The Evolution of Modern Office Buildings and Air Conditioning

The PSFS Building in Philadelphia, completed in 1932, broke new ground in its architectural style and the concept of air conditioning.

The First Century of Air Conditioning

This is the seventh article in our special series to commemorate a century of innovation in the HVAC&R arts and sciences.

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Air conditioning as we know it, providing thermal comfort by mechanical methods, first appeared in buildings about a hundred years ago. The ability to control temperature, humidity and air purity made urban development possible in the most inhospitable of locations. Together with electric lighting, air conditioning also eliminated restrictions on plan form and fenestration that architects had been constrained to work under since antiquity. But how did architects and engineers respond to these opportunities? What effect did this have on buildings? And, were the occupants any more comfortable?

These questions will be addressed in two articles reviewing the evolution of modern office building design and the impact of air conditioning. In this first article, the focus is on the period from the middle of the 19th century, when offices first emerged as a distinct category of building, to the advent of air conditioning in the 1930s. The design of early examples is reviewed, as well as the way architects attempted to provide cool comfort before air conditioning. Also addressed is the impact of air conditioning in terms of form and fenestration on office building design. The second article reviews the developments from the start of the post-World War II boom in air conditioning to the current state of the art.

Development of the Office Building

The description "fully air conditioned" is almost synonymous with large prestigious buildings, particularly commercial offices. However, with few exceptions such buildings did not exist much before the middle of the 19th century. Pevsner, in his *History of Building Types*[1] awards the title of the first office building to the Uffizi (*Ufficio* is Italian for office). It was built in the center of the old city of Florence between 1560–81 and designed for the Medici duke, Cosimo I, to provide government offices for the new State of Tuscany. It appears the architect, Vasari, encountered similar difficulties as his counterparts today.

It was two centuries before government offices on a similar scale were built. This was the development of a series of buildings in the Whitehall area of London to house the administration for the expanding British Empire. Soon after, offices were built speculatively for the first time to be leased as suites.[1] During the second half of the 19th century, the growth of commerce in general, and insurance companies in particular, meant large buildings were needed to house the rapidly increasing numbers of clerical and administrative workers.[3] By the end of the 19th century, offices had evolved as a distinct category of building to house clerical and administrative functions.

The internal environment used by these early office workers was determined largely by building features such as fenestra-

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tion, plan form and story height. Protection from extremes of the climate was restricted to passive measures such as opening windows and lowering shades when it was hot and using open coal fires or stoves, and eventually radiators, when it was cold. The features were determined by other factors including finance, function, location, current technology and architectural fashion.

Although electricity was common by the 1890s, the cost and output of the lamps meant that office work was still largely carried out by daylight. The ability to illuminate the full depth of the offices was, therefore, one of the most important provisions. Although it limited the maximum width of the office between the outside wall and the internal corridor, it also meant that natural ventilation was available from opening windows. The provision of adequate daylight to offices, and the consequent area of glazed wall and restriction in depth of offices from windows, was a major obstacle to architects attempting to provide the maximum of floor space from building plots. Keeping cool did not seem to be a major concern. The priorities appeared to be adequate ventilation for sanitary purposes[4] and the elimination of excessive humidity.[5] The latter was a particular problem in U.S. cities with warm, humid climates.

In retrospect, the using air conditioning in conjunction with the new electric artificial lighting offered great opportunities to transform buildings. Buildings could be designed without the constraints of passive measures to provide comfortable internal environments irrespective of the type and size of enclosure and to create offices of infinite depth without regard for fenestration. On the other hand, air conditioning necessitates ducts, plant and equipment that occupy valuable space. It also increases the initial and operating costs and energy usage. Furthermore, air conditioning does not always work and has to be controlled and maintained. Architects and engineers had to balance the pros and cons of these new technologies with centuries of knowledge of traditional methods.

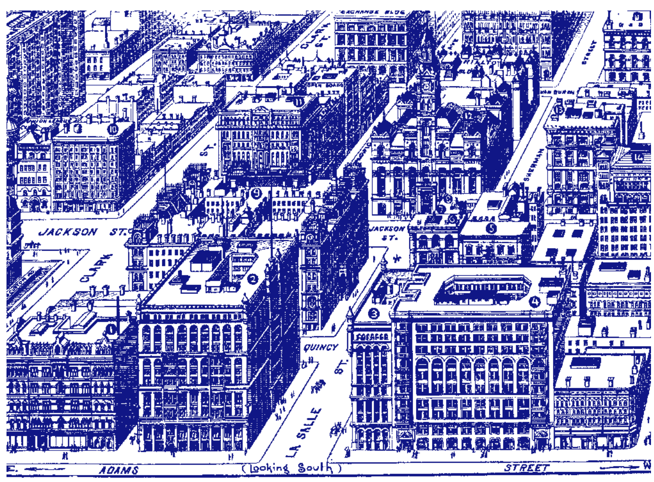


Figure 1: Bird's-eye view of Chicago Board of Trade district 1898.[8]

Office Buildings Before Air Conditioning

Most large offices built up to and around the end of the last century reflect the styles of classical architecture. They were based on designs that can be traced back to antiquity and share characteristics with Italian palaces of the Renaissance and the Roman houses described in Vitruvius's *The Ten Books on Architecture.*[6]

The resulting combination of classically proportioned facades, open courts and limited office depth was not peculiar to Europe. Many American architects of this era studied in Europe and adopted classical styles for their buildings. The use of open courts to provide light was prevalent as it allowed property investors to obtain the best ratio of lucrative office floor area to plot size. They were particularly common in Chicago because of the office building boom that followed the great fire of 1871. Height restrictions had been imposed to limit high vacancy rates. This is illustrated in *Figure 1*. The bird's-eye view is from a series of scale drawings of the Chicago downtown district published by Rand McNally[8] in 1898, and it shows the open courts of the Rookery and Rand McNally buildings.

This type of building was called a "Chicago Quarter Block," so called because they just filled the width of the blocks between streets. The style was exported to many U.S. cities. One of the best known, reputed to be a model office building of its time, is Louis Sullivan's Wainwright Building in St. Louis.[9] Sullivan adopted the same solution as the Uffizi, i.e., a "U" plan form to provide light and air to every office. The "U" plan form and an early photograph of the building are shown in *Figure 2*. Note the use of external sun-shades.

The basic need to provide daylight in offices was a constraint of every office building and was common to all styles of building evolving in major North Amercian cities. For example, by 1900 in New York, putative skyscrapers were reaching heights of nearly 120 m (400 ft), but the shape and size of the floor plan was still constrained by the need to provide adequate daylight for clerical work.

Mechanical Ventilation

Ventilation and the need for adequate supplies of fresh air were a preoccupation of heating and ventilating engineers in the 1890s.[4] As a result, mechanical ventilation had been introduced into many of the new larger and taller buildings. At a meeting of the fledgling American Society of Heating and Ventilating Engineers (ASHVE) in 1899, the author of a paper, "Some Points Regarding the Ventilation and Heating of Tall Buildings,"[10] commented that he had visited many offices in the most recent buildings. He noted that "when entered from the outside air, they appeared to possess at least some of the qualities of menageries…." He was referring to the odor and thought that it was a sure sign that ventilation was needed. In the context of the paper, he meant mechanical ventilation. He also described the types of mechanical ventilation systems in use in tall U.S. buildings and mentioned the problems of accommodating ducts. Some systems relied solely on exhaust ducts and extract fans with natural inlets. Others had blast (supply) fans with natural exhaust. One novel plant in a building in

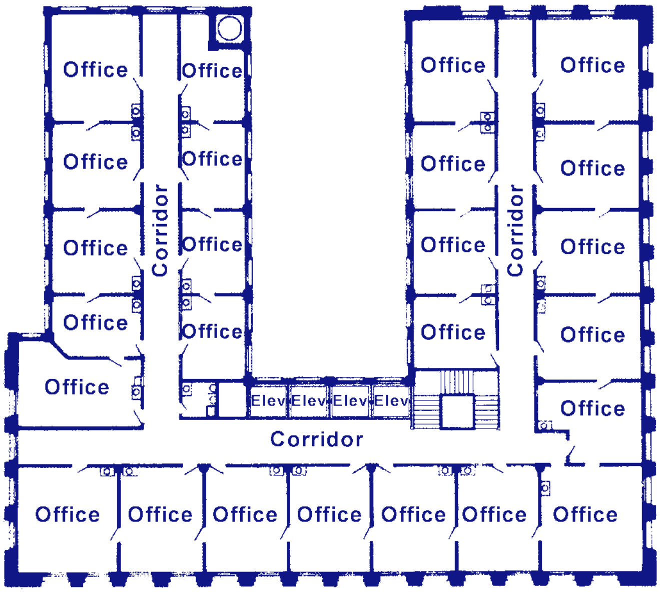
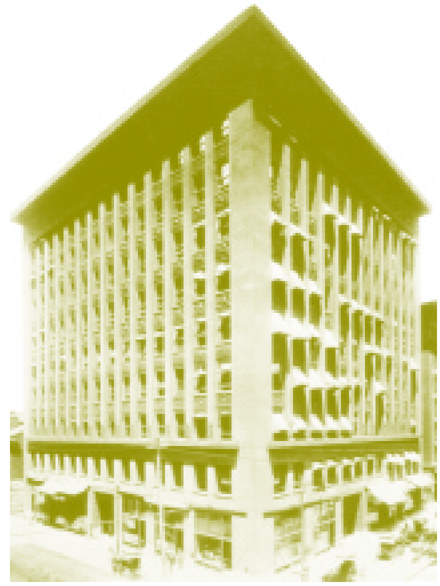


Figure 2: At left is the Wainwright Building (1891), second floor plan.[9] At right is an early photograph of Wainwright Building.[12]



Buffalo, N.Y., used the ventilation plant to entirely heat and ventilate the building (i.e., without using radiators). He suggested, with considerable foresight, that an ideal solution for such systems would be to have "double ducts," one hot and one cold.

Alfred R. Wolff was the leading exponent of the design of mechanical systems in the United States at the turn of the century and the person responsible for the "all-air" ventilation system at Buffalo. He designed about 100 systems between 1889 and his death in 1909.[11] These tall buildings were not mechanically ventilated throughout. For example, the 21-story American Surety Building in New York, completed in 1896, had a mechanical warm air supply and extract ventilation system providing four fresh air changes per hour, which only served the lower seven floors. The rationale was that lower floors suffered from the noise and smells of the street and that the occupants could not open windows for relief. The practice continued into the late 1920s and 1930s.

The problem of office overheating was not mentioned in the paper nor raised in the discussion. However, a comprehensive paper on "The Cooling of Closed Rooms,"[5] had been presented at a meeting of ASHVE the previous year, and a few mechanical cooling installations had already been completed.[11]

The Larkin Administration Building

The first office building to break the mold was the Larkin Administration Building, designed by Frank Lloyd Wright and completed in 1906. The brief from the client[12] required a sealed building with mechanical ventilation. No mention was made of cooling, but Wright specified a refrigeration plant that distributed cooling water at 10°C (50°F) to air-cooling coils in the air-handling plants.[13]

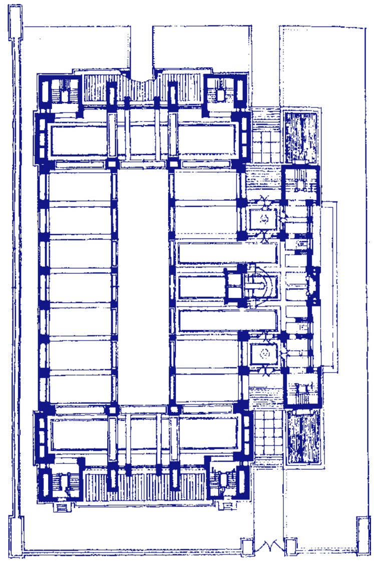
The external appearance, form and massing of the building was dramatically different from architectural fashion at the time. Most U.S. architects were still designing offices in the "Beaux Arts" style with heavily ornamented facades. The Larkin building was large and squat. Wright described it in his 1943 biography[13] as a "simple cliff of brick hermetically sealed (one of the first air-conditioned buildings in the country)." The term "air conditioning" was practically unknown in 1906 and did not come into common use until the 1920s.

Although the building appeared distinctly different, in terms of the mass it resembled the "Chicago Quarter Blocks" that Wright was involved with when he worked in Louis Sullivan's architectural offices in the 1890s. It had a basement and five floors above ground, and the office space surrounded a large atrium with a glazed roof, or light court as it was called (*Figure 3*). This provided daylight to inner spaces on the floors above ground, even though the building had electric lighting throughout. The large windows had an unusually high sill, 1.5 m (5 ft) above the floor level, and no sun shading, in contrast to most buildings of the period.

The mechanical ventilation system provided heating and cooling by 4 to 5 changes of full fresh air per hour treated in the basement air-handling plant. Air was exhausted from the offices at floor line in winter and from the ceiling in summer, presumably to maximize the respective heating and cooling effect. Although the cooling power was not great, by comparison with more recent systems, one can speculate that intrinsic features of the building would have meant that it was cool and comfortable in summer. These features that contribute to cool comfort include: the generous floor to ceiling height of 4 m (13 ft); the "thermal-mass" of the walls and ceilings; and the recessed windows. The only area where there was likely to be a lack of comfort was on the west side where clerks would have been in direct sunshine on summer afternoons. Later photographs show that blinds were eventually installed, presumably to minimize overheating.

The Larkin building was probably the first building designed to accommodate all the paraphernalia associated with modern air conditioning. Service ducts running from basement to roof were sited adjacent to staircases and expressed on the outside of the building. The ducts handled air drawn in and exhausted at roof level. Columns were extended with false sections to house steel supply ducts. Large areas of the basement were allocated to water storage and to air-handling plants drawing air from the top of the building. Although Wright specified a refrigeration machine, space was not allocated on the basement plan. Therefore, he might have been the first architect to underprovide space for an air-conditioning plant.

From the perspective of the history of air conditioning, this building is unique. Wright's design included working drawings of the ducting and plant and resolved many of the major issues decades ahead of other architects.



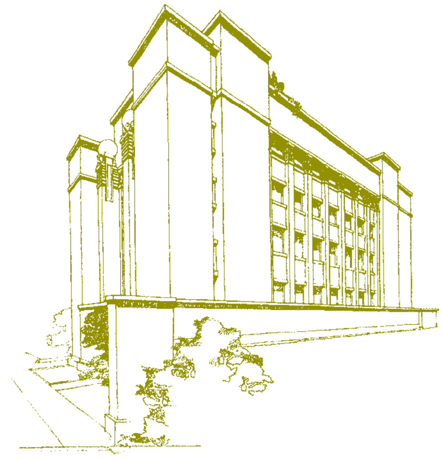


Figure 3: Interior (left) and exterior (above) views of the Larkin Administration Building.[14]

Naturally Ventilated Skyscrapers

Although the Larkin Building was widely reported and well received, the development of air conditioning in offices languished for the next 20 years. By the mid-1920s, air conditioning was installed in theatres, hotels and department stores, but rarely in offices, despite the mid-20s building boom. In fact, the skyscraper "as we know it" evolved without the benefit of air conditioning. Classic buildings such as the Woolworth and Chrysler reached unprecedented heights by relying on nature to provide lighting and ventilation. The form of office buildings was still dominated by the need to provide natural light to offices.

In the mid-1920s, as a prelude to the construction of a new headquarters and investment property for the conservative banking firm of S.W. Straus and Company in Chicago, an extensive study was carried out in an attempt to obtain the most efficient office building. Their measure of efficiency was achieving the greatest office area for a given cube of building.[15] The constraints were the plot size and the local building height limitations. The result was a 21-story building with a large light court surmounted by a nine-story tower *(Figure 4)*. The combination of the "doughnut" plan with a light court and the plot shape proved more efficient, in space terms, than the "E," "H" and "U" plan forms that also were used to optimize natural light and floor space.

The useful depth of office space was increased by locating ante-rooms between the window-lit office and the corridor. This was common practice in the U.S., probably as a consequence of filling the large floor plan area generated by the street planning grid. A typical arrangement allowed two-windowed offices and a "reception" area in a regular "T" shape. The reception space was used for secretaries, and these "second-class" workers had to rely on borrowed light and ventilation from the outer office. Although it seems no expense was spared—it cost $12,000,000 and was advertised as "Chicago's Finest Office Building"—it was not air conditioned. Only two years later, what was claimed to be the world's first fully air-conditioned office building was completed in San Antonio, Texas.

The Fully Air-Conditioned Office Building

A magazine was launched in 1929 called *Heating, Piping and Air Conditioning* (HPAC). The title and the relative position of the words "air conditioning" is probably a sign that the term was coming into common use. The lead article in the July issue[16] proclaimed the Milam Building the "first in the country to be completely equipped for air conditioning to provide year-round comfort," what we would describe now as fully air conditioned. Although air conditioned, the building form, fenestration, floor plans, etc., belong to the pre-air-conditioning era.

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

The duct distribution plan is shown in

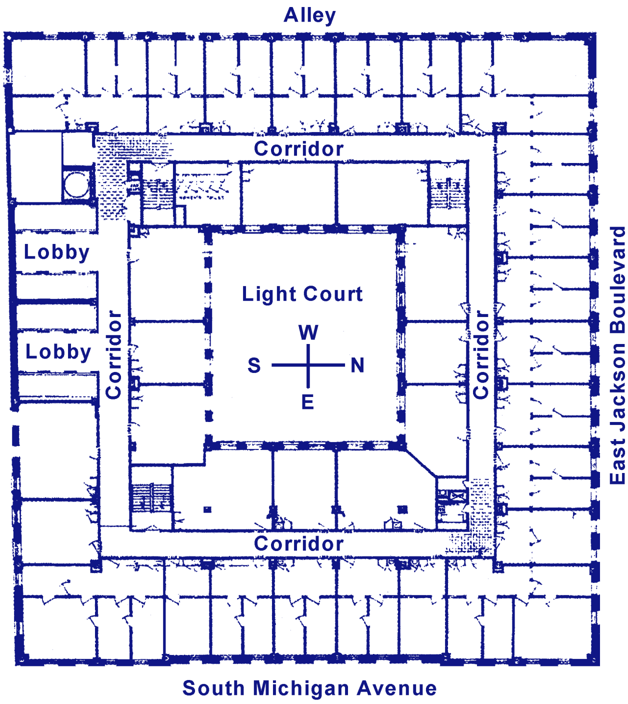


Figure 4: At left is the Straus Building, fourteenth floor plan (1924).[15] *The photograph at right shows the exterior of the Straus Building.*[15]

Figure 5. Ducts were housed in a false ceiling that formed a bulkhead that was lower than the main office ceiling. Air was supplied from side-wall outlets at a high level and returned to the fan room via transfer grilles and along corridors. The amount of fresh air makeup could be adjusted by hand. The refrigeration unit had a cooling capacity of 300 tons (1,100 kW), which when related to the area of 20,000 m^2 (220,000 ft^2), seems quite minimal. The maximum rate of cooling would have been about 54 W/m^2 (17 Btu/h·ft^2). Taking into account the outdoor design condition of 36°C db (96.8°F) and 23°C wb. (73.4°F), the design of the ductwork and the poor air distribution, it is unlikely that the occupants of the offices in the southwest corner enjoyed the benefits of a fully air-conditioned environment. Perhaps the ability to open windows was a significant factor.

Air Conditioning and the International Style

Although the office workers in the Milam Building might not have received the full benefits of air conditioning, they were considerably better off than the people in the Salvation Army Hostel designed by Le Corbusier and Jeanneret at about the same time. Le Corbusier had been collaborating with Gustave Lyon, who was developing air conditioning in Europe independent of the "experiments" in the U.S.[17] Lyon had completed the air conditioning for a 3,000-seat auditorium with his system called *l'air ponctuel,* which loosely translates as "regulated air."

Le Corbusier claimed to have invented a technique for canceling the cooling effects of the large glazed surfaces characteristic of the new architecture, subsequently called the "International Style." Le Corbusier's idea was to circulate air at a constant temperature of 18°C (64.4°F) between the panes of double glazed windows. He called the technique *le mur neutralisant* (neutralizing wall) and coupled it with Lyon's regulated air for a design of the Centrosoyus Palace in Moscow. The combination was called "conditioned air," which Lyon thought was "an idea of genius." The Russians obviously did not agree. They ignored the proposal and simply placed radiators behind the large opening windows.

The opportunity to use the concept came with the *Cite de Refuge*, a Salvation Army shelter in Paris. Le Corbusier conceived the idea to hermetically seal the south face of the building from floor to ceiling and wall to wall with 1,000 m^2 (11,000 ft^2) of glass. His view was that the glass could be hermetically sealed as "warm and cleaned air circulated abundantly inside." He was giving the "poor souls" "the free and ineffable joy of full light and the sun."

The building opened late and over budget on Dec. 7, 1933, in one of the coldest periods in memory. The temperature inside on that cold, sunny day was perfect. Unfortunately, the same could not be said during summer. Although the designers had intended to provide their version of air conditioning, the budget did not provide for the cooling plant, and the neutralizing wall had been omitted.[18] Sealed windows did not comply with regulations and ultimately, much to Le Corbusier's displeasure, the windows were changed to opening. It appears that this experience changed Le Corbusier's ideas about glazing. His subsequent buildings featured shading (which was eventually fitted to the hostel), and he is credited with inventing the *brise-soleil*.

The PSFS Building

The 32-story PSFS Building in Philadelphia, completed in 1932, broke new ground in its architectural style and the concept of air conditioning. The appearance was considered modern and distinctly different from any other in the U.S. The design reflected the International Style[19] with such features as an absence of external ornamentation, cubic shapes and a relatively large area of metal framed, ribbon windows *(Figure 6)*. The PSFS building shared these characteristics with Le Corbusier's Salvation Army Hostel and buildings by other leading architects of the time such as Gropius and Loos. But unlike their buildings, it was fully air conditioned.

It is difficult to understand why this building was air conditioned when other major buildings of the period were not. For example, the Empire State Building in New York City had only been completed a year earlier, and the RCA Building, the centerpiece of Rockefeller Center, had just started construction. Neither were air conditioned. The manager of the PSFS Building, writing in 1937,[20] claimed the reason was the prospect of increased rental income. However, the difference might have been that the PSFS was built for a prosperous savings fund society that had the funds available. It was a period of severe recession in the U.S., and property developers had still not identified any financial gain from air conditioning.

The design of the engineering systems at the PSFS Building included several innovations that pioneered the approach to servicing tall buildings. One of the more significant was the introduction of an intermediate level mechanical plant room floor on

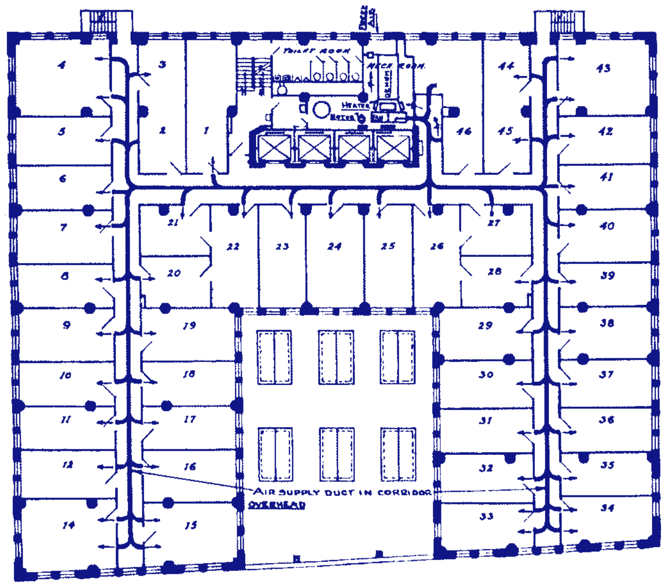


Figure 5a: Floor plan for the Milam Building (1929).[16]

Figure 5b: Exterior view of the Milam Building.

the 21st floor, in addition to the plant at roof level and in the basement. The concept reduced the space required for the vertical ducts by distributing them up and down from the roof, basement and intermediate plant floor. This division of the air supply plant dramatically reduced the floor space for vertical ducts.

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

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

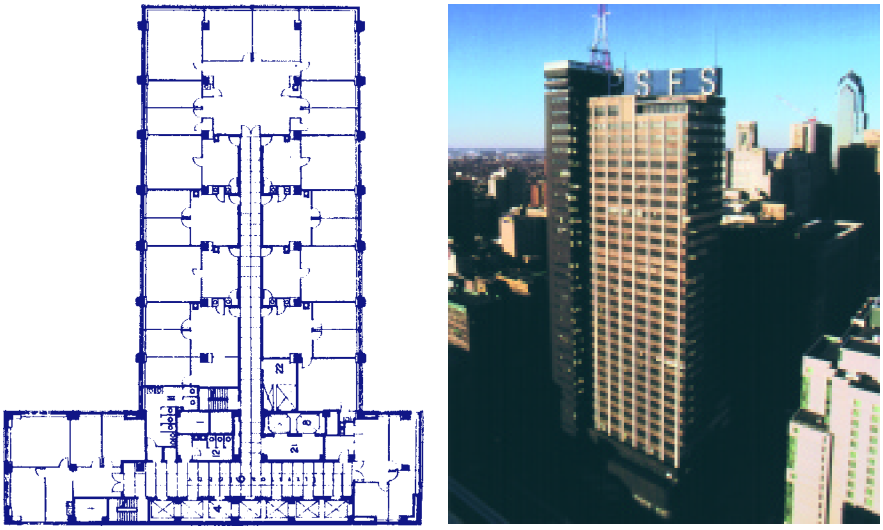


Figure 6: At left is the PSFS Building (1932), typical upper floor plan.[19] At right is a contemporary photograph of the PSFS Building.[19]

However, what is certain is that they used a novel architectural technique to conceal some of the air-conditioning paraphernalia. The large "PSFS" sign on the top of the building, lit by red neon at night, is a Philadelphia landmark. It was designed to conceal cooling towers. Notwithstanding this, and with the possible exception of Lloyd Wright's Larkin Building, air conditioning had achieved little impact on the appearance of buildings up to the mid-30s.

Strangely, one of the few that did was an office building for the Hershey chocolate company. The company decided to build a windowless air-conditioned building in the "very clean and beautiful country (side)" of Pennsylvania.[22] Another was a new office building for the Detroit Edison Company that avoided the need for "U," "H" or "E" floor plans and constructed one of the first deep-plan buildings without light courts.[23] A building that really took advantage of the opportunities that air conditioning offered before World War II was the Johnson's Wax Administration Building, completed in 1939. Frank Lloyd Wright included several innovative features in this sealed building. Apart from air conditioning, it had hydronic underfloor heating and clerestory windows constructed from bundles of glass tubes to produce diffuse light. The air-handling units were at roof level and resembled "nostrils" and carried out a similar function. However, these were all low-rise buildings and, even though mechanical plants at intermediate floors reduced the size of vertical ducts, the amount of floor space remained a major drawback in tall buildings.

Air conditioning in office buildings was becoming increasingly common until construction was interrupted by WWII. Some architects and clients had recognized some of the potential of air conditioning coupled with electric lighting. Windowless buildings were now a reality (and actually built). One major problem, the space required for ducts in tall buildings, had been reduced by introducing mid-height plant rooms. Terminal air-conditioning unit systems such as induction and fan coil were now available that further reduced space for air conditioning. However, up to this time, few architects had taken real advantage of the opportunities available. This was to change before the war was over.

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