Deep Space, Thin Walls: Environmental and Material Precursors to the Postwar Skyscraper

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The buildings of the twenties were designed to depend on natural ventilation and, to a large degree, on natural light. Even such comparatively recent buildings as the Empire State and the Rockefeller Center complex represent a concept of an office building as a shallow structure with rental space constructed around a center service core containing elevators, stairways, utilities and toilet facilities. Such structures give offices maximum possible exposure to exterior light and air. But with the great improvements in artificial lighting, and the development of year-round air conditioning, entirely different building concepts have become practicable. It is now possible to build deep space in buildings, with interior working space uninterrupted by service facilities—which can be located off to one side—and still make office space in such buildings efficient, functional, comfortable, and healthful.

—**Kenneth H. Ripnen**[1]

The Historically Invisible Prudential Building

In 1958, *Architectural Forum* hailed Chicago's Inland Steel Building as "the first major structure to be built in Chicago's Loop in 24 years," since the construction of the Field Building in 1934 (Figure 1).[2] The journal suggested that Inland Steel represented the rebirth of Chicago's business district and a bid by the city to regain the "architectural leadership" in steel-frame construction that it had ceded to New York in the 1910s. Chicago was at the time reeling from a surplus of office space, years of political corruption, and a decline in economic and cultural influence. A. J. Liebling's scathing 1952 *New Yorker* articles on the "Second City" had detailed the Loop's irrelevance: "Most Chicagoans," Liebling claimed, pass "through it barely more than once a year, and then just to view the Christmas decorations set out by the department store owners on State Street."[3] Inland's steel-and-glass exteriors, and the faith they represented in the Loop's potential, signaled a brighter future.

In its reporting on Inland Steel, however, *Architectural Forum* failed to note the recent completion of Chicago's tallest building—just six blocks away, first announced in 1951, and under construction from 1952 to 1955. Liebling, too, must have been aware of the massive structure planned for Chicago's most prominent site, on Michigan Avenue at Grant Park's north end. At height of just over 600 feet, with a television antenna that raised it to nearly 1,000 feet overall, the Prudential Building, designed by Naess & Murphy, was not only a "major structure" but also the tallest building in the United States west of Cleveland (Figure 2).[4] One million square feet of net lettable area made it "a one-building Rockefeller Center," with the largest office floors in the country

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Figure 1 Skidmore, Owings & Merrill, Inland Steel Building, Chicago, 1958 (Chicago History Museum; © Ezra Stoller/Esto).

outside New York, at 20,000 square feet each.[5] *Architectural Forum* had devoted several pages to the Prudential early in its design process, in 1952. Why would it ignore such an important local precedent in its coverage of Inland Steel? And why would Prudential's $40 million investment in downtown Chicago's future not even register with Liebling, who had been writing at the time of the company's heated announcement of its new building? Perhaps more intriguing, why would a building hailed as one of the era's largest and most technically advanced structures be practically invisible within the professional press and histories of postwar architecture?

Architectural Forum's indifference to the Prudential was evident even in its 1952 article. While the tower's commercial, mechanical, and structural achievements were impressive, the journal described the result as "no design experiment, no Lever House, no Alcoa, no UN Secretariat," all of which featured more striking skins of aluminum, steel, and glass. The Prudential was, in contrast, more "like Pittsburgh's Mellon–US Steel Building [Harrison & Abramovitz, 1951] . . . its emphatically vertical limestone and aluminum (or stainless steel) slab . . . contemporary with Rockefeller Center."[6] This was harsh criticism. Raymond Hood's main building for Rockefeller Center was finished in 1933. While Rockefeller Center's scale remained impressive in 1952, its stone-and-metal skin, punched with intermittent double-hung windows, was nearly a generation out of date.

Yet the Prudential stands as evidence that solid skins still offered a viable approach to cladding in the early 1950s. This solidity gave way to glass-and-aluminum skins as architects were inspired and encouraged by the successes of Lever House and Inland Steel, among others. But such enthusiasm was neither universal nor immediate. In Chicago, structures such as the United Insurance Building at 1 East Wacker Drive (Shaw, Metz and Associates, 1962) extended the Rockefeller Center model through the mid-1960s.[7] The near ubiquity of the postwar "glass box" was shadowed by more conservative architects' stubborn reliance on the Rockefeller Center formula: solid verticals married to punched windows and dark spandrels. Why would such a configuration persist in an era that seemed to offer widespread affirmation of the fantasies of glass proponents from the 1920s?

Figure 2 Naess & Murphy, Prudential Building, Chicago, 1955 (contemporary postcard, Thomas Leslie collection).

The emergence of the glass box was evolutionary; the form had its roots in technical advances that took place before the war but became commercially viable only with the impetus of a strong postwar economy and with refinements and improvements that came about through wartime efforts. Five developments—air-conditioning, fluorescent lighting, automated plate-glass manufacture, double glazing, and heat-absorbent glass—together enabled the larger floor plates and thin, transparent skins that dominated commercial high-rises after midcentury. The Prudential Building's mass and solidity reflect a key moment in postwar skyscraper development; its deep floor plates took advantage of what were by then well-proven advances in environmental control and lighting technology, but its solid skin shows that improvements in glass production and performance lagged behind. The glass box relied on the affordability and reliability of environmental systems and cladding technology to achieve comfort and performance standards at reasonable material and construction costs.

The Windowless Building of the Future

Historians have seen Ludwig Mies van der Rohe's 1921 competition entry for a skyscraper along Berlin's Friedrichstrasse as a harbinger of glass towers to come, a dream realized, for Sigfried Giedion, in the Lake Shore Drive Apartments thirty years later (Figure 3).[8] Like D. H. Burnham and Company's Reliance Building of 1895, to which Giedion compared it, Mies's crisp, vaporous glass tower scheme seemed "an architectonic anticipation of the future," a vision of pure forms and skins—"almost nothing"—enclosing open spaces within.[9] These proposals mixed, as Reyner Banham notes, the "last great manifestations of the Scheerbartian glass-dream" with diaphanous invisibility to inspire a new "skyscraper enthusiasm."[10] The almost contemporaneous selection of John Mead Howells and Raymond Hood's solid, neo-Gothic scheme for Chicago's Tribune Tower (1923), however, shows that such enthusiasm was not universal.

It was not just aesthetic conservatism that worked against such glass tower dreams. While European modernists saw the potential of glass, many others viewed the use of glass as a functional necessity that would be eliminated in technically informed buildings of the future. As early as 1898, architect and civil engineer Howard Constable, of New York City and Philadelphia, suggested that future office buildings would remove glass on environmental grounds:

> An office building without windows, without air shaft, light well, or inner court, with each and every office lighted, heated, and ventilated artificially—this is the newest idea in commercial edifice construction. . . . Its essential principle is that the light and air required for offices can best be furnished by scientific appliances in the building itself rather than have them come from the outside world. In fact, were it not for the decorative effect, as seen from the street, such a building could be merely four unbroken, unpierced, solid walls, with openings for the doorways alone.[11]

This scientifically derived windowless ideal gained further momentum in the 1930s. Climate-aware architects in Chicago and elsewhere decried the glass schemes of Mies and others. "Cables from Germany telling of glass walled skyscrapers, churches, factories, and homes have brought an emphatic 'no' from leading Chicago architects and engineers," noted *Tribune* real estate writer Al Chase. "In [Chicago's] climate the winter fuel bills would be so far beyond any ordinary pocketbook, and the cost of cooling this greenhouse type structure in summer so enormous, that they would be economically impossible."[12] In 1933, Keck & Keck's glass House of Tomorrow at the Chicago Century of Progress Exposition encountered similar criticism. "The air conditioning system," wrote domestic columnist Louise Bargelt, "works night and day all seasons of the year."[13] Publicity photos showed

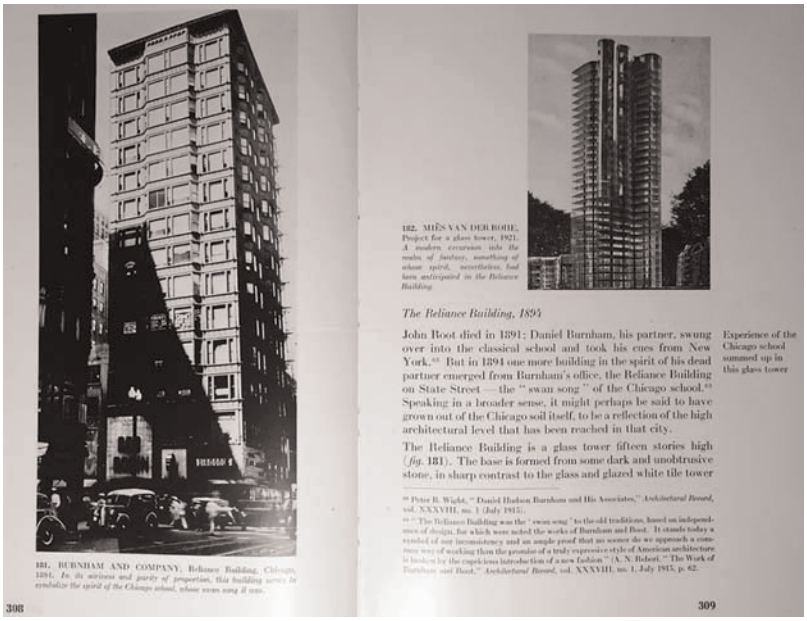


Figure 3 Glass towers: D. H. Burnham and Company, Reliance Building, Chicago, 1895 (left); and Ludwig Mies van der Rohe, glass skyscraper project, 1921 (Siegfried Giedion, *Space, Time and Architecture: The Growth of a New Tradition*, 5th ed., rev. and enlarged [Cambridge, Mass.: Harvard University Press, 1941, 1982).

Figure 4 Keck & Keck, House of Tomorrow, Century of Progress Exposition, Chicago, 1933 (Chicago History Museum).

the house with blinds drawn against the sun's heat and glare even while visitors were dressed for winter (Figure 4). The Kecks' Crystal House, constructed in 1934, faced similar issues.[14]

In contrast to such problematic glass houses, many building projects in the 1930s adopted Constable's vision of windowless structures. The Simonds Saw and Steel Company of Fitchburg, Massachusetts, constructed a factory complex entirely of solid walls from 1931 to 1937, replacing windows with "hundreds of 1,000 watt electric lights" that provided more reliable and uniform lighting. The factory was praised for its "radically advanced ideas for scientific creation of artificial lighting, ventilation, and other working conditions" (Figure 5).[15] In Chicago, Sears, Roebuck reversed the city's history of display and illumination windows in its retail palaces by constructing what it claimed to be the world's first "windowless store" at Sixty-Third and Halsted Streets (Figure 6). Designed by the company's in-house architects, Nimmons, Carr & Wright, the solid-walled store claimed numerous functional advantages over naturally illuminated and ventilated stores, including that

> air conditioning and lighting systems would work more efficiently with corresponding economies in operating costs; that deterioration of merchandise from sunlight, smoke and grime could be materially lessened; that disturbing noises could be better excluded; and finally . . . the lineal feet of wall space available for shelving and display might be increased by approximately 10 per cent of the total sales area, making for a much more compact and convenient arrangement of merchandise.[16]

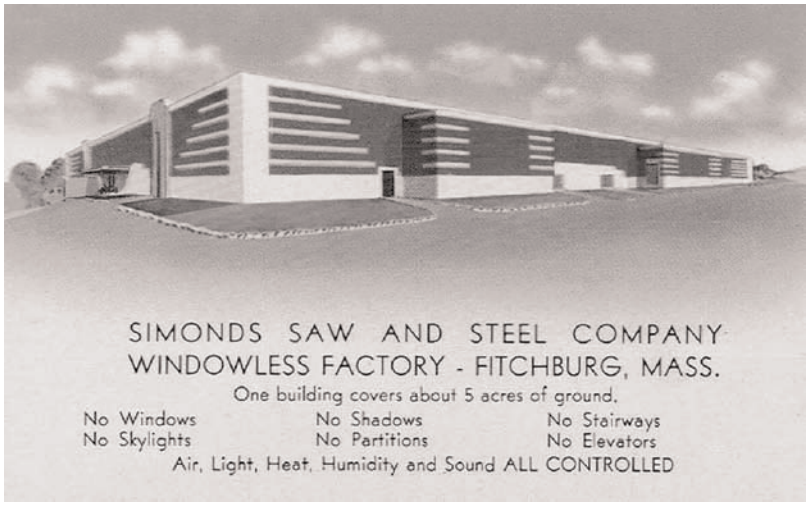


Figure 5 Austin Company, Simonds Saw Factory, Fitchburg, Massachusetts, 1931 (contemporary postcard, Thomas Leslie collection).

Figure 6 Nimmons, Carr & Wright, Sears, Roebuck & Company store, Englewood, Chicago, 1934 (*Chicago Tribune*, 20 May 1934).

"The window," *Architectural Forum* noted in response, "dies hard."

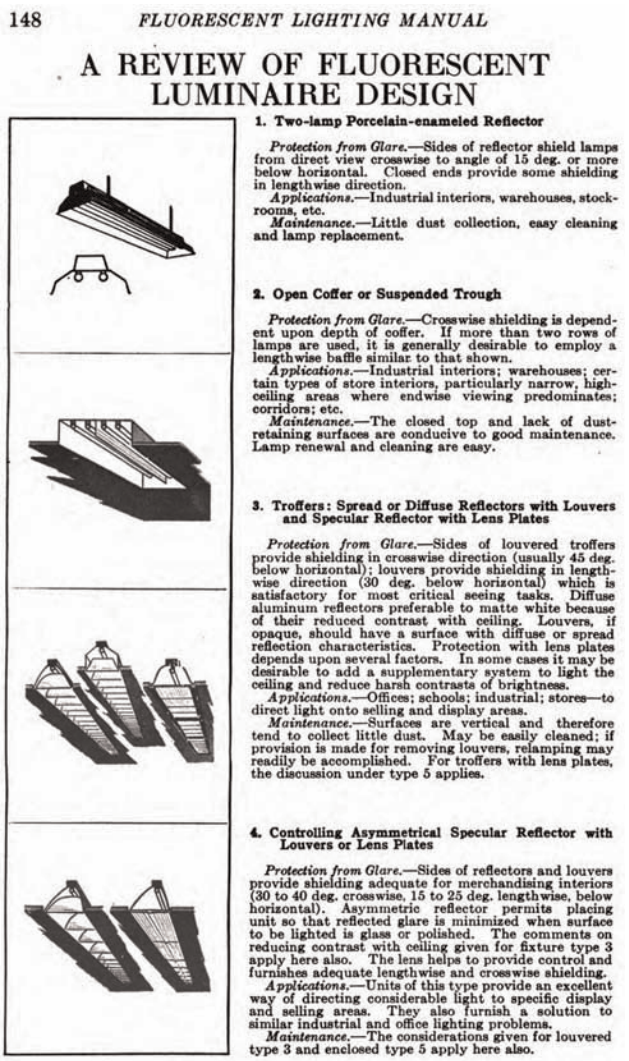
> For fifteen hundred years it has been the fundamental unit of architectural design. Although the windowless building has been a possibility since modern lighting and air conditioning became accomplished techniques, architects have until now ignored the opportunity of actually building one.[17]

Windowless factories and department stores seem anomalous in hindsight, but they represent an important moment in environmental and cladding technology; while advances in air-conditioning and lighting had been widely adopted by the mid-1930s, developments in glass were still nascent. Designers of office buildings and residences were slow to abandon windows entirely, as exterior views were considered amenities that could influence rents and home values. But windowless offices appeared in the 1930s, too, first as adjuncts to windowless factories, such as that built by Simonds, and eventually in the commercial market as well.[18] The popularity of glass block in the era's streamlined moderne offices and houses can be partially ascribed to the material's transparency and insulating capacity. It proved to be a crucial, if short-lived, solution to maintaining hints of exterior views without the heating and cooling costs that came with plate glass windows.[19] By 1935, mechanical provisions for interior comfort—air-conditioning and lighting in particular—had become cost-effective and reliable enough that office environments could be separated from natural sources of light and air. But glass development was not yet up to the task of insulating these environments from excessive light, heat, or cold. Advances in the manufacture of glass and in its performance would be necessary before the glass skin would be able to provide a functional enclosure that could challenge the windowless wall.

Toward the Deep Plan: Air-Conditioning and Fluorescent Lamps

Early attempts to cool the air in building interiors involved the use of electric refrigeration to produce ice or chemicals to remove condensation from moist, hot air. Neither process was adequate for large commercial spaces. Early mechanical air-conditioning systems used sprayed water and reheat coils, which were eventually coupled with a circulating refrigerant—usually ammonia, which sufficed for industrial applications that required stringent temperature and humidity control, such as lithography and newspaper printing.[20] Willis Carrier of Syracuse, New York, developed the first working system along these lines in the late 1910s. But ammonia was dangerous, and these early systems were unsuitable for commercial uses because they produced unregulated quantities of cold air. Separate advances in ventilation

Figure 7 George Willis and M. L. Diver, Milam Building, San Antonio, Texas, 1928 (photo by Thomas Leslie).



148 FLUORESCENT LIGHTING MANUAL

A REVIEW OF FLUORESCENT LUMINAIRE DESIGN

1. Two-lamp Porcelain-enameled Reflector

Protection from Glare.—Sides of reflector shield lamps from direct view crosswise to angle of 15 deg. or more below horizontal. Closed ends provide some shielding in lengthwise direction.
Applications.—Industrial interiors, warehouses, stockrooms, etc.
Maintenance.—Little dust collection, easy cleaning and lamp replacement.

2. Open Coffer or Suspended Trough

Protection from Glare.—Crosswise shielding is dependent upon depth of coffer. If more than two rows of lamps are used, it is generally desirable to employ a lengthwise baffle similar to that shown.
Applications.—Industrial interiors; warehouses; certain types of store interiors, particularly narrow, high-ceiling areas where endwise viewing predominates; corridors; etc.
Maintenance.—The closed top and lack of dust-retaining surfaces are conducive to good maintenance. Lamp renewal and cleaning are easy.

3. Troffers: Spread or Diffuse Reflectors with Louvers and Specular Reflector with Lens Plates

Protection from Glare.—Sides of louvered troffers provide shielding in crosswise direction (usually 45 deg. below horizontal); louvers provide shielding in lengthwise direction (30 deg. below horizontal) which is satisfactory for most critical seeing tasks. Diffuse aluminum reflectors preferable to matte white because of their reduced contrast with ceiling. Louvers, if opaque, should have a surface with diffuse or spread reflection characteristics. Protection with lens plates depends upon several factors. In some cases it may be desirable to add a supplementary system to light the ceiling and reduce harsh contrasts of brightness.
Applications.—Offices; schools; industrial; stores—to direct light onto selling and display areas.
Maintenance.—Surfaces are vertical and therefore tend to collect little dust. May be easily cleaned; if provision is made for removing louvers, relamping may readily be accomplished. For troffers with lens plates, the discussion under type 5 applies.

4. Controlling Asymmetrical Specular Reflector with Louvers or Lens Plates

Protection from Glare.—Sides of reflectors and louvers provide shielding adequate for merchandising interiors (30 to 40 deg. crosswise, 15 to 25 deg. lengthwise, below horizontal). Asymmetric reflector permits placing unit so that reflected glare is minimized when surface to be lighted is glass or polished. The comments on reducing contrast with ceiling given for fixture type 3 apply here also. The lens helps to provide control and furnishes adequate lengthwise and crosswise shielding.
Applications.—Units of this type provide an excellent way of directing considerable light to specific display and selling areas. They also furnish a solution to similar industrial and office lighting problems.
Maintenance.—The considerations given for louvered type 3 and enclosed type 5 apply here also.

Figure 8 Early fluorescent lighting fixtures showing baffles, lenses, and reflectors (from Charles L. Amick, *Fluorescent Lighting Manual* [New York: McGraw-Hill Book Co., Inc., 1942]).

systems, the development of less hazardous chemical refrigerants, and refinements to Carrier's centrifugal system led to the first practical commercial air-conditioning systems in 1923.

The Milam Building in San Antonio, Texas, completed in 1928, was the first fully air-conditioned high-rise office building, and its success inspired developers throughout the country to include the technology in other new construction (Figure 7). A string of hot summers in the mid-1930s further encouraged residential and commercial customers nationwide to retrofit houses, offices, and theaters to add air-conditioning. Cinemas and other theaters were the commercial properties best known for competing for patrons by offering air-conditioned interiors, but air-conditioning quickly became an expected amenity for top-class office space, too. During the summers of 1934–36, Chicago faced not only hot temperatures but also drought and huge dust clouds born of the Dust Bowl. Chicago's proximity to the drought-stricken plains meant that it suffered more than cities in the eastern United States; it became impossible for Chicagoans to open their windows, as dust "sifted into houses through every crack."[21] As a result, the city led the nation in new air-conditioning installations in 1934 and 1935.[22] Air-conditioning was far from a complete solution, however; San Antonio's Milam Building retained the operable windows and thin, cross-ventilated floor plates of its predecessors.[23] But greater efficiencies were expected. "Many engineers who have seen this Texas building," reported *Scientific American*, "predict that within five to ten years it will be the exception for a modern office structure to be erected without equipping it with its own weather-making plant."[24]

Just as efficient air-conditioning allowed designers to move offices away from direct access to fresh air, fluorescent lamps encouraged a similar separation from natural light. Incandescent lighting had enjoyed incremental improvements since the invention of longer-lasting, more efficient tungsten filaments in 1910–11; nearly 700 million incandescent lamps were manufactured in 1937 alone (Figure 8).[25] Decreasing electricity costs meant that electric lighting in

offices became ubiquitous, eliminating the need for large light-gathering windows and encouraging deeper office spaces. Incandescent lighting produced generous, comfortable illumination, but it was inefficient, converting less than 7 percent of incoming electricity into light. The remaining energy became waste heat, which added to cooling problems in the summer.

Patents for tungsten filaments expired in 1930, and General Electric, Thomas Edison's successor firm, faced competition in selling a product on which it had until then held a practical monopoly.[26] Fluorescent lighting, a technology that was first demonstrated by Alexandre-Edmond Becquerel in 1867 and on which Edison took out American patents in 1907, provided the company with a new market.[27] Fluorescent lamps rely on a low-voltage current to excite molecules of mercury vapor, which produces ultraviolet light. When this light strikes a powdered coating of a phosphorescent material, it is converted into light within the visible spectrum. The result is a diffuse, cool light rather than a point source. Fluorescent lamps are generally not bright enough to require visual shielding, and they convert more electricity into illumination than do incandescent lamps, so they produce less waste heat and give off more useful light per watt.

General Electric resumed Edison's experiments with fluorescence soon after its patent on tungsten filaments for incandescent lamps expired. In 1938, it announced a commercially viable fluorescent product, one that could last 2,500 hours, more than twice the life span of a typical incandescent lamp.[28] A 40-watt fluorescent produced more than 50 lumens per watt, while a 40-watt incandescent lamp could manage only 22 lumens. The new lamps cost more, but the savings they returned in electricity and maintenance costs paid for installation and equipment after just a few months. These advantages multiplied as Westinghouse and Consolidated Electric announced similar products based on technology licensed from GE, and when Sylvania announced an independent research and development effort in 1943 that spurred further competition. Fluorescent lighting became vital to wartime industry. Munitions factories had to be built to blackout standards, without windows or skylights that could reveal them to enemy aircraft at night. Heavy bomber plants in Fort Worth, Texas, and Tulsa, Oklahoma, for instance, used 200-watt fluorescent lamps, white fiberglass walls, and white-painted concrete flooring to illuminate their assembly bays.[29] Military investment and competing product development led to increasingly efficient lamps during the war, creating a mature industry that was well positioned for the residential and commercial growth of the postwar boom.[30]

Fluorescent lamps were not only more efficient at converting electricity into light but also more effective at distributing that light evenly over work areas. Replacing incandescent lamps' point sources with linear or planar fluorescent fixtures resulted in the distribution of light more evenly across factory floors and office desks. Fluorescents' cooler temperatures provided an additional advantage: while incandescent lamps required metal housings that would neither burn nor melt, fluorescents could be installed in fixtures made of plastic, a material that could be translucent or transparent, and that could therefore be shaped into optically useful lenses and diffusers. Manufacturers exploited these material qualities to produce inexpensive diffusers, reflectors, and lenses that could spread fluorescent light over desktops, ceilings, and walls or focus it on work surfaces.[31] The industry also standardized fixture sizes, producing lamps to fit 1-, 2-, and 4-foot modules. Standard fixtures provided enough light to illuminate office desks for about 5 feet in either direction if mounted in a ceiling 10 feet or higher; this led to standardized 10- or 11-foot floor modules.[32] Different light levels could be achieved within the same ceiling grid through the use of fixtures with two, three, or four lamps—a flexibility that responded to the developing preference for more open office spaces, particularly as corporations and their working units grew in scale.[33]

With proximity to exterior walls and windows eliminated as a necessity for lighting and ventilation, designers could increase floor plate depths from the narrow cross sections that had previously been required.[34] Chicago's 1934 Field Building is an instructive example of this change in massing. Its lower stories—the first new office floors in Chicago to be fully air-conditioned—are a full half-block deep, while its naturally ventilated upper stories are shaped into wings and a tower slab that are closer to the standard pre-air-conditioning office depth of 60 feet. As completed in 1955, the Prudential, Chicago's first fully air-conditioned skyscraper, has a floor depth of 75 feet at its narrowest. Its lower floors, where large, open-plan clerical offices were originally located, are 200 feet deep.

The deep, mechanically conditioned floor plate also challenged the logic of the conventional central service core. Placing elevators, stairs, and vertical plumbing runs into the middle of office floor plates left the full perimeter of those plates for offices, but in an era of open planning the central core "imposed arbitrary and artificial circulation patterns on each floor of the building," since it limited free, open space to a narrow zone surrounding the core. Now, with less of a premium on exterior exposure, it was possible to design buildings "in which service facilities are housed in an area which is an appendage to the open floor space, rather than a block dead center in it."[35] The Prudential Building represents an early application of this strategy as well; its blocky core was offset to the building's northern edge, allowing uninterrupted floor plates of 251 by 75 feet that could be planned with great flexibility (Figure 9).

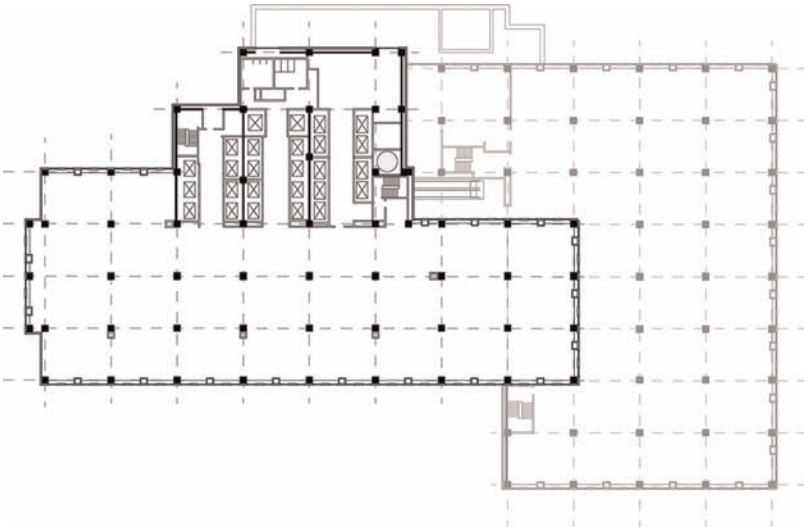


Figure 9 Naess & Murphy, Prudential Building, Chicago, 1955, digital reconstruction of floor plate (image by the authors).

The Prudential's systems matched its state-of-the-art planning. It provided radiant heating and cooling at its perimeter and ducted, conditioned air elsewhere, using 8,500 gallons of water per minute from the Chicago River to run its chillers. This system was the largest installation in the city and, at a cost of $3.5 million (equivalent to $31 million in 2016 dollars), one of the most expensive in the world.[36] Prudential's lighting, too, was notable. With the tallest floor-to-floor height of any American office building (13 feet), the Prudential was among the first to take full advantage of the broad light distribution afforded by fluorescents. Its fixtures were designed to provide 40 foot-candles at each desk, the highest standard in the country.[37] By comparison, suggested levels for office work in the 1910s had been as low as 15 to 18 foot-candles. Even in the 1930s, 10 foot-candles was considered acceptable before fluorescent fixtures reset lighting standards.[38] The *Chicago Tribune* called the Prudential's air-conditioning and fluorescent lighting "special architectural treatments," while *Architectural Forum* ranked them alongside record-beating elevators and enclosed parking as "advantages not found elsewhere in Chicago," features that would increase workers' efficiency, reduce turnover, and justify the building's high rents of $6.50 per square foot ($59 in 2016 dollars).[39]

The Prudential's massive floor plates, made possible by its lighting, heating, and cooling systems, became its signature. Chicago had never seen a building as tall and broad, and its position at the north end of Grant Park made a singular urban impact. While Naess & Murphy's design was praised by archconservative *Tribune* editorialist Chesly Manly as "reasserting" Chicago's "world leadership in commercial architecture," others were more measured in their responses, describing the Prudential as "an outsize headstone stuck up over the lake front."[40] Even Manly's effusive praise was tempered by his difficulty in describing what style the "world's finest office building" employed. "The only name for the style of the building, according to Naess and Murphy," Manly wrote, "is 'contemporary American office building,' a rather pedestrian term for such an imposing edifice. Its distinguishing characteristic, they said, is clean, vertical lines, without ornamentation or overhang."[41]

But the Prudential's vertical stone stripes and inset windows could have been found on many "contemporary American office buildings" built before the war, as *Architectural Forum* would point out. While the combined advantages of air-conditioning and fluorescent lighting allowed changes in building massing that would form the planning basis for glass boxes to come, it remained for technical developments in glass itself to match these systems' impact on building skins.

Toward the Glass Skin: Twin Grinding, Insulated Glazing, and Solex

Architectural Forum's implicit criticism of the Prudential—"no Lever House"—dovetailed with Naess & Murphy's own bland description of its conservative style.[42] Indiana limestone formed the bulk of the Prudential's exterior, rising in bands 2 feet, 8 inches wide over the building's height and framing inset aluminum spandrels and windows (Figure 10). The architects were conservative in their aesthetic, but this does not wholly explain their choice of cladding. Why would such a retrograde exterior be attached to such a progressively conceived interior? Or, put another way, why would Chicago have to wait an additional few years to see its first true glass curtain wall on a commercial structure, and what factors enabled these developments?

Hints lie within *Architectural Forum*'s reporting on the Prudential project. The Chicago building was one of several regional headquarters built by the Prudential Insurance

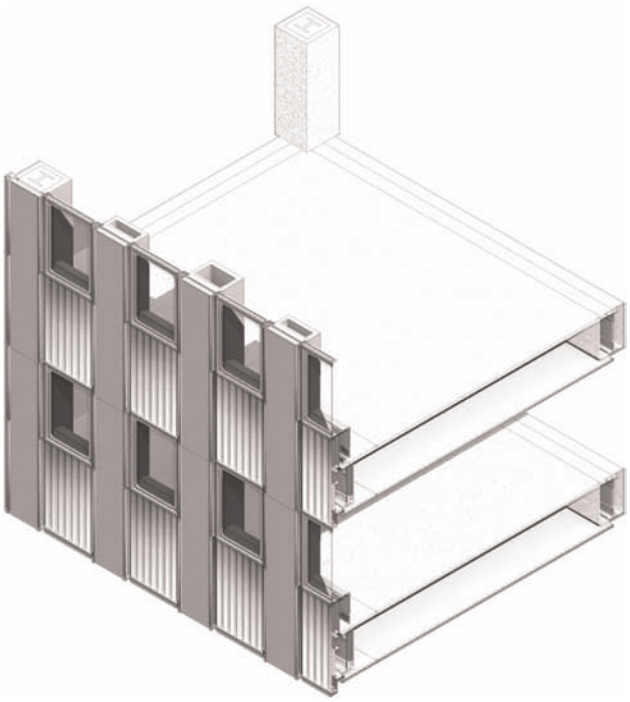


Figure 10 Naess & Murphy, Prudential Building, Chicago, 1955, digital reconstruction of cladding and structure (image by the authors).

Company during the postwar boom—Wurdeman and Becket's 1948 building for the company in Los Angeles and Boston's Prudential Center (Luckman Partnership, 1960–64) were parts of the same corporate program that built Chicago's landmark. The Los Angeles building, featuring two mid-rise office wings flanking an expressed central core, was clad in broad horizontal stripes of window glass more in line with International Style ideals. But this cladding scheme brought environmental penalties. *Architectural Forum* reported that glare from the unprotected glass had "been something of a problem." Chicago's cold winters would have compounded such glare and heat gain with wintertime heat loss—issues that had been all too apparent with enormous plate-glass windows in previous generations.[43] "High intensity lighting and air conditioning have convinced Prudential a window is just 'something to look out of,' " the journal continued, noting that the Chicago building's "reversion to the *Daily News*-RCA-Mellon building school" was not simply a concession to architectural tastes more staid than those shaping Los Angeles.[44] Rather, it was an acknowledgment that systems-based solutions to environmental issues still faced daunting heat gain and insulation challenges in more extreme climates. High prices, poor insulation in winter, and glare and heat in summer all militated against the glass skin's appearance until well after the war.

Plate-glass manufacture, which had always been a labor- and energy-intensive process, saw dramatic cost-saving developments around midcentury.[45] Melting silica required enormous quantities of fuel, and the casting process involved delicate cooling and hours or days of grinding and polishing to achieve a smooth surface. Throughout this process, large plate-glass sheets had to be moved and handled with utmost care. Well into the twentieth century, individual plates were still affixed to grinding tables by workers who pressed them into beds of plaster of Paris with their feet.[46] Three developments in the 1930s transformed plate glass from a handcrafted material to an industrialized one.

The first of these was the continuous furnace, in which a long ribbon of glass was drawn from a batch of molten material through rollers and annealing chambers. Variations on this idea were developed in Belgium by Émile Fourcault (1904–14), in the United States by Irving Colburn (1915–16), and in France by M. Bicheroux (1918). Libbey-Owens-Ford (LOF) of Toledo, Ohio, expanded the Colburn process to produce automotive glass for General Motors factories in Detroit, but its application for window glass also proved profitable. By combining melting, shaping, cooling, and annealing into a single linear production line, the Colburn process eliminated most of the labor that went into forming plate glass. This led to substantial price reductions through the 1930s. It also meant that products relying on careful control of temperature or process, in particular tempered and laminated glass, could be made with simple adjustments to the production line rather than continuous monitoring or handling.[47]

The expense of grinding and polishing was eased only by developments in England, where the Pilkington Brothers glass manufacturing company constructed factory lines in 1923 that used traveling tables arranged in series to polish the bottom surface of cooled glass after it emerged from the production furnaces. Pilkington's earliest versions of this process required workers to flip each glass piece and run it through the line a second time, but in 1935 the company built a twin grinding and polishing line that finished both sides of a drawn ribbon of glass simultaneously.[48] Further developments were halted by the onset of World War II, but the advantages of the twin grinder and polisher were apparent; Pilkington rebuilt its Doncaster factory to include a 300-meter-long automated machine that produced continuous ribbons of flawless plate glass that could be cut to any length. By 1953, Libbey-Owens-Ford had licensed this technology for the American market and reconfigured its Toledo plant to employ the new process. While LOF's ordinary window glass price rose 59 percent between 1921 and 1956, its price for polished plate glass fell by 2 percent, despite rising material and labor costs.[49]

Low material costs, however, did nothing to address the environmental problems associated with glass: insulation, glare, and heat gain.[50] Per inch of thickness, glass is roughly as good an insulator as brick, but glass windows, which use

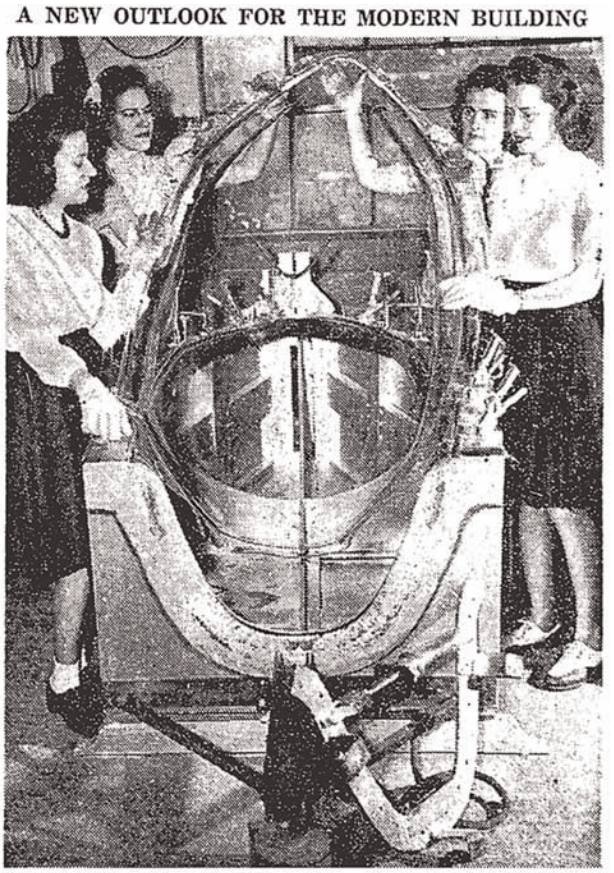
very thin sheets, have little practical insulating value. In addition to the energy and monetary costs of overcoming heat loss and gain through them, windows collect condensation, which forms when warm, damp air meets a cold surface. These problems worked against the glass wall in the 1930s even as mechanical systems proved able to standardize interior environments during all seasons. For instance, while Raymond Hood's 1930 McGraw-Hill Building in New York offered the illusion of continuous glass ribbons, this was the result of clever architectural composition. As a writer for *Architectural Record* observed, the building's solid verticals were tinted to read in line with normal-sized sash windows and "treated like mullions," albeit quite broad ones. True "glass wall construction," the author stated, was still "quite exceptional, and needs no more than passing reference." "A great amount of window area," he noted, "is rarely desirable."[51]

Solutions to glass's insulation, heat gain, and condensation problems emerged more slowly than had advances in air-conditioning and fluorescent lighting. Providing a temporary second layer of glass, or storm sash, was a proven method that added a thin cushion of insulating air, but infiltration between the two layers was inevitable and brought with it condensation, frosting, and dust. Nevertheless, conductive heat loss was a serious enough problem that in 1932 the *American Journal of Public Health* suggested that hospital designs incorporate fixed, multiple-layered windows to maintain interior environments. "By the use of double or triple glass, with an air-space between, noise and draft, odors, dust, pollen, insects, etc., can be kept out, light at the same time being admitted," wrote A. S. Bacon, superintendent of Chicago's Presbyterian Hospital."[52] Bacon recognized that the fixed window had to be linked to effective, efficient provision of cleaned, conditioned air, and he suggested the installation of an individual unit in each room that would filter, humidify, and temper outside air locally—describing the basic configuration and operation of a window-unit air conditioner three years before such a device became available. But his emphasis was on the insulating value that could be achieved by layers of air trapped between fixed glass plates: "Proper window construction will also keep out cold in winter and heat in summer. By using a single glass, on a zero day with an inside temperature of 70°F., the glass surface temperature will be 17.3°F. With double glass the surface temperature will be 49°F., and with triple glass the surface temperature will be 59.9°F."[53]

Others noted that vacuum was more effective than air in improving the thermal performance of glass. *Architectural Record* reported in 1932 that tests done by Air-Control Systems, Inc., a mechanical engineering firm, determined that double glazing surrounding a fully evacuated central void conducted less than half the heat conducted by a single glass plate.[54] This would be practical, however, only if the unit could be fully and reliably sealed; otherwise, humidity would migrate between the layers of glass and condense on the cooler surface. This condensation problem remained unsolved until 1934, when Charles D. Haven of Milwaukee, a refrigeration engineer, patented the Thermopane unit, which consisted of two layers of glass held apart by a continuous rubber strip.[55] A hypodermic needle, inserted through the rubber seal, was used to fill the air space between the two layers with dehydrated air, which eliminated moisture and encouraged the evaporation of any volatile compounds in the rubber and adhesives. The spacer strip itself was flexible, allowing for differential expansion between warm and cold sheets of glass. This, too, had been a fatal flaw in early experiments. Adhesives strong enough to hold units together had also been strong enough to transmit stresses across them, leading to cracking as a warm glass layer expanded and a cooler glass layer contracted. With these problems solved by flexible rubber, Haven wrote, "Thermopane fills a dire need in air conditioned buildings and vehicles."[56]

Despite this claim, insulated glass remained troublesome. Haven's Thermopane units were assembled and sealed with shellac- and varnish-based adhesives that deteriorated when exposed to weather, breaking the airtight seals and allowing in moisture and dust. Libbey-Owens-Ford, which had also experimented—unsuccessfully—with sealed double-paned units, purchased Thermopane in 1937 and launched a major development effort in collaboration with Haven to improve his system.[57] Better dehydration methods formed the basis for a 1940 patent, and in 1941 the company patented a flexible metal sealant that avoided the problems with cracking seen with the rubber seals. The new sealant proved critical to the commercial viability of insulated glass, but skeptical architects and builders required proof of the material's reliability in building skins before they would adopt it. This came in 1939, when Richard Byrd's Antarctic Service Expedition installed LOF's "non-frosting glass" in its prefabricated laboratories. "The new windows consist of layers of heat tempered glass with the space between them filled with dehydrated air," the *Science News-Letter* reported. "With no moisture within to condense and freeze, the panes will supply good light for the new laboratories to be established by the expedition. Being heat tempered, the panes have added strength which will allow the scientists to walk on them, if necessary, and shovel off snow."[58]

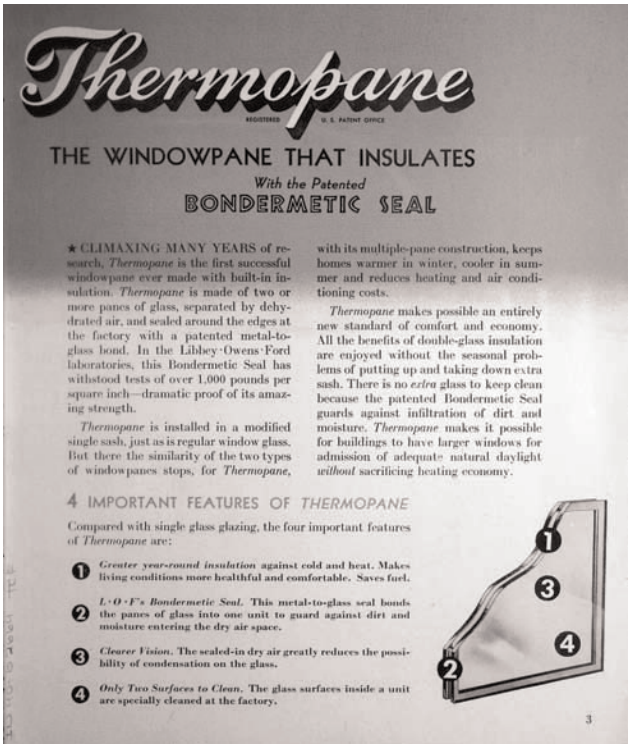
These units remained experimental, however, and it was not until late in World War II, when LOF began producing Thermopane "bubbletop" canopies for P-47 fighter planes, that the company achieved the economies of scale necessary for commercial production (Figure 11). In 1945, after the war's end, LOF announced that it would continue the production



A NEW OUTLOOK FOR THE MODERN BUILDING

The Libbey-Owens-Ford Glass Company announced yesterday large-scale production in Thermopane, a prefabricated double-glass insulating windowpane, formerly used, as shown above, in the canopies of the Army's P-47 fighter planes, and now going into homes, schools, hospitals and commercial structures.

Figure 11 Thermopane aircraft canopy (*New York Times*, 25 Aug. 1946).



Thermopane

REGISTERED U. S. PATENT OFFICE

THE WINDOWPANE THAT INSULATES

With the Patented

BONDERMETIC SEAL

★ CLIMAXING MANY YEARS of research, *Thermopane* is the first successful windowpane ever made with built-in insulation. *Thermopane* is made of two or more panes of glass, separated by dehydrated air, and sealed around the edges at the factory with a patented metal-to-glass bond. In the Libbey-Owens-Ford laboratories, this Bondermetic Seal has withstood tests of over 1,000 pounds per square inch—dramatic proof of its amazing strength.

Thermopane is installed in a modified single sash, just as is regular window glass. But there the similarity of the two types of windowpanes stops, for *Thermopane*, with its multiple-pane construction, keeps homes warmer in winter, cooler in summer and reduces heating and air conditioning costs.

Thermopane makes possible an entirely new standard of comfort and economy. All the benefits of double-glass insulation are enjoyed without the seasonal problems of putting up and taking down extra sash. There is no *extra* glass to keep clean because the patented Bondermetic Seal guards against infiltration of dirt and moisture. *Thermopane* makes it possible for buildings to have larger windows for admission of adequate natural daylight *without* sacrificing heating economy.

4 IMPORTANT FEATURES OF *THERMOPANE*

Compared with single glass glazing, the four important features of *Thermopane* are:

1. *Greater year-round insulation* against cold and heat. Makes living conditions more healthful and comfortable. Saves fuel.
2. *L·O·F's Bondermetic Seal.* This metal-to-glass seal bonds the panes of glass into one unit to guard against dirt and moisture entering the dry air space.
3. *Clearer Vision.* The sealed-in dry air greatly reduces the possibility of condensation on the glass.
4. *Only Two Surfaces to Clean.* The glass surfaces inside a unit are specially cleaned at the factory.

3

Figure 12 Advertising brochure for Thermopane windows, ca. 1950 (Libbey-Owens-Ford, The Ward M. Canaday Center for Special Collections, The University of Toledo, Folder 27, Box 18, MSS-066).

of Thermopane "for installation in homes, schools, hospitals, and commercial structures."[59] One year later, LOF's main rival, Pittsburgh Plate Glass (PPG), introduced a competing product called Twindow.[60]

LOF embarked on a major campaign to convert its wartime innovation into a market-dominant product (Figure 12). In 1951, a full-page advertisement in *Time* magazine made the case for Thermopane in office buildings:

> Light, spacious-looking offices like this are economical as well as a joy to work in—when you understand all the aspects of big glass areas. These windows are *Thermopane* insulating glass, two panes of glass with ½″ dry air hermetically sealed between.
>
> *Thermopane* reduces heat transmission through glass. Saves fuel in winter. Saves air conditioning costs in summer. . . . Because cold drafts are greatly reduced, employees can be seated close to these windows. This brings more high-cost floor space into maximum use.[61]

Further separating itself from its rival, LOF sponsored a national solar house design program in 1947, commissioning architects throughout the country to propose schemes appropriate to their local climates that could be built for $15,000 and that would highlight the potential for Thermopane as "the windowpane for solar houses."[62] George Fred Keck designed a rectilinear home for Illinois that showed lessons learned from the heat gain problems that his Crystal House and House of Tomorrow had encountered; his design for LOF featured deep overhangs to keep out summer sun and a solid north wall to insulate during the winter. Other architects commissioned included Pietro Belluschi in Oregon, Edward Durell Stone in New York, Louis Kahn and Oscar Stonorov in Pennsylvania, and Hugh Stubbins Jr. in Massachusetts. Homeowners and architects were quick to grasp Thermopane's potential; sales more than quadrupled from 1945 to 1955.[63]

Addressing the poor insulating qualities of glass, however, solved only half the problem. Glare in the low winter sun and heat in the summer meant that the large glass panels made possible by Thermopane and Twindow still brought excessive light and heat gain. Here, too, a solution lay in developments that had taken place during the Great Depression. In 1933 Donald Ellsworth Sharp and James Bailey of the Mississippi Glass Company's New York operation filed a patent for "heat absorbing glass." It was common knowledge among glassmakers that glass mixtures with added ferrous iron produced a material that absorbed more infrared light than

visible light. The altered chemistry of such glass gave it a strong green tint that was difficult to control, however, and produced bubbling during the casting process. But Sharp and Bailey were able to produce consistent glass with a pale blue-green tint by adjusting admixtures of carbon, aluminum, and antimony oxide. Furthermore, they found that adding cobalt produced an even bluer glass that eliminated unpleasant yellow light. The results, they claimed, reduced radiant heat by more than 75 percent while reducing 25 percent of the associated visible spectrum—filtering out sunlight's negative aspects while maximizing its benefits.[64] In 1941, LOF improved on these efficiencies by more than 10 percent by adding fluorite and salt to high-iron glass.[65] Tempering and adding calcium or alumina also limited the thermal expansion that was inevitable in such absorptive material, which made it suitable for use with thermally sensitive insulated units.

At least three products emerged from the patents for heat-absorbing glass by 1950. In St. Louis, Missouri, the Mississippi Glass Company produced a product called Coolite that combined high-iron glass with a rough surface to absorb heat and diffuse light.[66] LOF matched this with Aklo Glass, which absorbed half the heat energy of incoming light while providing "soft, eye-resting light . . . like having sunglasses in windows."[67] Both Coolite and Aklo were industrial products, designed for factories where exterior views were not necessary. It fell to Pittsburgh Plate Glass to develop the first polished plate glass with heat absorption. Solex became the industry standard almost immediately—"the best glass under the sun!"—offering a trademark "soft, greenish color" while "reducing heat and glare" and keeping interiors "ten to twenty degrees cooler" than outside even without mechanical air-conditioning.[68]

Early Applications, Mixed Results: Equitable Building, U.N. Secretariat, and Lever House

Heat-absorbing glass mounted in double-layered, insulating units saw its first commercial application in Pietro Belluschi's Equitable Building in Portland, Oregon (1944–48) (Figure 13). While the building's structure had to be concrete, not steel, because of ongoing Department of Defense rationing, everything else about the Equitable emphasized lightness and transparency. Oregon had become a center of aluminum production because of its abundant, cheap hydroelectric power, and Belluschi took advantage of the material's unprecedented precision in fabrication and low local costs for Equitable's column covers and glazing bars. Aluminum's strength allowed these bars to frame massive glass lights of 70 square feet each. While these were initially specified as Thermopane, LOF balked at the sizes required, and Belluschi eventually persuaded PPG to manufacture custom sizes of its Solex in its Twindow system for the project.[69] These windows extended from a chair-height rail to the ceiling, above solid spandrel panels that were holdovers from prewar fire codes. Designed to prevent fire from spreading between floors through open windows, such codes required fireproof panels that extended up and down from the edge of each floor, assuming that solid façade elements would cover floor edges and interstitial spaces. This assumption was challenged by the curtain wall's prospective transparency, but similar codes throughout North America prevented the full flourishing of the glass wall for a decade after the Equitable. Belluschi deferred to these code requirements by incorporating dark-green spandrel panels above each floor to cover short walls of lightweight concrete that matched the height of air-conditioning cabinets within, creating an integrated section of space, skin, lighting, and ventilation (Figure 14). Inside, the building used heat pumps to produce heated or chilled water that conditioned air in exchange units on each floor. Ducts moved conditioned air from these units to ceiling registers in the offices. The modest heat generated by fluorescent and cold-cathode lamps then drafted warm exhaust air into return plenums within the offices' ceilings.[70]

The need for Solex and insulated glass was not particularly pressing in Portland. The city's mild climate and overcast conditions meant that even limited solar control and insulation made such a prodigiously transparent skin economical. The Equitable suffered minor failures—cracking in the Solex glass was attributed to uneven heating, which became a more vexing problem on later structures—but overall the building performed well, and its success inspired other syntheses of air-conditioning, glass, and fluorescent lighting.[71] The glass buildings that followed the Equitable, however—the United Nations Secretariat (Harrison & Abramovitz et al., 1947–50) and Skidmore, Owings & Merrill's Lever House (1950–52)—only partially met its high standards. The Secretariat featured two enormous suspended glass façades, each 544 feet tall and 287 feet wide, shimmering "cellophane" façades stretched between two enormous marble walls and held in place by steel mullions (Figure 15). The marble slabs were immediately criticized for their monumental character, but soon after the building's opening, the shortcomings of the veil-like curtain walls became apparent. During the Secretariat's design, Le Corbusier, as design consultant, had argued for giant *brises-soleil* to shade the east- and west-facing glass walls from low morning and afternoon sun. Wallace Harrison had specified insulated glass for the entire façade, presenting engineering data from Syska Hennessy, the mechanical engineering firm on the project, to demonstrate its necessity. But these commonsense ideas were rejected when the United Nations insisted on operable windows that would allow staff to adjust their office environments.[72] The Secretariat thus relied on the heat-absorbing capacity of uninsulated, single-thickness Solex to resist New York's summer sun and on its

Figure 13 Pietro Belluschi, Equitable Building, Portland, Oregon, 1948 (contemporary postcard, Thomas Leslie collection).

dubious insulating qualities to maintain comfortable indoor temperatures. The results were predictable. The building's operable windows allowed humidity to infiltrate the entire building, while summer sun outstripped the air-conditioning system's capacity to cool the building's perimeters. To make the offices habitable, management installed heat-reflective film inside many windows, but this left no way for the glass to shed heat during the day, causing several windows to break under thermal strain.[73]

SOM's Lever House also featured single-glazed Solex held in steel mullions across its broad north- and south-facing façades (Figure 16). Unlike the Secretariat's operable windows, Lever House's cladding was fixed, which kept dirt, humidity, and noise out. PPG made Lever House an advertising centerpiece, seeing it as a test case for the efficacy of heat-absorbing glass on south-facing façades. But here, too, there were shortcomings. Even with the heat-absorbing qualities of Solex, Lever House's south-facing glass façade taxed the building's air-conditioning system. As with the Equitable Building and the Secretariat, the design of Lever House's façade was restricted by continuing prewar codes that required fire protection above and below the slab. Lever House's dark-green spandrel panels thus had to be backed up by brick fire walls, leaving an unventilated air space that could not dissipate the inevitable buildup of heat on a summer day (Figure 17). As a result, many of Lever House's spandrels cracked due to thermal stress, a problem that was rectified (as at the Secretariat) only with a complete curtain wall replacement in 2011.

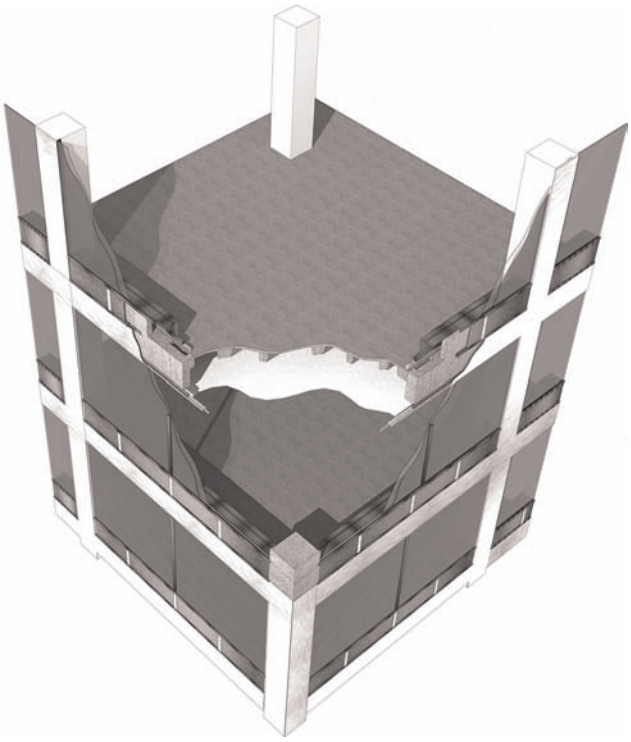


Figure 14 Pietro Belluschi, Equitable Building, Portland, Oregon, 1948, digital reconstruction of cladding (image by the authors).

Figure 16 Skidmore, Owings & Merrill, Lever House, New York, 1952 (contemporary postcard, Thomas Leslie collection).

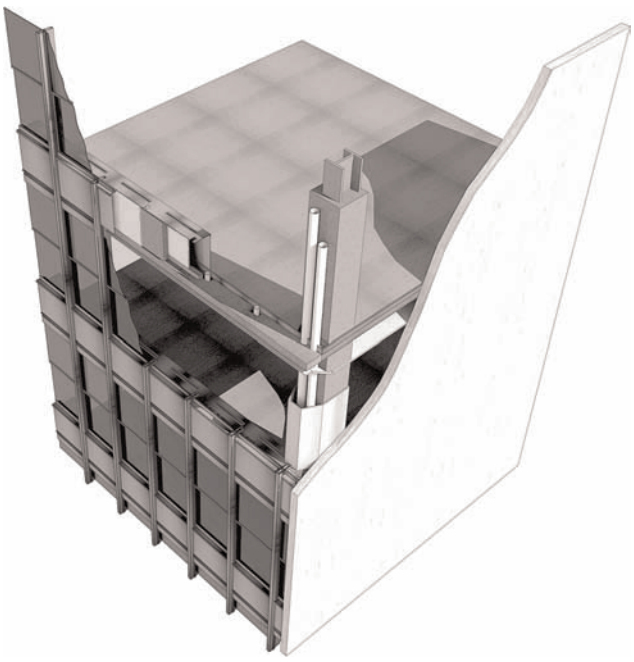


Figure 15 Harrison & Abramovitz et al., United Nations Secretariat, New York, 1952, digital reconstruction of cladding (image by the authors).

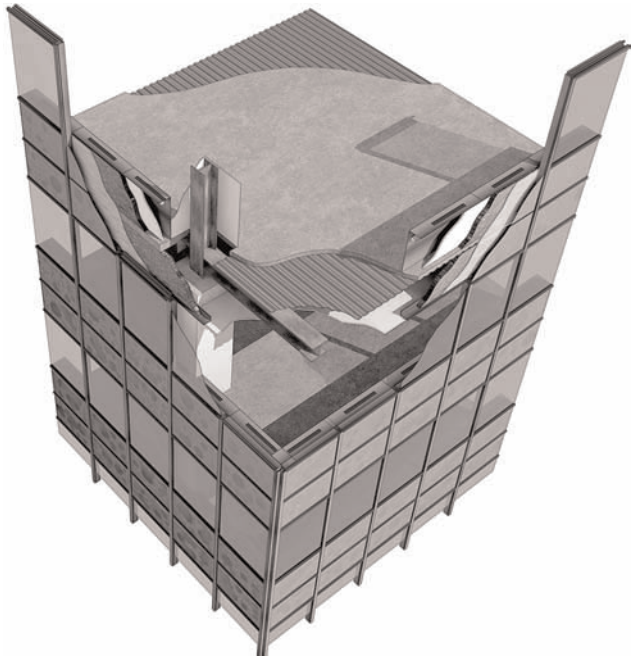


Figure 17 Skidmore, Owings & Merrill, Lever House, New York, 1952, digital reconstruction of cladding (image by the authors).

Figure 18 Harrison & Abramovitz, Alcoa Building, Pittsburgh, 1952 (photo by Nicholas Traub; HABS PA-6724-1, Library of Congress P&P).

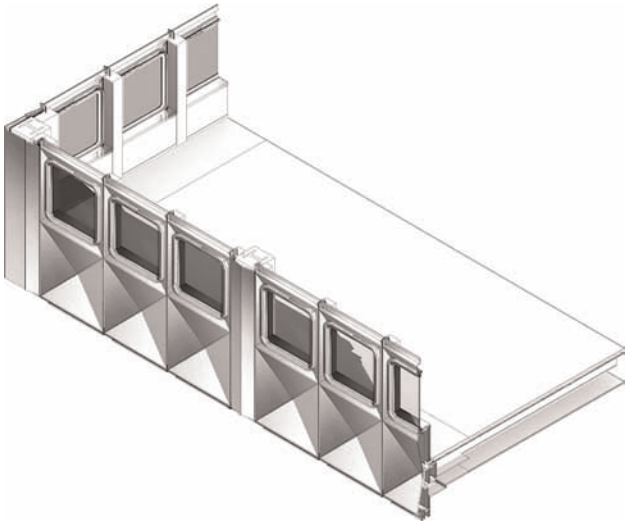


Figure 19 Harrison & Abramovitz, Alcoa Building, Pittsburgh, 1952, digital reconstruction of cladding (image by the authors).

The Ongoing Case for Solid Skins

With this mixed record, it was understandable that the glass skin was not universally accepted in commercial buildings of the early 1950s. The windowless office continued to find adherents who based their decisions on technical grounds; in January 1952, just months before its coverage of Lever House, *Architectural Record* reported on a low-rise office building designed by Charles Hartmann for the engineering firm of P. L. Davidson in Greensboro, North Carolina. Davidson had designed numerous windowless factories, and the firm's home office, which featured glazing only on its main entrance, was intended as a demonstration project. The interior was provided with "year-round air conditioning, fluorescent lighting, and acoustic tiles," all contained within solid walls. "The resulting windowless building," *Architectural Record* noted, "demonstrates a number of economies in construction and operation," including "a high degree of quietness and lack of outside distraction in the offices, and a considerable amount of flexibility in the placement of furniture and equipment. . . . Further savings were effected in the air conditioning and heating system."[74]

Elsewhere, larger office projects designed and built in the same period as Lever House, the U.N. Secretariat, and the Equitable showed a similar wariness toward the emerging glass skin formula. Most notable was the Alcoa Building in Pittsburgh, designed by Harrison & Abramovitz and completed in 1952, which placed 50-by-55-inch double-glazed, heat-absorbing windows within a predominantly solid aluminum skin (Figure 18). The use of aluminum here was an obvious advertisement for Alcoa the company, which was keen to find new markets for its products after demand slowed in the postwar years. Among other innovations, the building's air-conditioning system used ceiling-mounted diffusers over the windows and an aluminum-piped radiant ceiling to balance convective and conductive heating and cooling. The building was sealed and air-conditioned, but its windows were designed to pivot open for cleaning; each had an inflatable tube around its edges that provided an air-tight seal after closing. Fireproof walls of perlite (lightweight concrete) extended above and below each floor just as at the Secretariat and Lever House, hidden behind stamped panels of aluminum here rather than behind opaque glass (Figure 19). Harrison & Abramovitz repeated Alcoa's aluminum-panel cladding in the Republic Bank Tower in Dallas (1954), and the Socony–Mobil Building in New York City (1954–56). Elsewhere, the firm relied on striated façade solutions derived from Hood's Rockefeller Center. For instance, for 525 William Penn Place (now Citizens Bank Tower) in Pittsburgh (1951), the formula was extended to forty-one floors of vertical limestone and dark metal with inset, sealed windows.

This tentative balance between solid and glass was the solution Naess & Murphy adopted in 1951 for Chicago's Prudential Building.[75] By this point Belluschi's Equitable Building had been open for a little more than two years, but Lever House and the Secretariat were just being completed. Like the Equitable, Lever House, and the Secretariat, the

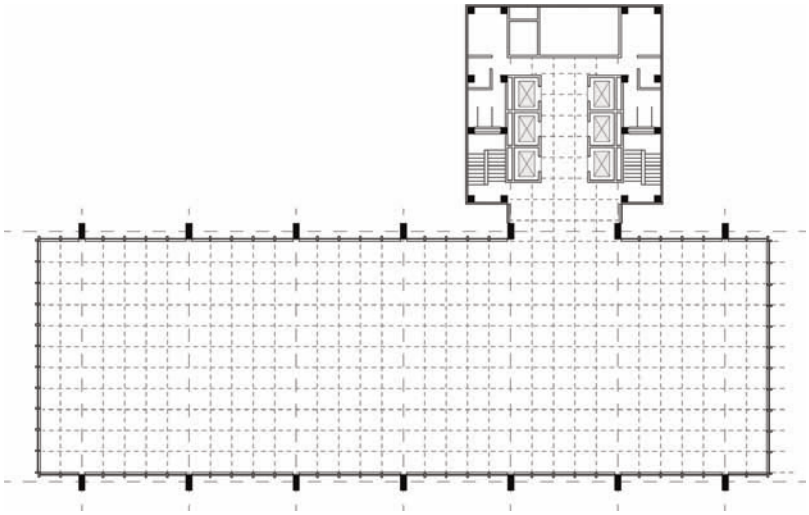


Figure 20 Skidmore, Owings & Merrill, Inland Steel Building, Chicago, 1958, digital reconstruction of typical floor plate (image by the authors).

Prudential featured an exterior skin supplemented by a fire-resisting concrete block wall behind each floor's spandrel; in this case, however, this solid band was covered by a metal panel the width of the windows above and below, creating vertical striations between solid limestone cladding strips. The "relatively small" windows were attributable, according to *Architectural Forum*, not only to the city's "conservatism" but also to the "glare . . . and heavy heat loss" that would have come with the larger expanses of glass found in Portland and New York.[76] With the experience of Prudential's glare-ridden Los Angeles building, the mixed performance of the U.N. Secretariat's curtain walls, and minor but persistent cracking in other poorly ventilated Solex installations, the architects found it prudent, especially in Chicago's harsh climate, to revert to the proven formula of smaller punched windows in a solid skin.[77]

Inland Steel: "Column-Less Space and Wafer-Thin Walls"

The Prudential Building thus broke little new ground architecturally, but its commercial success proved that Chicago's downtown market had returned, and it offered more functional, flexible office space than any other building in the city.[78] No other Loop skyscrapers could boast floor plates of the Prudential's scale or openness, and with new, larger corporations seeking open space, the building's flexibility became a model for downtown development. There were few immediate opportunities to match the size of the Prudential's 20,000-square-foot floors, but the Inland Steel Company took inspiration from the building's success and announced in 1954—a year before the Prudential opened—that it would move its own headquarters across Dearborn Street from its offices in Daniel Burnham's 1905 First National Bank Building. Inland proposed a modest seventeen floors of 14,000 square feet each, with the company occupying one-third of the building and leasing out the remainder.[79] From its first public announcement, however, it was clear that this smaller building would be more advanced in its planning and its cladding than the Prudential. John Merrill of Skidmore, Owings & Merrill had been on the commission that negotiated a new building code in the late 1940s, and he promised that Inland would become the first Chicago building to take advantage of its more liberal provisions.[80] With new performance standards, architects had greater freedom to develop their own fire-rated wall assemblies, and the 1949 Chicago code also loosened restrictions on exterior walls themselves, which now needed only a one-hour fire rating instead of a four-hour rating. The new code's intent was to "encourage the use of aluminum and other lightweight materials for outside wall panels." SOM chose stainless steel instead of aluminum, a nod to the client's product but also evidence of aluminum's high regional cost in the Midwest.[81]

Inland's planning matched its innovative cladding. Rather than embedding the service core in the center of the floor plate, which would have limited depth and flexibility, or embedding it in the side or end of a slab, as at the Prudential or Lever House, SOM designed Inland's service core as a detached tower connected by glass corridors to the pure, prismatic glass-and-steel-clad offices alongside it (Figure 20). By inverting the curtain wall's traditional logic and placing the building's columns outside the skin, SOM pushed flexibility even further than Naess & Murphy had at the Prudential; Inland's floors had no intervening columns, as their loads were carried by deep cross girders that passed through the curtain wall and connected to the outboard columns in stiff, welded connections. At 58 by 177 feet, Inland's floor plates were not the scale of the Prudential's, but with no interior columns they offered more agile

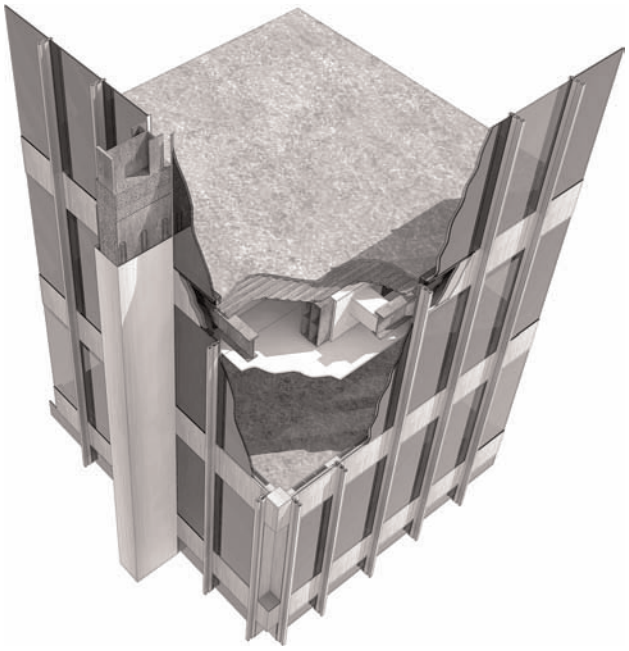


Figure 21 Skidmore, Owings & Merrill, Inland Steel Building, Chicago, 1958, digital reconstruction of cladding (image by the authors).

planning, enhanced by provisions for light and air through a 5-foot, 2-inch ceiling grid.[82]

More than in any previous glass box, Inland Steel's air-conditioning system was integrated with its curtain wall and structure. Ductwork in the ceilings provided conditioned air from vertical risers in the service tower to the interior of each floor plate, while separately mixed and dehumidified air was directed to the perimeter through the voids left by each floor plate's corrugated steel deck.[83] A small sill box that rose just 2 inches from the finish floor delineated the junction between the floor and the exterior wall, providing a short toe kick that protected the bottom edge of the curtain wall glass. Supplying conditioned air against the surface of the insulated glass provided a better defense against condensation than radiators while avoiding the noise and maintenance of water pipes (Figure 21). This detail also avoided taller cabinetry like the more traditional sills in the Prudential, the Secretariat, and Lever House.

"Ideally," wrote *Architectural Record* on Inland's opening in 1958, "the architect would like column-less space and wafer-thin walls for an office building."[84] If new structural techniques and more flexible methods of servicing and illuminating broad, open offices allowed the former, Chicago's new fire code permitted the latter. SOM's detailing protected exterior girders with 2-inch-thick precast concrete panels, but these covered only the depth of the floor and ceiling space, eliminating the walls extending above and below the floor that had backed up earlier curtain walls. Inland's glass was insulated Solex—in more modest individual sizes than the Equitable's—held on to the building structure by 3⅛-inch-wide brake-shaped steel mullions. At the structural columns, these connections became difficult as structural continuity was at odds with the need to prevent cold bridges from forming between exposed surfaces and the building interior, but SOM resolved this by relying on the low conductivity of fireproofing concrete around the columns to form an imperfect but effective enough thermal barrier.[85] Inland's exterior detailing expressed the relationship between structural and cladding elements through layering and proportioning—an almost Gothic intertwining of vertical and horizontal elements emphasized by reentrant details at the corners. The result was a visual warp and weft that revealed the twin functions of the tall office building: to support floors of lettable space and to separate this space from the vagaries of outdoor climate.

Coda: Further Developments in Postwar Cladding

Even Inland Steel presented an incomplete assemblage of the key cladding advances of the 1930s. It was fully air-conditioned, and it used double glazing and heat-absorbing glass to allow the most transparency possible around flexible-plan office spaces. But it did not use aluminum for its cladding—another important technical development that became a crucial component of curtain walls from the 1960s forward. The transition from stainless steel to aluminum for mullions and other substructural cladding elements was gradual; Alcoa's rivals, Reynolds and Kaiser, built headquarters and plant buildings in Richmond, Virginia, and Oakland, California, respectively, in the 1950s that provided further demonstrations of aluminum's potential for curtain wall panels and extruded mullions. SOM's designs for Heinz's vinegar plant in 1953 and a dormitory at Carnegie Mellon University (then the Carnegie Institute of Technology) in 1955, both in Pittsburgh, served as forays by Alcoa into the broader market, but it was not until several projects in 1957–58 that the tall aluminum-and-glass curtain wall gained the confidence of owners and architects. Buildings from this era included Mies's Commonwealth Promenade Apartments (1953–56) and their contemporaries at 900–910 Lake Shore Drive (1953–55), both in Chicago, the Standard Federal Building in Los Angeles by Welton Becket (1954), and the Equitable Life Assurance Building in San Francisco by Loubet & Glynn (1954).[86] Within a few years, thin, aluminum-framed, double-glazed curtain walls were as common as the deep, air-conditioned, fluorescently illuminated floor plates they enclosed. Easier fabrication and lighter weight made these systems more and more competitive economically as aluminum prices declined from 1956 through the 1973 energy crisis.[87]

Developments in glass continued through the 1950s and 1960s, too. Of particular importance was Pilkington's

invention of the float glass process, which used baths of molten tin, a material with a high surface tension, to float molten glass through its first production stages. The resulting product was perfectly surfaced on both sides, requiring no grinding or polishing—and thus no handling—when it emerged from the production line.[88] The process improved quality and eliminated much of the remaining manual labor involved in producing plate glass. Pilkington announced the process in 1959, although it took several years of refinement to address issues of thickness and consistency. The first float glass plants in the United States were built in 1964, one by Pittsburgh Plate Glass in Cumberland, Maryland, and one by LOF in Toledo. General Motors began switching from polished plate to float glass for its automotive glass that same year, and by the end of the decade half of the glass in the domestic industry was produced using the new process.[89] Projects such as I. M. Pei's John Hancock Tower in Boston (1968–76), Roche Dinkeloo's College Life Assurance complex in Indianapolis (1972), and Cesar Pelli's Pacific Design Center in Los Angeles (1975) deployed double-glazed float glass with varied tints to manage solar gain, along with more sophisticated sealants and precisely formed aluminum mullions that reduced air infiltration and improved reliability.

The emergence of glass as a ubiquitous material was not only the fulfillment of nineteenth- and early twentieth-century modernist prophecies. The yearnings of Bruno Taut and Paul Scheerbart, and the International Style's evangelism for volume over mass, may have been frustrated by conservative aesthetic preferences for monumental solidity in the 1930s and 1940s. But the emergence of such material ideals has never been simply a cultural phenomenon; the myth of a progressive crystalline architecture struggling to emerge from its masonry bounds is belied by a more complex and revealing evolution of materials and systems. Before the glass skin could emerge as a tectonic reality, it had to be useful and affordable. The former was guaranteed only by improvements in its insulating capacity and by the moderation of its transparency, the latter only by refinements in fabrication. If the window "died hard," the solid skin survived well into the postwar era, when the costs of glass manufacture fell and the insulating and shading abilities of glass products improved. As with many technical developments, higher performance and lower costs led professional practice and building legislation; concerns about cracking, thermal expansion, and glare were accompanied by political inertia among city governments used to the reassuring fire resistance of solid stone or concrete. In each of these realms—materials science and production, environmental performance, architectural design, and urban politics—the history of the glass box shows that the skyscraper was a phenomenon deeply embedded in the technical, political, economic, and social networks of the time.

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Notes

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Kenneth H. Ripnen, *Office Building and Office Layout Planning* (New York: McGraw-Hill, 1960), 2–3.

2. "The Inland Steel Building, Chicago, IL," *Architectural Forum* 108 (Apr. 1958), 89.

3. A. J. Liebling, "Profiles: Second City, III—The Massacree," *New Yorker*, 26 Jan. 1952, 33.

4. "Chicago's Prudential Building," *Architectural Forum* 97 (Aug. 1952), 90–99.

5. Ibid., 95.

6. Ibid., 91.

7. "New and Old Materials Give Life to Skyscrapers," *Chicago Tribune*, 20 Feb. 1966, L1.

8. Sigfried Giedion, *Space, Time and Architecture: The Growth of a New Tradition*, 3rd ed. (Cambridge, Mass.: Harvard University Press, 1954), 384–86.

9. Ibid., 386. While Giedion dates the Reliance to 1894, local press reported on its opening in March 1895.

10. Reyner Banham, *Theory and Design in the First Machine Age* (Cambridge, Mass.: MIT Press, 1960), 267–68, 290.

11. Howard Constable, quoted in "Windowless Buildings Next," *Chicago Daily Tribune*, 13 Mar. 1898, 37.

12. Al Chase, "Architects Do Bit o' Throwing at Glass Homes," *Chicago Daily Tribune*, 13 Sept. 1931, 26.

13. Louise Bargelt, "House of Tomorrow at Century of Progress Has Walls of Glass," *Chicago Daily Tribune*, 11 June 1933, D5.

14. "The glass walls required total atmospheric control to make the house habitable." Thomas M. Slade, " 'The Crystal House' of 1934," *JSAH* 29, no. 4 (Dec. 1970), 352. See also Catherine Collins, "Energy: In the '30s, Keck Brothers Saw the Light, and Solar Came to Chicago," *Chicago Tribune*, 30 Oct. 1983.

15. "Plan Windowless Factory in East for Simonds Saw & Steel," *Chicago Daily Tribune*, 14 Oct. 1930, 29.

16. "Without Windows," *Architectural Forum* 62, no. 3 (Mar. 1935), 207.

17. Ibid.

18. See, for instance, "Milwaukee: Three-Way Air Conditioning in Triple-Use Structure, Grassold & Johnson, Architects," *Architectural Record*, Sept. 1938, 51–54.

19. "Design for Air Conditioning Plus Access to Outside Air, J. Douglas Lorenz, AIA, Architect," *Architectural Record*, Oct. 1938, 58–60. Chicago's George Fred Keck, likely influenced by the poor thermal performance of his House of Tomorrow, designed for the Century of Progress Exposition, was a leading proponent of the use of glass block. His 1938 Bruning residence in Wilmette, just north of Chicago, was used in advertising for the

Insulux brand of glass blocks: "Large expanses of wall area can be given over to INSULUX without any fear of excessive heat loss." "Modern to the Minute . . . Insulux Glass Block, Pioneered and Perfected by Owens-Illinois," advertisement, *Architectural Record*, Oct. 1938, 143.

20. See Cecil Elliott, "Air Conditioning," in *Technics and Architecture* (Cambridge, Mass.: MIT Press, 1993), 308–26.

21. "City Choked by Drouth [*sic*], Dust," *Chicago Daily Tribune*, 11 May 1934, 1.

22. "Chicago Takes Nation's Lead in Air Conditioning," *Chicago Daily Tribune*, 20 Aug. 1934, 24; "Chicago Leads the Country in Air Conditioning Installations," *Chicago Daily Tribune*, 30 May 1935, 21.

23. "The Milam Building in San Antonio, Texas, is one of the few office buildings in the world which have their own private 'weather men' for manufacturing weather to suit the needs of their tenants." Ruel McDaniel, "Tailor-Made Weather for Offices," *Scientific American*, July 1929, 24.

24. Ibid.

25. Arthur A. Bright Jr. and W. Rupert Maclaurin, "Economic Factors Influencing the Development and Introduction of the Fluorescent Lamp," *Journal of Political Economy* 51, no. 5 (Oct. 1943), 429–50.

26. Ibid.

27. Thomas Edison, fluorescent electric lamp, U.S. Patent 865,367, filed 19 May 1896, renewed 29 Apr. 1902, issued 10 Sept. 1907.

28. "High Efficiency from New Lamps," *Scientific American*, July 1936, 15.

29. H. T. Rutledge, "Insulating 'Blackout' Plants," *Scientific American*, Dec. 1941, 328–29.

30. Bright and Maclaurin, "Economic Factors."

31. Charles A. Breskin, "Partners in Light," *Scientific American*, May 1946, 197–98.

32. "There are many ways of attaining the recommended lighting levels for office areas, but perhaps the most effective is through use of 2-foot wide parallel fluorescent strips spaced 10 feet apart in private and general office areas. These are used where the ceiling height is between 9 and 10 feet. The fixtures are controlled locally by column switches rather than through a master board. For special work, a pendant fixture may be used instead of a unit set flush in the ceiling. The differing light levels specified for different types of work may be maintained with uniform fixtures since a varying number of tubes may be used within each fixture. The 2-foot fixture recommended can be used with as few as two tubes or as many as six, depending on the desired lighting intensity." Ripnen, *Office Building*, 53.

33. "Given these conditions, the integrated office layout can offer all the advantages of the specially partitioned, custom-built office without the disadvantages of compartmented space. Where physical separation by a wall is necessary or justified, movable partial-height partitions can be used within the open general area. Continuous-strip underfloor ducts permit placement of electric outlets or telephone outlets at frequent enough intervals along the duct to allow flexibility in desk arrangement. Moreover, such open arrangements permit continuous-strip, overhead-lighting layouts within each structural module and regularly spaced grills or perforated ceiling for air-conditioning supply and return. These are possible because the absence of interior walls makes specially designed lighting patterns and air-conditioning ducts unnecessary. Thus the open general plan is not only simpler and cheaper to use than the compartmented plan; its flexibility in terms of rearrangement of work stations is further assured by the fact that changes in departmental lines require no changes whatever in structural, physical, and mechanical features." Ibid., 28.

34. Ibid., 80–81.

35. Ibid., 81.

36. Al Chase, "Prudential Air Conditioning Project Begun," *Chicago Daily Tribune*, 14 Dec. 1952, B7.

37. A foot-candle is a standard measurement of lighting intensity, defined by the illumination from a standard candle at a distance of one foot. "Chicago's Prudential Building," 91.

38. Louis Bell, *The Art of Illumination* (New York: McGraw-Hill, 1912), 21; A. Lawrence Kocher and Albert Frey, "Windows," *Architectural Record*, Feb. 1931, 127.

39. "They'll Drink to 4 States on 'Top of the Rock,' " *Chicago Daily Tribune*, 21 Mar. 1955, A1; "Chicago's Prudential Building."

40. Chesly Manly, "Chicago Proof of Beauty in a Skyscraper," *Chicago Daily Tribune*, 7 Nov. 1954, 28; "Lake Front Headstone," *Chicago Daily Tribune*, 8 Jun. 1952, 24. The Prudential had been built in a brief period of zoning reform in which the city's traditional cornice line limit of about 264 feet and the ruling 1:10 setbacks that had governed construction since 1922 had been jettisoned in favor of a volumetric limit that restricted a building's total measure in cubic feet to just 144 times its site area. This would have capped most construction at twelve or thirteen stories, but the Prudential's designers had skirted the intent—if not the precise wording—of the new code by purchasing air rights for a vast area of freight yards surrounding its site. The result was a building that not only punched through previous height limits but also caused immediate calls for the zoning code to be rewritten using precursors to the floor area ratio standards still in use today.

41. Manly, "Chicago Proof of Beauty," 28.

42. The Prudential's façade is commonly ascribed to Carl Landefeld, whom Naess & Murphy hired from Hood's office for the express purpose of the project. See Franz Schulze, *Oral History of Carter Manny* (Chicago: Chicago Architects Oral History Project, 1995), 139.

43. An example is the public library built in Chicago in 1897, where uncomfortable quantities of morning sun streamed through the huge plate-glass windows in the reading room overlooking Lake Michigan to the east. One newspaper noted: "Until a few days ago the big expanse of plate glass that lights the reference room was not protected even by awnings and the sun beat into the room with broiling intensity during the morning hours. For the last few days the room has been almost uninhabitable and the employees of the department have suffered intensely." "Suffer in the Library," *Chicago Daily Tribune*, 21 July 1898, 7.

44. "Chicago's Prudential Building," 92.

45. See "The American Plate Glass Industry," *Scientific American*, 9 Mar. 1895, 151; "Manufacture of Plate Glass," *Scientific American*, 18 May 1901, 304, 311.

46. A. E. Owen, "Some Developments in the Manufacture, and in the Technical Uses, of Glass," *Science Progress* 47, no. 186 (Apr. 1959), 258–73.

47. LOF's tempered and laminated products alone were credited with reducing automobile accident fatalities caused by flying glass by 65 percent. Albert A. Hopkins, "Glass and the Machine Age," *Scientific American*, May 1932, 286–88.

48. H. Moore, "Recent Advances in the Manufacture of Plate and Sheet Glass," *Journal of the Royal Society of Arts* 98, no. 4810 (16 Dec. 1949), 98, 100.

49. "Libbey-Owens-Ford," in "Proceedings, Tenth Annual Convention, National Federation of Financial Analysts Societies, May 20 to 23, 1957," special issue, *Analysts Journal* 13, no. 3 (June 1957), 170–72.

50. See "Old and New Chicago," *Chicago Daily Tribune*, 24 May 1896, 43.

51. E. E. R. Tratman, "Windows for Residential, Public, and Commercial Buildings," *Architectural Record*, Sept. 1933, 245.

52. A. S. Bacon, "Doing Away with the Open Window in the Hospital," *American Journal of Public Health* 22 (Dec. 1932), 1301.

53. Ibid.

54. "As W. D. Jordan, president of Air-Control Systems, Inc., writes in reply to an inquiry, 'The prevailing tendency to provide the best of insulation in the side walls and ceiling and then do nothing about the excessive and extravagant heat loss through exposed glass appears to be very inconsistent from the standpoint of fuel cost.' " The article goes on to quote Jordan's listed "heat transmission coefficients for a few types of common walls compared with glass . . . expressed in B.t.u. per hour per square foot per 1°F, temperature difference": 8-inch brick wall with ¾-inch plaster, 0.261; 12-inch brick wall with

¾-inch plaster, 0.216; 8-inch hollow tile with 4-inch brick veneer outside and 4-inch plaster inside, 0.195; 12-inch hollow tile with stucco exterior and ¾-inch plaster inside, 0.186; frame wall, 2-inch by 4-inch studs, 1-inch wood sheathing and wood siding on exterior, with wood lath and plaster on inside, 0.262; exposed glass, single pane, 1.130; exposed glass, double glazed, 0.450. Following this listing, Jordan is quoted further: " 'The figures given on the different types of walls do not contemplate any insulating material. The heat loss through single glass is about 5 times as great per square foot as the average for those uninsulated walls. Despite that fact, people continue to buy expensive insulating material to decrease the comparatively small loss through the walls and then build in more and bigger windows having 5 times the heat loss.' " C. Theodore Larson, "Air Conditioning Equipment, Part II," *Architectural Record*, Oct. 1932, 280.

55. Ibid., 260–80.

56. Charles D. Haven, multi-ply glass sheet glazing unit, U.S. Patent 2,030,869, filed 12 Oct. 1934, issued 18 Feb. 1936.

57. See Libbey-Owens-Ford Glass Company v. General Aluminum Window Co., Inc., Patent Appeal No. 6495, 275 F.2d 947 (U.S. Court of Customs and Patent Appeals, 15 Mar. 1960).

58. "Byrd Expedition Takes Non-frosting Window Panes," *Science News-Letter* 36, no. 21 (18 Nov. 1939), 329.

59. "A New Outlook for the Modern Building," *New York Times*, 25 Aug. 1946.

60. Kenneth M. Wilson, "Plate Glass in America: A Brief History," *Journal of Glass Studies* 43 (2001), 152. Wilson states the date of Twindow's introduction as 1953, but see "Insulating Window: Multi-glazed with Sealed Inter-pane Space," *Scientific American*, Sept. 1946, 130.

61. "Isn't This a Wonderful Office!," advertisement, *Time*, 15 Jan. 1951, 47.

62. Maron J. Simon, ed., *Your Solar House* (New York: Simon & Schuster, 1947), 12.

63. "Libbey-Owens-Ford," 170. See also "Flat Glass Output Hits All-Time Peak," *New York Times*, 18 June 1948.

64. Donald Ellsworth Sharp and James Bailey, heat absorbing glass, U.S. Patent 2,034,991, filed 26 June 1933, issued 24 Mar. 1936.

65. Glenn O. Mock and Richard W. Ricker, heat absorbing glass, U.S. Patent 2,397,195, filed 9 Jan. 1941, issued 26 Mar. 1946.

66. "Plenty of Light to Make It Right!," advertisement for Mississippi Glass Company, *Architectural Record*, Mar. 1952, 261.

67. "Ideal Light for Efficient Work: Filtered Daylight," advertisement for Blue Ridge Patterned Glass (a subsidiary of LOF), *Architectural Record*, Mar. 1952, n.p.

68. "In Modern Buildings, the Trend Is toward Solex Heat-Absorbing Glass," advertisement for Pittsburgh Plate Glass, *Architectural Record*, July 1952, 76–77.

69. Meredith L. Clausen, "Belluschi and the Equitable Building in History," *JSAH* 50, no. 2 (June 1991), 119.

70. "Equitable Builds a Leader," *Architectural Forum* 89 (Sept. 1948), 102.

71. Clausen, "Belluschi and the Equitable Building," 119.

72. Joann Gonchar, "Revival of an Icon: The United Nations Renovation Team Brings Back the Long-Faded Luster of the Secretariat While Satisfying Ambitious Performance Goals," *Architectural Record*, Sept. 2012, 106–12.

73. For other issues with the Secretariat, see George Barrett, "Too Few Windows, U.N. Staff Cries," *New York Times*, 5 Oct. 1950. The curtain wall suffered problems with leaking weep holes that ultimately led to corrosion in the steel mullions.

74. "Windowless Office for an Engineer," *Architectural Record*, Jan. 1952, 152–53.

75. Al Chase, "Prudential Life Skyscraper Big Step to Chicago," *Chicago Daily Tribune*, 1 Mar. 1951, 4; "Model of Proposed Skyscraper," *Chicago Daily Tribune*, 22 Dec. 1951, B5.

76. "Chicago's Prudential Building," 92. Climate data can be summarized in "heating and cooling degree days," which are measures of how much the outside air temperature varies from 65 degrees Fahrenheit each day of the year. All three cities have similar cooling degree days during a typical summer, but Chicago's heating degree days in a normal winter are between 30 and 40 percent greater than either Portland's or New York's. See James Owenby, Richard Heim Jr., Michael Burgin, and Devoyd Ezell, "Climatography of the U.S. No. 81—Supplement 3," National Oceanic and Atmospheric Administration, http://www.ncdc.noaa.gov/oa/documentlibrary/clim81supp3/clim81.html (accessed 12 July 2016).

77. Naess & Murphy adopted the Alcoa Building's system of double-glazed, pivoting windows with inflatable seals for the Prudential's façade, showing that project's clear influence. Designs for Alcoa and its window system were published in *Architectural Forum* in November 1949. Chase, "Prudential Air Conditioning Project Begun."

78. "City Building Triumphs Are Cited," *Chicago Daily Tribune*, 8 June 1956, B11.

79. "Loop Building Is Planned by Inland Steel," *Chicago Daily Tribune*, 20 Aug. 1954, B5.

80. "Loop Sustains Brisk Building Pace thru Year," *Chicago Daily Tribune*, 2 Jan. 1957, A4.

81. "Code's Changes Speed Building, Slash Expense," *Chicago Daily Tribune*, 31 Dec. 1949, 4.

82. Ibid.

83. "From Inland's zinc coated or galvanized sheets Inland Steel Products Company at their Milwaukee plant created the patented Celluflor conduit forms through which the electricity, water, telephone, and much of the air conditioning moves within the flooring." "Inland Steel Building: Fact Sheet," 6, typescript, SOM Archives, Chicago.

84. "Inland Steel Building, Chicago," *Architectural Record*, Apr. 1958, 169.

85. For details, see ibid., 169–78.

86. For a complete list of curtain wall buildings constructed in the 1950s, see William Dudley Hunt Jr., *The Contemporary Curtain Wall* (New York: F. W. Dodge Corporation, 1958), 407–16. Mies remained skeptical of insulated glazing—all of these apartments were originally clad with single-thickness windows.

87. Carmine Nappi, "The Global Aluminium Industry: 40 Years from 1972," World Aluminium, Feb. 2013, http://www.world-aluminium.org/media/filer_public/2013/02/25/an_outlook_of_the_global_aluminium_industry_1972_-_present_day.pdf (accessed 13 July 2016).

88. See L. A. B. Pilkington, "Review Lecture. The Float Glass Process," *Proceedings of the Royal Society of London A: Mathematical and Physical Sciences* 314, no. 1516 (16 Dec. 1969), 1–25.

89. Philip Shabecoff, "Outlook in Glass Termed Clouded," *New York Times*, 23 Aug. 1964; William M. Bethke, "The Outlook for the Flat Glass Industry," *Financial Analysts Journal* 29, no. 1 (Jan.–Feb. 1973), 42.