 2790 kW, total power installed 3600 kVA.[17]

1959 Centro Pirelli, Milan

One of the largest and earliest air conditioned office buildings in Europe is the Pirelli Building **[3.13]** [Giovanni Ponti with structural engineer, Pier Luigi Nervi, 1959] rising from Central Station Square in Milan. A technical paper describes the air conditioning in considerable detail and is accompanied by both floor layout drawings **[3.14]** and system schematics. It also states: [20]

"The building has a total height of 135 m, of which 8.5 m is below ground. It has a length of 70.4 m and a maximum width at the centre (the building is tapered at both ends in plan) of 18.5 m. The main elevations face north-west and south-east...... (There are) twenty-nine identical floors, 3.7 m floor height....The structure is of reinforced concrete. In Italy today it is possible to build tall buildings more cheaply in reinforced concrete than in steel. For comparable storey heights it is possible to have bigger windows with less projections..... curtain walls in aluminium and plate glass were used to fill in the vertical spaces left in the structure......Tower block area (per floor) approx 1100 m^2 .... (total 330,000 m^2 gross)."

The solution adopted for air conditioning was to use an induction system for external areas of office accommodation in the tower (some 1500 induction units) with a single-duct all-air system for core areas. The basement and lower three floors in the tower, housing conference rooms, a computer centre and the like, were air conditioned by a high-velocity dual-duct system. The combination of perimeter induction with single-duct for internal areas and dual-duct for special areas was a pattern of air conditioning to be repeated in many European high-rise office buildings over the next decade.

The basement cooling plant was equipped with two centrifugal water chillers having a total cooling capacity of 893 TR (3130 kW), operating in conjunction with a well-water cooling system having both intake and discharge wells. The well yielded 250 $m^{3/}$h of water at 15^o C, being used for precooling the conditioned air (providing about 18% of the peak cooling load) and then serving as condenser cooling water.

1959 Castrol House, London
As London rose from the destruction of the bombing, a number of new offices took shape. Typical of the new style was Castrol House **[3.15]** [Gollins, Melvin, Ward & Partners, 1959], bearing superficial resemblances to New York's Lever Building -a curtain wall tower on a podium. But there the similarity ended. No air conditioning was provided, just radiant ceiling panel heating and natural ventilation by sliding windows which proved to be a poor substitute. The lesson that in these new lightweight curtain walled offices with large areas of glazing, even with tinted glass and internal blinds, air conditioning was essential took some time to be learned. The working conditions were uncomfortable. The storey height was often inadequate. They lacked flexibility for change. Many of these buildings have been converted or demolished.

3.3 The Sixties: air conditioning comes to Europe

The Seagram style, both building and air conditioning, was extensively copied. It had an extraordinary impact on skyscraper office design during the 1960s. Mies's believed in purity of form, and relied on structure, shape and scale to achieve elegance and beauty. His ideas were taken up by SOM, Philip Johnson, I M Pei, Roche and Dinkeloo, and others.

One of the first buildings to borrow from the Seagram design was the Union Carbide Building **[3.16]** [SOM, 1960] which with 1.5 million ft^2 (139,000 m^2) of office space and 52-storeys high made it the tallest building to be erected in New York since 1931. The stainless-steel curtain wall, except for the mullions, was coloured black. Its outer appearance was generally not well received, but the interior design and layout was much admired,[10] *"Inside the building, a highly integrated partition-and-ceiling system incorporated lighting, air conditioning and sound control. The typical floors of Union Carbide accommodated an unprecedented degree of modular design in the ceiling grid, furniture, filing and storage systems, and introduced clustered workstations with low dividers."*

A similar office skyscraper was the Chase Manhattan Bank, New York **[3.17]** [SOM, 1961] rising to 60-storeys and a height of 813 ft (248 m) with 2.3 million ft^2 (213,000 m^2) of accommodation. The office floors were essentially column-free with the central core ingeniously place off-centre, creating more office space on the southern aspect and giving greater flexibility of layout. The tower was sheathed in panels of anodised aluminium. The air conditioning and mechanical services were designed by JB&B (Jaros, Baum and Bolles) with three dedicated services floors being provided at intermediate levels in the tower.

There was a new major office building for New York which adopted a different style. This was the **Pan-Am** building [Emery Roth & Sons, Walter Gropius and Pietro Belluschi, 1963] the largest commercial office building of its time with a floor area of 2.4 million ft^2 (222,200 m^2). The building was large and brutal. Clad in precast concrete panels it attracted considerable criticism. It is hard to believe that Belluschi, the architect of the Equitable in Portland, played any major part in its design. At 59-storeys and 808 ft (246 m) high, now known as the MetLife Building, it rises above Grand Central Station, blocking the skyline from upper Park Avenue. The broad sides of the building face south-north to minimise the air conditioning load, the systems being designed by JB&B. However, the Pan-Am Building was an undoubted commercial success.

In Europe in general, and in London in particular, a number of new medium height and high-rise office buildings were under construction. Many Lever look-a-likes were built, such as the six similar office blocks of 1960-63 in the City of London, 220 ft (67 m) high, on common 2-storey podia connected by pedestrian bridges (collectively known as London Wall). The scheme was a disaster in every way imaginable. Both the external environment and the internal environments (without air conditioning) were unacceptable.

The United States also pioneered the use of high-velocity all-air systems of both the single-duct and dual-duct type. The late 1950s and early 60s had seen the introduction of this knowledge, and the associated equipment, into the UK where it was used in a number of medium-size buildings. Many of these installations were not provided with refrigeration. The taller buildings, up to about 400 ft (122 m) in height required a different solution, and it was available in low-pressure induction systems from Scandinavia, and high-pressure systems from the United States and Italy.

1962 Bayer AG Building, Leverkusen
When completed this head office for Bayer **[3.18]** [Helmut Hentrich, Hubert Petschnigg et al, 1962] was described as Germany's tallest and most modern office block at 132 m high, with a volume of 171,735 m^3 and 20,800 m^2 of useful office space, accommodating some 2200 employees. Perimeter offices were air conditioned **[3.19]** by a system of under-window induction units, and internal zones by an all-air supply system, working in conjunction with an extract air system removing lamp heat from lighting fixtures through side exhaust grilles or troffers. The services statistics[17]

include: heating 8720 kW, cooling by three centrifugal chillers total 3870 kW, total power installed 6000 kVA.

1962 E S & A Robinson, Bristol

The new 15-storey block in Bristol for the packaging company, E S & A Robinson **[3.20]** [John Collins, 1962] was one of the first of the new air conditioned office buildings erected in the UK in the post-war building boom. A building plan of 125 x 100 ft (38 x 30 m) provides nearly 190,000 ft^2 (17,600 m^2) of gross area. The external facade incorporates 1/4-inch (6 mm) clear float glass with bronze window frames, internal blinds being fitted on west, south and east elevations. The building is not typical of UK office design at this time which generally favoured long rectangular layouts, giving two external zones separated by a central corridor. Air conditioning was provided by a perimeter induction system (1030 Trane HP Unitrane units) with the refrigeration plant comprising two Trane Centravac centrifugal chillers. The design-contractor was G N Haden. (Research by the CIBSE Heritage Group[21] has uncovered a number of construction photographs, the original linen record drawings of the plant room, system schematics and an original specification. The latter is notable for containing a comprehensive commissioning and flushing routine, some ten years before the publication of the first CIBSE (then IHVE) Commissioning Codes.)

1962 Co-operative Insurance Society Building, Manchester

At its time claimed to be the tallest office building in the UK, the CIS complex **[3.21** [G S Hay with Sir John Burnet Tait, 1962] comprises a 25-storey main tower rising to 400 ft (122 m), a 14-storey tower alongside, and a large 5-storey Podium block, altogether giving 700,000 ft^2 (64,800 m^2) of gross floor area.[22,23] The tower is steel frame construction with a structural supporting spine of reinforced concrete. This projecting spine houses vertical service shafts, lifts, lavatories and emergency stairs, leaving clear open floor spaces for the offices (an idea probably copied from the Inland Steel Building, Chicago [SOM,1957]. The facade of the building is made up of lightweight curtain walling with anodised aluminium mullions and vitreous enamelled sheet steel infilling panels backed with thermal insulation, used with single glazing and internal venetian blinds.

The main office spaces are air conditioned **[3.22]** by a two-pipe Weathermaster high-velocity, induction unit system (over 2000 units), designed and installed by Carrier and the Co-op Engineering Department, and operating on the changeover control arrangement. The total air volume handled by all high velocity plants is 220,000 ft^3/min (103 m^3/s). Inner zones of the Main Tower are served by low velocity plants providing a total of some 52,000 ft^3/min (24.5 m^3/s). Special areas elsewhere are air conditioned by conventional low-velocity all-air systems. The main boilers are high-pressure hot water type. The capacity of the refrigerating plant is not stated, but the peak cooling requirement for the entire office complex appears to be in the region of 1500 TR (5265 kW). A central control room housing a control panel with mimic diagrams is provided.

1962 Shell Centre, London

Shell Centre **[3.23]** [Easton & Robertson, Cusdin, Preston & Smith, 1962] was built as the central offices of the Royal Dutch/Shell Group companies in London and at the time of completion was said to be the largest air-conditioned office block in Europe. It accommodated some 5000 employees who had previously been housed in more than thirty office buildings. Situated on the south bank of the River Thames it occupies part of the site of the 1951 Festival of Britain. The Upstream Building has a 26-storey steel-framed tower block rising 351 ft (107 m) above street level, with a U-shaped 10-storey block adjoining. The Downstream Building consists of an L-shaped building, also of 10-storeys, with a 3-storey wing. The gross floor area of the development was nearly 1.9 million ft^2 (174,400 m^2) providing around 600,000 ft^2 (55,600 m^2) of net office space.

The project design commenced in 1953. The site was both dirty and noisy. It was a bold decision to fully air condition a building of this size considering the lack of expertise in Europe at this time. The design philosophy has been stated in a technical paper describing the mechanical services: [24]

"The building has deliberately a quality of solidity and permanency and incorporates mechanical services and equipment designed to give a high standard of living for the occupants and to maintain the standard for many years. Expenditure on the services was judged with this end in mind."

Additional information on the building and details of the lighting, generally 2.75 W/ft^2 (30 W/m^2) using recessed fittings) are available elsewhere.[25] The air conditioning, the lighting and the ceiling design were carefully co-ordinated **[3.24]** to minimise heat gains to the occupied space.

The low-energy design of the building was remarkable in a period when curtain wall construction with 75% single glazing was common in London's office blocks. The design finally adopted used double-glazed windows having a light coloured venetian blind between two panes of clear glass, the window area being either 27 or 36% of the wall area. The external walls are of Portland stone and brick cavity construction, 18 inches (0.46 m) thick.

A technical evaluation considered a number of alternative systems of air conditioning; radiant ceiling with either low or high air pressure distribution, double-duct, induction or fan-coil. The choice by the design-contractor G N Haden was a chilled water radiant ceiling system, a decision endorsed by the client's advisory consultant, C S Leopold of Philadelphia, for the following reasons:

"The main advantage of radiant cooling lies in the fact that less space is required for pipes to transfer heat by water than for ducts to transfer heat by air. The cost of pumping water is a small fraction of the cost of delivering air for the same heat transfer. The air supply may be substantially reduced to that required for ventilation and humidity control and approximately half the cooling load."

The air conditioning was controlled by modular thermostatic temperature controls with local automatic water valves on both outer and inner office ceiling panel grids (some 3000 sets in total). As befits a large building of this era, a large central control panel, complete with the usual mimic diagrams, was provided to operate and monitor some 200 mechanical plants.

The decision was also taken to provide 2700 TR (9500 kW) of refrigeration, employing 3 x 33% electrically-driven centrifugal chillers. The calculated load was 2300 TR (8100 kW), quite a high value for a "low energy" building, largely explained by the rather high electrical/lighting loading allowance of 4.5 W/ft^2 (49 W/m^2) which alone amounts to nearly one-third of the cooling load. The designers had space problems in siting cooling towers and opted for using river water for cooling the condensers. A discussion following presentation of the technical paper reveals the designers believed that the amount of supply air provided for core areas should have been greater, that the corridor ventilation was inadequate, and that satisfactory re-aerating of the river cooling water, after being used for condensing, was not being achieved. However, it is interesting to note that extensive off-site prefabrication (now a feature of many large installations of the late 1990s) was employed to handle the repetitive co-ordinated services arrangements. A final observation is that while radiant ceiling cooling was almost unheard of in 1962, (the Alcoa Building, Pittsburgh, 1953 being a notable exception) now some 45 years later, both chilled beam and chilled ceiling systems are in vogue.

1962 Millbank Development, London

Standing on the north bank of the River Thames, and dwarfing the nearby Tate Gallery, the Millbank Development **[3.25]** [Ronald Ward & Partners, 1962] comprises a 12-storey low-rise office block and a 30-storey, 400 ft (122 m) tower. Once better known as the Vicker's Building, the tower, essentially square with curved sides, sheathed in a "shiny envelope" of greenish curtain walling is considered by many to be an outstanding example of this genre. Air conditioning was provided by a Velovent low-pressure induction system installed by Ellis's. Unshaded by other buildings the internal venetian blinds are always well in evidence.

1963 New Zealand House, London

Built as the High Commission for the Government of New Zealand, these offices at Haymarket/Pall Mall were erected on the site of the old Carlton Hotel which was demolished beginning in 1957. The planning of New Zealand House **[3.26]** [Robert Matthew, Johnson-Marshall & Partners, 1963] commenced in 1956, when air conditioning of offices in the UK was not normally contemplated. The designers, J Roger Preston & Partners, expressed their concerns about the noise, dust and traffic fumes at the busy location. They recognised that the proposed large areas of glazing would lead to high solar gains and used an architect's model of the building to demonstrate these effects. They reported, [26] *"this exposure to sun combined with the very large proportion of glass used in the construction, makes it in our opinion imperative to have some measure of air conditioning, and we must record that we shall be very unhappy otherwise."* These recommendations were accepted.

The overall building plan consisted of a 4-storey podium (or lower block) covering the whole site, with a tower block rising 15-storeys above the podium. Planning restrictions required the podium to be 60 ft (18 m) to cornice level to match surrounding commercial premises with a flat-topped tower to a maximum height of 225 ft (68 m). No plant rooms, lift-gear rooms, cooling towers or other structures were permitted above this height. This provided a gross 200,000 ft^2 (18,500 m^2) of accommodation. The almost full height glazing (single in the tower, double in the podium) required the use of venetian blinds, located inside and between the panes of glass respectively, the latter being motorised.

A design study favoured the adoption of low-velocity air conditioning at 1000-1500 ft/min (5-7.5 m/s). At this period in the 1950s there was concern about the lack of suitable high-velocity equipment, high pressure duct construction and the perceived higher running costs (certainly true in the case of an all-air comparison). The solution adopted used local air plants at alternate levels in the tower with the majority of podium air plants, refrigeration, boilers and (surprisingly) cooling towers located at the lowest level in a sub-basement.

The five lower level air handling plants provided a total supply air volume of 153,000 ft^3/min (72 m^3/s), while in the tower a further six plants supplied some 75,000 $ft^{3/}$min (35 m^3/s). The tower air plants used local zone heating and cooling coils for control purposes. The refrigeration plant comprised two reciprocating chillers, each of 160 TR (560 kW) capacity. The two matching cooling towers were "shoehorned" into the sub-basement. The designers noted: *"This arrangement of operating four fans in parallel against a significant suction head due to the duct, though forced upon us by circumstances, is not one to be recommended and has caused difficulties in operation."* The installation, by Benham & Sons, incorporated a large central control panel having walk-in space behind, with a mimic diagram of the whole building with illuminated panels to indicate the operation of each plant. However, in the discussion following the presentation of the technical paper on the air conditioning, the following comment was made: [26]

"If I may paraphrase the Duke of Edinburgh's speech to this Institution, it is not the beautiful engine rooms and glossy panels which count, but the air which comes out of the grilles and the effect which the conditions provided have on the users of the building."

After experience in use the designers stated that 3 x 40% duty chillers, ie. 384 TR (1350 kW) would have, with hindsight, provided greater flexibility and a desirable measure of standby capacity.

1966 Birmingham Post and Mail Building, Birmingham

This newspaper headquarters **[3.27]** [John H D Madin &Partners, 1966] embraced two systems of air conditioning designed and installed by Carrier. There was comfort air conditioning in the curtain-walled office tower mainly by induction units and mechanical ventilation with provision for refrigeration in the huge, adjoining, almost windowless, works block with a lowest basement floor some 60 ft (18 m) below pavement level (and with about half its enclosed volume underground). The building, 549 ft long by 171 ft wide (167 x 52 m), is surmounted by a 213 ft (65 m) high office tower. The central office block, beneath the tower, and the tower itself, are of reinforced concrete construction with "*a transparent light glass skin, which also provides natural light for the smaller office accommodation."* [27] This is typical of UK curtain-wall office blocks of the period, but not particularly helpful in minimising the air conditioning cooling load. The total building cost was £7,500,000 for a complex of 500,000 ft^2 (46,300 m^2) gross area. The cost of the air conditioning was £400,000.

Ten of the thirteen floors in the tower and two of the lower office floors were air conditioned by a Weathermaster high-velocity induction unit system (427 units). The induction unit system was at this time being widely used in the UK for office air conditioning. The 14th floor Directors' Suite was separately conditioned by a Carrier all-air "Executair" system. The lower level Advertisement Hall was provided with a low-velocity all-air system. The central refrigeration plant at Basement-2 was a single hermetic centrifugal chiller of 240 TR (840 kW) capacity.

1967 Britannic House, Moorfields, London

Britannic House **[3.28]** [J F Milton Cashmore & Partners, 1967] in Moorfields was built as the Headquarters of BP (British Petroleum) and formed part of the Barbican Redevelopment Scheme in the City of London. The following basic facts were given by the designers, G H Buckle & Partners, [28, 29]

"The tower building is approximately 400 ft (122 m) high, with 35 floors above ground level.
There are a lower ground floor and three basements, the lowest being 58 ft (18 m) below street level. There is also an adjoining podium block having six floors above ground level. The whole building has a capacity for some 2100 staff...... The building is completely air-conditioned...The structure is basically reinforced concrete with stainless steel column sheathing. Windows are double glazed with venetian blinds between the panes.

Total floor area (excluding plant rooms)	*589,000 ft^2 (54,540 m^2)*
Area of tower block	*206 ft x 72 ft (63 x 22 m)*
Approximate total cost of project (excluding land)	*£12,000,000*
Cost of all mechanical services	*£2,300,000 (19.2%)*
Commencement of design	*December 1962*
Award of contracts	*June 1963*
Start of occupation	*March 1967"*

Choice of air conditioning was between double-duct, induction, conventional low velocity, and radiant heating/cooling and fan-coil units. After analysis of technical and cost factors, induction was selected. Further analysis decided in favour of two-pipe distribution, rather than three-pipe or four-pipe and the decision, after making part-load calculations, was taken to use a non-changeover system (ie. chilled water throughout the year in normal hours, with primary air carrying the entire heating load in winter). The use of non-changeover at this time was unusual since installations in the United States (where heating and cooling seasons are more defined and extreme) generally used changeover control (ie. chilled water in summer, hot water in winter). The approximate cost of the air conditioning was £1,700,000, or 14.2% of total.)

A detailed description of the air conditioning and all other services, with technical information and system schematics is available in the paper.[29] Some 3500 Hi-Jet induction units were provided. The main refrigerating plant comprised 2-centrifugal chillers, 1 x 500 TR (1755 kW), 1 x 250 TR (880 kW) and 2-absorption chillers, each 475 TR (1670 kW). The total refrigerating capacity, installed at Basement-3 level, was therefore 1700 TR (nearly 6000 kW) of cooling) and operated with nine induced-draught cooling towers at the 34th floor. Absorption chillers were included to take up spare boiler capacity in summer and to reduce electrical maximum demand charges. The boiler plant comprised four HPHW forced circulation water tube boilers, with a total output of 52 x 10^6 Btu/h (15,236 kW).

Another feature, relatively unusual at the time in UK installations, was the provision of a large central Honeywell control panel with mimic diagrams of the systems, status (running/off) lights, a 1000-point temperature "scan-alarm", and a multipoint strip chart recorder. How different from the desk-top computer systems of today.

Summary of the Sixties

By the end of the decade, comfort air conditioning for offices was well established on both sides of the Atlantic. Induction unit systems had by now virtually supplanted dual-duct all-air systems for use in exterior zones, This was particularly true in the UK where most office buildings were long and narrow with no interior zones, while an overseas example is **[3.29]** [Her Britannic Majesty's Embassy in Madrid][W S Bryant & Blanco Soler]. It was recognised that dual-duct systems took up more building space and that duct cross-overs in false ceilings were a problem. Also the capital costs were higher and so too were the running costs. Other types of air conditioning had been tried. A few small office blocks used ventilating ceiling systems. A number of water-to-air unitary heat pump systems, such as VersaTemp, were installed. None of these found any widescale application.

However, there were some new systems and equipment being developed, including variable air volume (VAV). An early UK application was at the new **Cadbury Head Office Building** at Bournville, near Birmingham, in 1966. The 6-storey 'T'-shaped block of some 100,000 ft^2 (9260 m^2) was converted from an existing factory building. The floor-to-ceilings heights were exceptionally high, the windows large and the width of the building required that the air conditioning, designed and installed by Brightside, be suitable to cater for two external zones, two internal zones and a central corridor. The decision was taken to treat external areas with a Hi-Jet induction system and use a Barber-Colman Jetronic[30] high velocity all-air system for interior zones.

The interior zone system used constant volume induction boxes, mixing a cold air stream from a central plant with warm room air extracted through the ceiling lighting fixtures. The interior zone supply and the combined internal/external zones extract operated in VAV mode, having fan inlet guide vane control. Although designed for air conditioning, the refrigeration plant was omitted. Perhaps not an auspicious start for VAV in the UK, but later it would be recognised that VAV could be used for cooling both exterior and interior office areas providing a way could be found to successfully deal with the perimeter winter heating load.

3.4 The Seventies: the boom years

The next advances in air conditioning design were generated in the United States where many very large office buildings took shape. Many of these many were super-skyscrapers, with heights in excess of 700 ft (213 m). The **[3.30]** **John Hancock Centre in Chicago**, actually completed in 1969, stood at 1127 ft (344 m), while newcomers like **New York's World Trade Centre**, and **Sears Tower in Chicago** rose over 1300 ft (400 m). Not only were these buildings taller, the offices were much deeper, the floor areas much larger. A typical floor in the 1924 Straus Building in Chicago enclosed some 27,000 ft^2 (2500 m^2) of space, but due to the light court, the rentable area was only 17,000 ft^2 (1570 m^2). By comparison, in the Sears Tower, the area of the largest floors is around 50,000 ft^2 (4630 m^2) with 40,000 ft^2 (3700 m^2) being rentable area.[31] Furthermore, areas as far as 70 ft (21 m) from the windows were used as office workspace. This was all now possible by improvements in lighting and air conditioning. Reliable all-air systems and VAV boxes were perfected for use in these large internal zones.

In 1974, Los Angeles had its first real skyscraper, the 858 ft (262 m) high **United California Bank**, then the tallest building in the United States west of Chicago. Taking advantage of the milder climate, the air conditioning was provided by an all-air VAV system, which also served the building's exterior zones. The speculative rentable-office market also took off. The concept of "shell and core" services was developed, the landlord providing the boilers, chillers, and the air and pipe risers, leaving the tenant to complete the services in his office space to suit his own particular needs. Equipment improved. Big leaps were made in automatic control and monitoring technology. Larger and better refrigeration plant was manufactured with, in the case of the World Trade Centre, individual machine capacities up to 7000 TR (24,500 kW).

In the UK also there was a wave of speculative office development. Tenants were attracted to air conditioned premises in city centre locations. Unfortunately, with landlords eager to maximise profit, many of these air conditioning systems were far too basic -unsuitable for partitioning flexibility, lacking individual automatic control, often noisy, frequently not properly commissioned and badly maintained. Too often, air conditioning acquired a bad name. Meanwhile, particularly in London, hotel air conditioning (aided by a Government subsidy) flourished. Hotel bedrooms were cooled by a variety of unit air conditioning, heat pump and fan-coil systems.

Air conditioning spread to the new large department stores and following the early 1970s oil crisis, the watchword became "energy conservation." **Bentalls** new store at Bracknell had local all-air systems with a 3-pipe hot water heating/chilled water cooling distribution system, with double-bundle refrigeration condensers to utilise low-grade rejected heat, and with a large sprinkler tank serving as a heat source/sink. **Fenwicks** new store at London's Brent Cross went one better using triple-bundle condensers, the third bundle being used to preheat domestic hot water. The offices and cigarette factory of **W D & H O Wills** at Hartcliffe in Bristol (now a derelict site) had air conditioning with 4000 TR (14,100 kW) of absorption refrigerating machines employing four chillers. The all air conditioned **Hallamshire Hospital** in Sheffield was provided with 3000 TR (10,500 kW) of absorption refrigeration using six chillers.

Meanwhile, in Asia, the first major skyscraper was **[3.31]** [**The Jardine Building, Hong Kong**, 1973] at the time of construction at 586 ft (179 m) and 52 floors the tallest in Asia, its large unusual porthole windows giving incredible views of the harbour.

In the later 1970s, the air conditioning industry in the UK underwent significant changes. Clients became more enlightened. Good architects recognised the special effort needed to get the air conditioning design team involved at the earliest possible moment. The designers became more confident, experienced and innovative. Contractors improved planning and installation techniques. Circular and oval spiral ducting with standard fittings became widely available. The practice of duct air leakage testing was adopted. Piping prefabrication was started by a few firms. The choice of refrigeration widened as machines, such as the Dunham Bush oil-injected screw machine and large capacity air-cooled chillers appeared. Improved equipment and control technology became available as ideas and hardware were imported from Europe and the United States. UK firms were quick to export their air conditioning expertise to the developing area of the world, especially the Middle East, parts of Africa and Asia. The 1970s were the air conditioning boom years.

1973 Standard Oil Building, Chicago

The Standard Oil Building **[3.32]** [Edward Durrell Stone & Associates with the Perkins & Will Partnership, 1973], "Big Stan" to Chicagoans was completed in 1973, being 1,136 ft (346 m) tall, with 80-storeys and an area of 2.7 million ft^2 (250,000 m^2). It was Chicago's tallest building until surpassed in height by Sears Tower in 1974. Square in plan and measuring 194 ft (59 m) on each side, with 15 ft (4.6 m) cut-outs at the corners, each floor is some 30,700 ft^2 (2840 m^2). The steel frame building was originally clad in white Carrara marble, which weathered badly, being total replaced by granite panels in 1992. The structural frame design is unusual: [1]

"The tower design is based on an innovative tubular structural system, in which closely-spaced peripheral columns form a hollow tube. Five-foot (1.5 m) "V"-shaped sections, part of the building frame absorb wind loads. The system permits a column-free interior and totally flexible floor planning between the service core and the exterior walls."

Single glazing is employed with bronze coloured heat absorbing glass; the glass area is around only 15% of the total wall area. Perimeter areas are air conditioned by a two-pipe induction system with primary air and secondary water risers located inside the "V"-shaped columns.[32] Interior area are served by a single-duct terminal reheat system. Fan rooms are located at floors 81 (feeding down), 28 (feeding up) and 27 (feeding down). The basement refrigeration plant of 6200 TR (21,760 kW) has two absorption and two hermetic centrifugal chillers with a further one of each type of machine on the 81st floor, another 2600 TR (9120 kW). The absorption units provide 40% of the load. The air conditioning designer was Cosenti Associates.

1972/1973 World Trade Centre, New York (written before 9/11)

The twin towers of the New York's World Trade Centre **[3.33]** [Minoru Yamasaki & Associates with Emery Roth & Sons, 1973] dominate the lower Manhattan waterfront and form part of the impressive gateway to New York Harbour. The first tower (One World Trade Centre) was completed in 1972, the second tower (Two World Trade Centre) was finished in 1973. Their height is 1,368 ft and 1,362 ft (some 415 m) respectively. Both are 110-storeys and 209 ft (64 m) square. Their combined area is 13 million ft^2 (1.2 million m^2). The style of architecture has been described as "Modernist, in a Neo-Gothic Revival".[1] The structure is a "framed-tube" with closely spaced exterior columns and beams, providing a system of load-bearing walls, having aluminium and stainless steel cladding and vertical floor-to-ceiling "ribbon" bronze-tinted glazing.

The exterior offices spaces are air conditioned by an induction system[33] and
"........supply and return air devices that serve the tower begin with trunks running up and
down the core from the mechanical equipment rooms, and end at the combination light troffer-air diffusers in the ceilings of all typical floors"

The air conditioning statistics are impressive:
"......... 100,000 supply and return air devices to circulate the 11 million cfm (ft^3 /min) (5180 m3/s) of air, 100 fans, 250 steam humidifiers, 300 pumps, 100 heat exchangers and interchangers, 30,000 under-the-window induction units (by Carrier).......and 49,000 tons (TR) of refrigeration (about 172,000 kW of cooling)."

The refrigeration plant comprises seven 7000 TR (24,570 kW) centrifugal chillers by York, among the largest ever manufactured, for what at the time (and probably still is) the largest refrigerating plant for comfort air conditioning in the world. The chillers are driven by 13.8 kV water-cooled synchronous motors. There are no cooling towers. Water taken from the River Hudson is used for condenser cooling, 90,000 US gal/min (5.7 m^3/s) through a 5 ft (1.5 m) diameter intake pipe. The chilled water pumps stand nearly 8 ft (2.5 m) high. The low pressure zone pumps have 1250 hp (933 kW) motors, while the high pressure zone pumps have 600 hp (448 kW) motors.

The client, the Port of New York Authority, described the twin towers as *"the first buildings of the 21st century."* The air conditioning was designed by JB&B and installed by the Sand-Couture Joint Venture.

The towers were destroyed in the 9/11 terrorist attack.

1974 United California Bank, Los Angeles

The United California Bank **[3.34]** [Charles Luckman Associates, 1974], is 858 ft (262 m) high. Measuring 184 x 124 ft (56 x38 m) at the base, the 62-storey structure provides 1.25 million ft^2 (115,740 m^2) of accommodation. The curtain wall construction consists of bronze coloured solar glass and spandrels set between bronze coloured aluminium mullions. Air conditioned throughout, to a design by Syska & Hennessey (Levin & McCann Division), the system is of the all-air type described as of variable air volume double-duct design, [34] all-air systems being popular in Los Angeles at that time *"because they eliminate the need to use a steam fitter to install zones in tenant spaces since heating can also be accomplished by air alone."* Fan rooms (on floors 4, 5, 22, 42, 61 & 62) feed cold air through three parallel duct risers, and cold or hot air through a single riser, to dual-duct loops on each floor. A fifth hot air riser is provided for heating only and boosting the capacity of the warm air floor loop. The air capacity is 21,000 ft^3/min (9.9 m^3/s) per floor. Refrigeration was provided by four chillers, each of 900 TR (3160 kW) on the roof, chiller size being limited by the lifting capacity of the construction crane. Following a major fire in 1988, which destroyed 5 floors, all of Los Angeles' tall buildings are required to be fitted with sprinkler system.

1974 Sears Tower, Chicago

The Sears Tower **[3.35]** [SOM, structural engineer Fazlur Khan, 1974], for some 15 years the tallest building in the world at 1454 ft (443 m) is in effect nine skyscrapers of varying heights bundled into one and *"a prototype of structural efficiency,"* [13] The style of structure known as "bundle tube" is in effect a cluster of framed tubes, interconnected at their common sides, being relatively lightweight yet immensely strong. [35] The curtain wall of black aluminium and bronze-tinted glass encloses some 3.7 million ft^2 (344,000 m^2) over 110-storeys.

In the air conditioning design by JB&B, major plant floors occupy levels 2/3, 29/32, 64/65, 88/89 and 104/109, the latter housing four giant cooling towers, each 24 ft (7 m) square and 3-storeys high. The refrigeration plant, comprising 5 water chillers with a total capacity of 18,600 TR (65,300 kW), is located on the 29th floor.[35] The statistics of these giant office buildings are hard to take in. The typical daytime population is around 10,000 people. The building weighs 223,000 tons, though taller than the Empire State at 365,000 tons. There are 16,100 external panes of glass, 145,000 light fixtures and electrical items, 25,000 (40,000 km) of plumbing, 104 lifts, 18 escalators, 6 window-washing machines, and even heated pavements around the building.

But is the building a success? Opinions vary, but considerable criticism has been levelled at the amount of building sway on very windy days (Chicago is renowned as "the Windy City") and the trail of shattered windows. In fact, the *Wall Street Journal* (2 November, 1988) devoted an article to the subject, quoting the secretary who *"heard that one man was blown out and then blown back in."*[13]

1974 La Tour Maine-Montparnasse, Paris.

The Main-Montparnasse Tower **[3.36]** [Beaudouin, Cassan, de Marien and Saubot, with Epstein of Chicago, 1974], the first skyscraper to be built in Paris created much discontent as it changed the traditional and much-loved skyline with 58-storeys rising to a height of 210 m, providing 104, 600 m^2 of floor area, [36] with low height offices on a podium to one side. The buildings were fully air conditioned by a high-pressure induction unit system, with a giant cooling tower sitting on the roof of the low-level building.

The architects had sought, [37]

"to soften its chunky profile with a sinuous indented plan. The elevations were wrapped around the body of the building using an unobtrusive curtain-wall system. Vertical and horizontal strips in contrasting colours were employed to emphasise height and to mark the approach to the upper section of the building, which was given a slightly tapered effect by a number of subtle features."

Generally, Parisians were not impressed, but the die was cast. An even greater cause of discontent was emerging over the western skyline; the Défense office complex. The boom in high-rise air conditioned office blocks had reached Paris.

1975 Pennzoil Place, Houston

Of striking design, Pennzoil Place **[3.37]** [Philip Johnson and John Burgee, 1975] is a 36-storey office block, 430 ft (120 m) high with top sloping facades of around 45 degrees. The floor area is 1.8 million ft^2 (167,000 m^2) in twin towers of curtain wall with solar glass. The towers are linked by an atrium lobby. Nothing is surprising in air conditioning. The choice by the designers, I A Manan & Associates, was back to dual-duct using two air plants per floor and a central fresh air plant on the roof. Sixteen air handlers served the atrium. Refrigeration was supplied by four 1600 TR (5600 kW) chillers, linked to a five-cell roof top cooling tower. Heating was from basement MPHW boilers with nitrogen pressurisation and, almost unbelievably, the boiler flues discharged through a 33 ft (10 m) high stack at the pavement edge.[38]

1978 Bateson Building, Sacremento

Following the energy crisis of the early 1970s, and spiralling energy costs, both ASHRAE and the CIBSE produced Energy Codes designed to reduce consumption in existing buildings and to limit the energy requirements of heating, lighting and air conditioning in new buildings. Air conditioning engineers began to include methods of heat recovery in their designs: recuperators, thermal wheels, run-round coils, double-bundle refrigeration condensers and the like. All too often these were omitted at the last moment to reduce capital costs. Elsewhere, a number of enlightened clients, architects and engineers sought other ways of reducing energy use, following the adage *"the best way to save energy is not to use it in the first place."*

A number of state office buildings in California were constructed for experimental purposes, the best known being the Bateson Building **[3.38]** [Peter Calthorpe et al, 1978] in Sacremento. Here the aim was to avoid the use of air conditioning altogether and save 75% of normal energy costs by passive building design,[39]

"The interior of the Bateson Building is organised around a four-storey courtyard that serves as a thermal buffer and air circulation space. The sawtooth monitors are fitted with louvres on their south faces to control heat gain but unshaded on the north to admit light. Four tall fan-ventilated tubes prevent thermal stratification by circulating air in the courtyard. The most important energy-conservative devices are invisible. A rock bed under the building acts as a thermal mass. Night air circulated over the rocks cools them and they in turn cool the internal air of the building during the day."

Every side of the building was constructed to suit its orientation. On the south, windows are shaded by deep "trellises and decks" (brise soleil). East and west are fitted with retractable canvas shades, while the north elevation is glazed with flush clear glass. The building was not a complete success, for it has been reported that many of the passive solar devices have never worked as intended, but the Bateson represents an attempted return to the virtues of controlled natural ventilation.

Postscript to the boom years

The 1970s started with the induction unit system being the favourite choice for the air conditioning of perimeter zones in office skyscrapers in the United States, with internal zones catered for by all-air zone reheat or VAV systems. Most air conditioned UK offices in the 1970s were treated in similar fashion, an example being London's 400 ft (122 m) high **King's Reach Tower** **[3.39]** [R Seifert & Partners] on the south side of Southwark Bridge, which was provided with an induction unit air conditioning system. This building was said to be "a sawn-off" version of the design for the 1981 NatWest Tower in the City (also Seifert) which at 600 ft (183 m) was, when constructed, the tallest building in the UK and claimed to be the tallest cantilevered building in the world. By way of comparison, in Hong Kong until the mid-1970s, most air conditioning for the larger offices was by fan-coil unit systems. Then there was a change to VAV as in the 600 ft high, 51 storey **[3.40]** [**Sun Hung Kai Centre**], which was particular suited to the local climate where only a small amount of winter heating is necessary.

However, energy concerns started to change the face of buildings and environmental control designs. In future years, concerns over "green" issues and advances in thermal modelling using computers, would signal the beginnings of the fall of the fully air conditioned building.