"Insulation with Vision": The Development of Insulated Glazing, 1930–1980

Thomas Leslie

"Thermopane offers arresting possibilities . . . It is possible for the first time to combine insulation with vision."—*House and Garden,* March 1940

Futuristic predictions by architects for all-glass residential and commercial construction seemed poised for realization in the 1930s, when air conditioning and central heating promised, for the first time, that home dwellers or office workers could sit comfortably in their living rooms or at their desks looking out through huge, vaporously thin picture windows to the hot or cold landscape outside. Early experiments in the new architecture of mechanically conditioned residences, however, suggested that mechanical systems could be only part of the equation. Although early air-conditioning systems were technically and economically successful, the thermal inefficiencies of glass made such systems ineffective and expensive to operate. While the architectural avant-garde continued to preach the gospel of the glass building, failures such as Le Corbusier's Cité du Refuge in Paris in 1936—where a single-glazed, south-facing facade left dormitory rooms unbearably hot in summer and cold in winter—exemplified the real limitations that glass offered.[1] Early innovations addressed the issue only partially: "storm sashes" that added a second thickness of glass were troublesome to maintain and offered only incremental improvements in actual insulation.

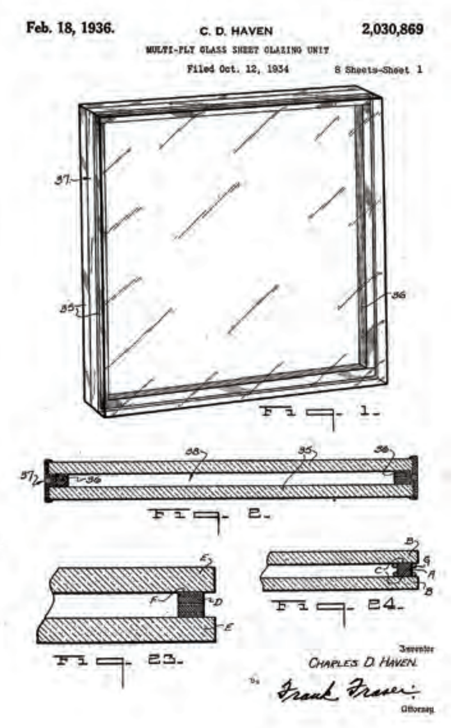


Fig. 1. Charles D. Haven, Multi-Ply Glass Sheet Glazing Unit, U.S. Patent 2,030,869, filed October 12, 1934, and issued February 18, 1936.

Throughout the 1920s and 1930s, the economics of heating and cooling favored smaller windows in commercial, residential, and industrial construction. As the cost of electric lighting fell, for instance, the large, light-gathering windows that were common in commercial buildings in the 1890s and early 1900s disappeared, replaced by building skins that incorporated smaller, double-hung windows within solid, better-insulating skins of stone and metal.[2] For houses, architects were often advised to use storm sashes that provided a second layer of glass, sheltering a thin jacket of air that added some insulating value. This air jacket, however, could easily form a convective loop, removing heat from the warmer pane and transferring it to the cooler pane with remarkable effectiveness. Condensation remained a problem, with the added difficulty that it now occurred against the outer face of the inner window in summer, making cleaning and maintenance difficult. In addition, thicker, bulkier frames and hanging devices cluttered architectural lines, and the visual distortions and added weight of the second glass layer meant that storm sashes were impractical for large windows.[3]

These "picture" windows, which would become a feature of postwar houses, were foreseen throughout the 1940s: *Chicago Tribune* home columnist Louise Bargelt noted a growing interest in larger windows as early as 1941, and the term appears with increasing frequency in the architectural and popular press from 1945 to 1960.[4] As New York cooling engineer A. Warren Canney noted in a pair of 1938 articles on air conditioning in *Architectural Record*, heat loss or gain from windows remained a key concern of architects and builders. "The full value of air conditioning," wrote Canney, "cannot be realized where single-glass windows are used. The effective temperature . . . in a room can be perfect, but if, for example, the side of the room is completely of single glass, and if it is cold outside, an occupant would be uncomfortably chilly because of excessive loss of body heat by radiation."[5] Fixtures supplying hot air or radiant heat directly below the window itself could address the radiant issue, but these required additional fixtures or cabinets that had to be integrated architecturally. Even in an era of inexpensive energy, the cost of heating cold windows was self-evidently inefficient. Large glass surfaces remained "out of the question" for environmental reasons through the 1930s.[6]

Early Experiments with Insulating Glass

The imperfect performance of storm sashes could have been improved if the air space between the two glass surfaces were completely, permanently sealed, thus preventing dust, moisture, and mold or mildew from forming on the inaccessible, interior glass surfaces while preventing infiltration of outside air and, if the air space were thin enough, frustrating the formation of convective currents. A fully isolated space between glass panes would have enough insulating value to at least keep the inner sheet warmer than the exterior, thereby preventing condensation, maintaining thermal separation, and eliminating large, cold surfaces that would drain body heat through radiation. Attempts at such "insulating glass" failed, however, because the two panes of glass—one colder than the other—would expand and contract at different rates. This differential thermal expansion or contraction strained the sealant material that held them together—typically rubber or putty. Under such constant, repetitive strain, these organic materials cracked, leading to air and moisture infiltration and thus staining of the internal surfaces.

Charles D. Haven, a refrigeration engineer in Milwaukee, worked daily with refrigerated meat cabinets in butcher shops that posed condensation and insulation challenges similar to those of residential and commercial buildings. After pondering the condensation on a trolley-car window, he experimented in his home with a double-glass sandwich that sealed the troublesome air space of storm sashes, preventing moist air from entering and thus eliminating any condensation.[7] To solve the problem of strain on seals, Haven attached laminated rubber strips to glass panes with mixtures of shellac and alcohol, creating a "yieldable separator" that accommodated differential expansion and contraction while providing a reliable atmospheric seal. By setting these strips slightly in from the edges of glass sheets, he could coat the external edges of the resulting panel with an additional liquid seal, protecting the separator strips from air and moisture. Haven then punctured this seal with two hypodermic needles and replaced the atmosphere between the glass sheets by pumping in dehydrated air. The needle holes were then filled, leaving the resulting panel with a hermetically sealed, thoroughly desiccated chamber, 1/8-inch thick, which provided a thermal break and a useful amount of insulation between inside and outside. Haven christened his invention "Thermopane," offering it as a solution for "buildings, vehicles . . . refrigerators, and display cases." Haven's invention was announced in *Architectural Record* in 1932, and he received a patent for it in 1934 (Fig. 1).[8]

Glass manufacturer Libbey-Owens-Ford (L-O-F) Glass Company recognized the potential for Thermopane's insulating abilities, and the company negotiated with Haven for its rights, opening a subsidiary to produce and market the product and making Haven its president.[9] Problems with manufacturing and performance emerged quickly, however. Seals on early Thermopane units failed, introducing moisture to the internal air layer, which then condensed onto the cooler glass surfaces, fogging the window. Working with L-O-F engineer John J. Hopfield, Haven also tried to keep moisture from infiltrating Thermopane panels by introducing layers of chemical desiccants to fully dry the interior air.[10] After an initial release in 1938, the company pulled the product from the market in 1939 due to broken seals that led to intractable condensation problems.[11] L-O-F instead concentrated its advertising on "window conditioning," a more traditional storm sash formed from two physically separate panes of glass that could be opened or removed to manually clean condensation and dust from the interior surfaces.[12] Window conditioning did nothing to solve the labor or design problems inherent with the storm sashes, but the system did, advantageously from L-O-F's point of view, double the amount of its product in each window.

Glass Block: A Viable Environmental Alternative

While Thermopane's developers struggled to perfect its troubling seals, glass block—a material that had long functioned as a light-admitting insert into vaulted sidewalk pavements or as a prismatic facade surface that threw light far back into otherwise dark spaces—was marketed as an ideal cladding material for air-conditioned buildings. Because of its hollow construction and its overall thickness, glass block provided better insulation than plate or sheet glass, though at the cost of visual distortion that rendered it translucent rather than transparent.[13] Pittsburgh Plate Glass (PPG), L-O-F's greatest rival, sold its "PC"-brand glass blocks by touting their insulating ability and by subtly disparaging the double-glazed approach that L-O-F was marketing. "PC Glass Blocks assure generous daylight in building interiors . . . without the heat loss and insulating difficulties which usually accompany large areas of clear glass," PPG's 1938 advertising campaign promised, adding that "A PC Glass Block panel combines the light-transmitting properties of glass with the insulating value of a masonry wall."[14] L-O-F produced a similar product, "Insulux," which it marketed through its Owens-Illinois subsidiary, also touting its insulating ability.

Glass-block walls became a signature of the streamlined moderne style in the 1930s, appearing in otherwise "windowless" buildings to provide daylight in climate-controlled factories, theaters, offices, and residences. Chicago architect George Keck was among the converts to glass block: his Bruning residence in Wilmette, Illinois, was widely praised for its signature round staircase, clad in a half-cylinder of light-diffusing, insulating Insulux (Fig. 2).[15] But the thickness and uneven surface of glass block restricted its applicability. Its obscuring qualities were fine—even beneficial—for industrial applications or for interiors where light and privacy were concerns. But for picture windows in residential construction or office or store windows in commercial situations, glass block was not a feasible solution. Architects, builders, and clients had little choice but to use single-pane plate glass where full transparency was desired.

Fig. 2. Pittsburgh Plate Glass advertisement, *Architectural Record,* April 1938. The advertisement features the Bruning residence in Wilmette, Illinois, designed by architect George Fred Keck.

Thermopane: The First Commercially Viable Insulated Glass

Hopfield and Haven continued to work on solutions for Thermopane's troublesome seals, applying for a patent on a new sealing process, which was granted in 1941. Their application noted the problems that had plagued the product in its early years. After describing the differential thermal expansion between conditioned and unconditioned surfaces, their patent noted that the "customary" method of sealing the glass sheets with "adhesive or cement" and "separator strips of felt, rubber, cork, wood, etc." had failed to exclude atmospheric moisture and had introduced volatile compounds into the dehydrated air space that had stained the interior surfaces of units.

Worse, though, was the finding that cyclical expansion and contraction had, despite Haven's early claims, affected the adhesives themselves, which broke down and failed.[16] Haven and Hopfield experimented with numerous inorganic seals, finally settling on an all-metal seal that was formed by a spray of molten aluminum onto a hot glass sheet. These two hot materials formed a chemical bond to which further layers of aluminum and other metals could be applied. Eventually, the process applied coats of copper, tin, or lead and finally a layer of solder that could then be fused to a similar coating on another, similarly prepared glass sheet. Once properly placed, the two sheets were then held together with a continuous solder joint, resulting in a fully sealed unit that fused the two glass sheets with a flexible metal joint that contained no organic compounds and could accommodate the cyclical expansion and contraction caused by thermal extremes (Fig. 3). Hopfield, whose background was in applied physics, continued to experiment with the composition of metals in the seal and

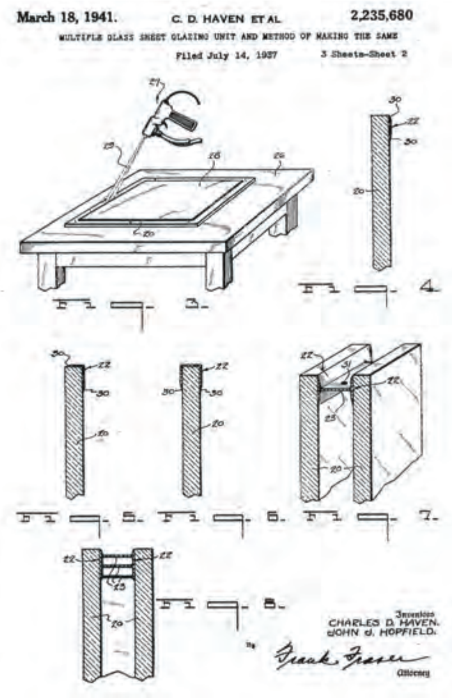


Fig. 3. Charles D. Haven and John Hopfield, Multiple Glass Sheet Glazing Unit and Method of Making the Same, U.S. Patent 2,235,680, filed July 14, 1937, and issued March 18, 1941.

with its geometry, finally settling on an ideal temperature for the glass (327.4°C (or 621.32°F), roughly the temperature at which lead melts) that avoided compromising any tempering done prior to sealing.[17] Finally, Hopfield and Haven improved the outer, shellac-based coating that covered the fragile edges of the glass and metal seals and kept out air, moisture, and dust. With more refinements to the process that enabled mass production using staged assembly and soldering, L-O-F experimented with the reconstituted Thermopane in prototype installations installed between 1939 and 1943 that demonstrated the reliability of the new metal seals.

The most dramatic of these came when L-O-F supplied Admiral Richard Byrd with insulated glass panels for prefabricated laboratories that he carried on his third Antarctic expedition in 1939 and 1940. *Science News Letter*, among others, noted the “sixteen panes of non-frosting glass” that provided skylights for the laboratory “with added strength which will allow the scientists to walk on them, if necessary, and shovel off snow.”[18] Byrd later wrote that these “worked better than any skylights that had been used on the former Byrd expeditions. The glass was clear even with temperature differentials ranging from minus 75°F outside to above 80°F on the inside” (Fig. 4).[19] The success of Thermopane in the Antarctic was matched by a handful of experimental applications in factories—particularly the Loose-Wiles Biscuit Factory in Oakland, California, completed in September 1940. The 1942 Farmers and Mechanics Savings Bank in Minneapolis, a landmark moderne office and banking hall designed by Dale McEnary and Edwin Krafft, used Thermopane for its large fluted windows. During the winter of 1942–1943, the Cranbrook Library in Michigan, designed by Eliel Saarinen, had its windows retrofitted with Thermopane to correct a nagging condensation problem.[20]

These Thermopane installations demonstrated its viability, but wartime building restrictions frustrated further market expansion. The material proved, however, to have considerable importance for the military. Its most notable application was in aircraft cockpits, where condensation from pilots’ breath at high altitudes fogged cockpit windows, often with deadly results. The U.S. Army commissioned L-O-F to develop and manufacture double-glass canopy elements for its P-47 aircraft in 1943 and 1944, when variants of the fighter’s design included higher-visibility “bubbletop” canopies. These double-glass canopies required careful production and assembly to match hermetically sealed pieces to the complex double curvature involved. The windshields performed well, however, and the knowledge gained by this difficult production process provided L-O-F with important manufacturing skills after the war.[21] Elsewhere, Thermopane saw wartime use in testing chambers that reproduced high-altitude conditions for aircraft manufacturers, in control towers at military airfields in extreme climates, and in trucks and tanks where optical devices for aiming weapons required fog-free transparency.[22]

After the war L-O-F looked for opportunities to apply its “air-conditioned glass sandwich” to civilian use. In 1946 the company launched a major advertising campaign to promote Thermopane in all areas of construction, particularly for picture windows. Here again, George Keck proved to be an architectural ally; his designs for 30 houses in a “solar subdivision” in Glenview, Illinois, in 1940 used Thermopane as a key element of the sun-based climate strategy for the houses—the “machine-age miracle,” press reports noted, that “does away with the heat losses likely to occur at night.”[23] Keck also designed prefabricated speculative housing in Rockford, Illinois, that incorporated Thermopane in large picture windows—a growing trend in residential construction made possible in midwestern summers and winters only by insulated glass.[24]

Publicity for these projects and a growing taste among residential and commercial clients for large windows and air conditioning fueled a robust market. L-O-F developed improved products, including windows with three layers of glass, which provided even greater insulation. To meet demand, in 1946 the company constructed a new factory building in its Rossford, Ohio, complex dedicated to the manufacture of Thermopane, but even its capacity was soon outstripped (Fig. 5). Residential builders faced slow production and back orders of two years.[25] Boston’s John Hancock Building, which opened in 1949, was the first skyscraper to employ Thermopane throughout its exterior skin, using over 17,000 double-glazed units that complemented the building’s pioneering use of air conditioning in the northeast U.S. (Fig. 6).[26]

Thermopane’s popularity helped to revive the glass industry alongside new demands for automobile glass.

American glass production reached record levels in 1948, by which time L-O-F had caught up to demand for Thermopane and was assuring customers of 45-day delivery schedules.[27] In the 12 years following the war, L-O-F's window-glass production increased by 56 percent, and its plate-glass capacity rose by 166 percent, symptomatic of the growing desire for glass in houses and offices. But its Thermopane production beat all of the company's single-glazed products in growth, increasing by 220 percent over the same period. The growing application of large glass surfaces was also driven in part by building economics. While average prices for building materials rose 150 percent from the mid-1920s to the mid-1950s, L-O-F's prices for glass fell in real terms over the same period.[28] The glass box was not only an aesthetic desire; beginning in the 1950s, it became environmentally feasible and even economically preferable to stone, brick, and other cladding materials.

Postwar Competition and Development

While Thermopane was the leading insulated-glass product, L-O-F did have competition, primarily from

Fig. 4. Sample of triple-paned Thermopane installed in Admiral Richard Byrd's Antarctic Laboratory, 1939.

Fig. 5. Production of Thermopane at L-O-F's plant in Rossford, Ohio, 1956.

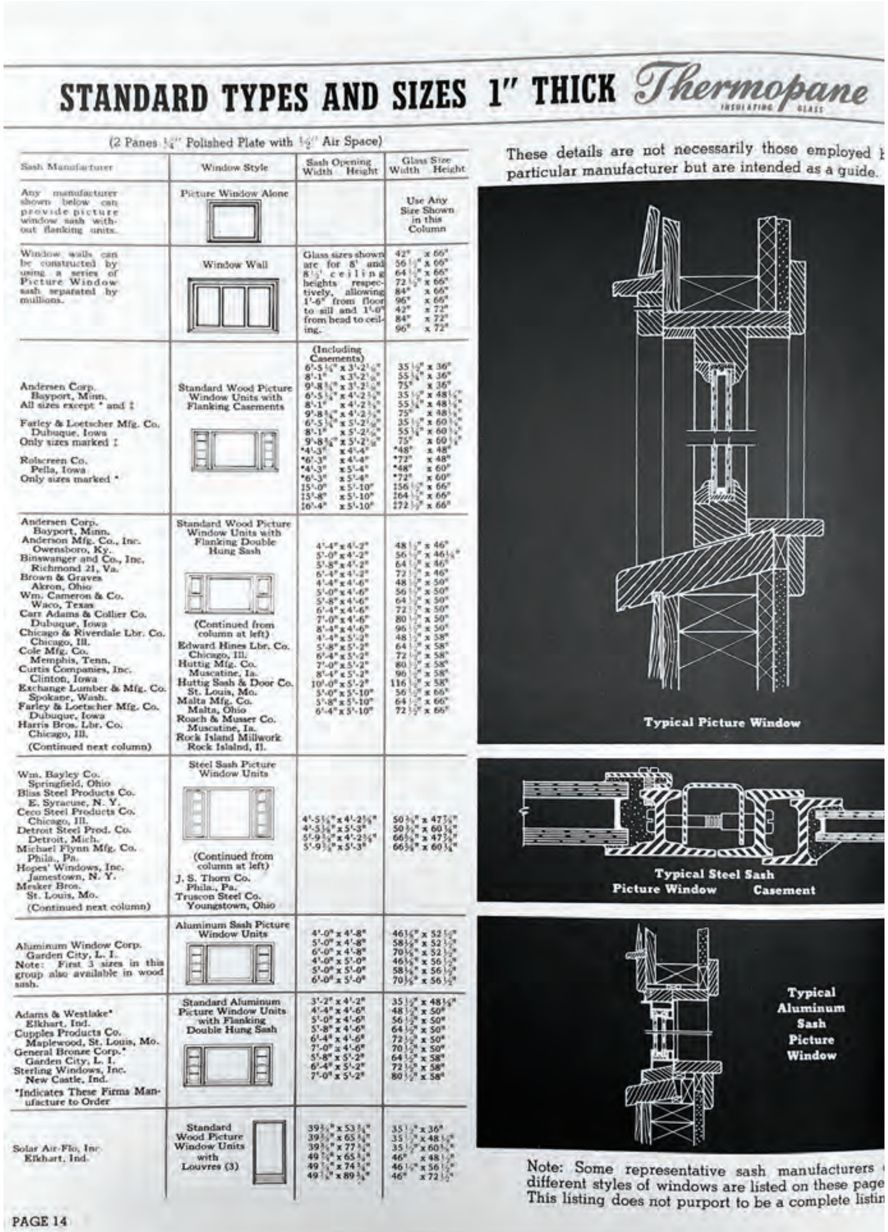
Fig. 6. L-O-F Glass Company, advertisement, ca. 1947. The advertisement features the John Hancock Building in Boston, Massachusetts.

Fig. 7. Pittsburgh Plate Glass advertisement, *The Saturday Evening Post*, April 6, 1957.

its longtime manufacturing rival, Pittsburgh Plate Glass. Capitalizing on L-O-F's early problems with condensation, Pittsburgh Plate patented improvements in 1941, including a second internal seal that created a narrow auxiliary air chamber. Stocked with chemical desiccants, this reservoir intercepted any moisture infiltration before it reached the internal air space.[29] The resulting product, christened "Twindow," was released in 1946. It used another newly affordable material, aluminum, in place of stainless steel. This substitution reduced weight, increased the seals' precision—and therefore their bond—and created the desiccating chamber that provided an additional layer of condensation prevention compared to L-O-F's product (Fig. 7).[30] PPG installed the first insulated glazing on a major commercial high-rise, at Pietro Belluschi's Equitable Building in Portland, Oregon, completed in 1949.[31] After this remarkable beginning in the commercial market, PPG concentrated on the residential market, launching a major advertising campaign in 1953 and bolstering its seals with stainless-steel external channels (Fig. 8).[32]

L-O-F saw additional market potential in a small but burgeoning market for solar homes in the late 1940s. Passive solar heating relies on large areas of south-facing glass with carefully designed shading to exclude high, undesirable summer sun. However, large areas of single-glazed windows were problematic at night, and L-O-F recognized that Thermopane could help address this problem. The company embarked on a campaign in 1949 to introduce solar concepts to the residential market: producing paper sun-angle calculators that eased calculation of shading structures; the company also sponsored a nationwide program to design solar homes for each state in the country. Even homeowners uninterested in the efficiency benefits of passive solar design were persuaded by the visual possibilities offered by Thermopane and Twindow. L-O-F and PPG both marketed the picture window as a fundamental element in the developing conception of the postwar house. Lower glass prices helped to popularize picture windows throughout the United States, and the performance and lower cost of insulated glass enabled—and even encouraged—the use of large windows in any climate.

Throughout the 1950s, however, failures haunted both manufacturers' products. PPG's glass on the Equitable Building suffered cracking, which was attributed to the use of high-iron glass that absorbed solar radiation but could not shed it quickly enough, resulting in unchecked thermal expansion.[33] Thermopane, too, saw nagging failures in its seals: as late as 1963, press reports noted that its units did "not last nearly as long as consumers might reasonably expect, in view of the high prices charged for these windows."[34] Similarly, chemical desiccants eventually reached their saturation point if exposed continually to moisture. Patents throughout the 1940s and 1950s detailed methods of incorporating greater quantities of these materials in hidden voids and channels to ensure longer glass life. By the mid-1960s L-O-F was willing to warrant their Thermopane units for 10 years against seal failure.[35] But the company also offered an all-glass unit that replaced the seals with a welded glass cap, which it warranted for twice as long. Further work in the 1970s led to hybrid metal and plastic seals that provided greater ductility while controlling off-gassing of the soldered metal between the glass panels. Finally, inert gases with lower conductance, in particular argon, replaced dehydrated air beginning in the 1980s, reducing the need for chemical desiccants while further improving thermal performance. Failures of insulated glass panels today are typically related to moisture collection in channels supporting units and to gas leakage, but the advances made in the last half of the twentieth century have made them sufficiently reliable to become commonplace in commercial and residential construction in a broad range of climatic conditions.



STANDARD TYPES AND SIZES 1" THICK Thermopane INSULATING GLASS

(2 Panes ¼" Polished Plate with ½" Air Space)

Sash Manufacturer	Window Style	Sash Opening Width Height	Glass Size Width Height
Any manufacturer shown below can provide picture window sash without flanking units.	Picture Window Alone		Use Any Size Shown in this Column
Window walls can be constructed by using a series of Picture Window sash separated by mullions.	Window Wall	Glass sizes shown are for 8' and 8½' ceiling heights respectively, allowing 1'-6" from floor to sill and 1'-0" from head to ceiling.	42" x 66" 56½" x 66" 64½" x 66" 72½" x 66" 84" x 66" 96" x 66" 42" x 72" 84" x 72" 96" x 72"
Andersen Corp. Bayport, Minn. All sizes except * and ‡ Farley & Loetscher Mfg. Co. Dubuque, Iowa Only sizes marked ‡ Rolscreen Co. Pella, Iowa Only sizes marked *	Standard Wood Picture Window Units with Flanking Casements	(Including Casements) 6'-5¼" x 3'-2⅛" 8'-1" x 3'-2⅛" 9'-8¾" x 3'-2⅛" 6'-5¼" x 4'-2⅛" 8'-1" x 4'-2⅛" 9'-8¾" x 4'-2⅛" 6'-5¼" x 5'-2⅛" 8'-1" x 5'-2⅛" 9'-8¾" x 5'-2⅛" *4'-3" x 4'-4" *6'-3" x 4'-4" *4'-3" x 5'-4" *6'-3" x 5'-4" ‡5'-0" x 5'-10" ‡5'-8" x 5'-10" ‡6'-4" x 5'-10"	35½" x 36" 55¼" x 36" 75" x 36" 35½" x 48½" 55¼" x 48½" 75" x 48½" 35½" x 60½" 55¼" x 60½" 75" x 60½" *48" x 48" *72" x 48" *48" x 60" *72" x 60" ‡56½" x 66" ‡64½" x 66" ‡72½" x 66"
Andersen Corp. Bayport, Minn. Anderson Mfg. Co., Inc. Owensboro, Ky. Binswanger and Co., Inc. Richmond 21, Va. Brown & Graves Akron, Ohio Wm. Cameron & Co. Waco, Texas Carr Adams & Collier Co. Dubuque, Iowa Chicago & Riverdale Lbr. Co. Chicago, Ill. Cole Mfg. Co. Memphis, Tenn. Curtis Companies, Inc. Clinton, Iowa Exchange Lumber & Mfg. Co. Spokane, Wash. Farley & Loetscher Mfg. Co. Dubuque, Iowa Harris Bros. Lbr. Co. Chicago, Ill. (Continued next column)	Standard Wood Picture Window Units with Flanking Double Hung Sash (Continued from column at left) Edward Hines Lbr. Co. Chicago, Ill. Huttig Mfg. Co. Muscatine, Ia. Huttig Sash & Door Co. St. Louis, Mo. Malta Mfg. Co. Malta, Ohio Roach & Musser Co. Muscatine, Ia. Rock Island Millwork Rock Islaind, Il.	4'-4" x 4'-2" 5'-0" x 4'-2" 5'-8" x 4'-2" 6'-4" x 4'-2" 4'-4" x 4'-6" 5'-0" x 4'-6" 5'-8" x 4'-6" 6'-4" x 4'-6" 7'-0" x 4'-6" 8'-4" x 4'-6" 4'-4" x 5'-2" 5'-8" x 5'-2" 6'-4" x 5'-2" 7'-0" x 5'-2" 8'-4" x 5'-2" 10'-0" x 5'-2" 5'-0" x 5'-10" 5'-8" x 5'-10" 6'-4" x 5'-10"	48½" x 46" 56½" x 46½" 64½" x 46" 72½" x 46" 48½" x 50" 56½" x 50" 64½" x 50" 72½" x 50" 80½" x 50" 96½" x 50" 48½" x 58" 64½" x 58" 72½" x 58" 80½" x 58" 96½" x 58" 116½" x 58" 56½" x 66" 64½" x 66" 72½" x 66"
Wm. Bayley Co. Springfield, Ohio Bliss Steel Products Co. E. Syracuse, N. Y. Ceco Steel Products Co. Chicago, Ill. Detroit Steel Prod. Co. Detroit, Mich. Michael Flynn Mfg. Co. Phila., Pa. Hopes' Windows, Inc. Jamestown, N. Y. Mesker Bros. St. Louis, Mo. (Continued next column)	Steel Sash Picture Window Units (Continued from column at left) J. S. Thorn Co. Phila., Pa. Truscon Steel Co. Youngstown, Ohio	4'-5⅛" x 4'-2⅝" 4'-5⅛" x 5'-3" 5'-9⅝" x 4'-2⅝" 5'-9⅝" x 5'-3"	50⅜" x 47⅞" 50⅜" x 60¼" 66⅞" x 47⅞" 66⅞" x 60¼"
Aluminum Window Corp. Garden City, L. I. Note: First 3 sizes in this group also available in wood sash.	Aluminum Sash Picture Window Units	4'-0" x 4'-8" 5'-0" x 4'-8" 6'-0" x 4'-8" 4'-0" x 5'-0" 5'-0" x 5'-0" 6'-0" x 5'-0"	46⅛" x 52½" 58⅛" x 52½" 70⅛" x 52½" 46⅛" x 56½" 58⅛" x 56½" 70⅛" x 56½"
Adams & Westlake* Elkhart, Ind. Cupples Products Co. Maplewood, St. Louis, Mo. General Bronze Corp.* Garden City, L. I. Sterling Windows, Inc. New Castle, Ind. *Indicates These Firms Manufacture to Order	Standard Aluminum Picture Window Units with Flanking Double Hung Sash	3'-2" x 4'-2" 4'-4" x 4'-6" 5'-0" x 4'-6" 5'-8" x 4'-6" 6'-4" x 4'-6" 7'-0" x 4'-6" 5'-8" x 5'-2" 6'-4" x 5'-2" 7'-0" x 5'-2"	35½" x 48½" 48½" x 50" 56½" x 50" 64½" x 50" 72½" x 50" 70½" x 50" 64½" x 58" 72½" x 58" 80½" x 58"
Solar Air-Flo, Inc. Elkhart, Ind.	Standard Wood Picture Window Units with Louvres (3)	39⅝" x 53¾" 39⅝" x 65¾" 39⅝" x 77¾" 49⅝" x 65¾" 49⅝" x 74¾" 49⅝" x 89¾"	35½" x 36" 35½" x 48½" 35½" x 60½" 46" x 48½" 46½" x 56½" 46" x 72½"

These details are not necessarily those employed b[y] particular manufacturer but are intended as a guide.

Note: Some representative sash manufacturers different styles of windows are listed on these page This listing does not purport to be a complete listin

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Fig. 8. Thermopane sizes and suggested installation details. *Thermopane Insulating Glass: Manual, Including Technical Data Sheets*. Toledo, Ohio: Libbey-Owens-Ford, 1951.

Conclusions

While insulated glazing itself is nearly an invisible technology—Haven's goal in the 1930s was, after all, the provision of clear vision with insulation, and the economics of windows have always kept installations as thin as possible—it has nevertheless been critical in the development of curtain walls in commercial construction and picture windows in residential. The glass curtain wall would be thermally impossible without the insulating qualities of Thermopane and its successors, as would the expanses of glass in the large windows, sliding doors, and walls that defined mid-century residential modernism. Coupling the innate human desire for clear vision and sunlight with the provision of insulation enabled the environmentally impractical fantasy of the early modernists—the glass skin—to become ubiquitous in the later twentieth century. Thermopane, Twindow, and other forms of insulated glazing allowed the beneficial light-transmitting qualities of glass, while reducing its less desirable ability to transmit heat. Although it has not been a universal solution—single glazing is still often used in industrial situations or where the balance of construction versus life-cycle energy costs is tilted in its favor—insulated glazing has become one of the most pervasive and reliable technologies in modern construction. Taken for granted by architects, the history of insulated glass shows that the advances by industry in the middle of the century provided a material as vital to technically proficient construction as the more celebrated examples of steel, aluminum, or concrete.

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Notes

1. Vanessa Fernandez, "Preservation of Modern-Era Office Buildings and Their Environmental Controls," *APT Bulletin: The Journal of Preservation Technology* 42, nos. 2–3 (2011), 21–26.

2. Thomas Leslie, "Glass and Light: The Influence of Interior Illumination on the Chicago School," *Journal of Architectural Education* 58, no. 1 (2004), 13–24.

3. Despite these issues, storm sashes remained a recommended method for insulating windows well into the 1930s. According to an article published in 1932, "Double Glazing should soon pay for itself through the reduction in cost of fuel. In summer it will increase the indoor comfort by greatly reducing the heat transmission rate. If the space is to be cooled, the double glazing will effect a real saving in the cost of refrigeration by materially decreasing the heat load. Moreover, the double glazing will make it possible to obtain a healthful humidity during the winter months without excessive condensation.

"The most important requirement in double glazing is air-tightness, so that no dirt will be able to filter in. The glazing should be done during weather as dry as possible so that there will be a minimum of moisture in the air space." C. Theodore Larson, "Air Conditioning Equipment [Part II]," *Architectural Record* 72, no. 5 (Oct. 1932), 280.

4. Louis Bargelt, "Pivot Window Perfected for Modern Home," *Chicago Daily Tribune*, Jan. 3, 1941, 16.

5. A. Warren Canney, "Effect of Air Conditioning on Building Design," *Architectural Record* 152 (Feb. 1938), 73.

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

7. *Thermopane: A Transparent Insulating Glass Unit for Homes and Other Types of Buildings* (Toledo: L-O-F Glass Co., 1946), 4.

8. Contemporary accounts remarked on the new product's simplicity and expense: "Recently there has been placed on the market a new window product [Thermopane, manufactured by Charles D. Haven, Milwaukee] consisting of two panes of glass permanently sealed together with 1/8" to 1/4" air space between. This air space is chemically dehydrated so that no moisture exists to form condensation when the outside temperature drops. The product is handled like a single sheet of glass. The cost is approximately three times as great but said to be worth the difference in fuel economy." Larson, 280. C. D. Haven, Multi-Ply Glass Sheet Glazing Unit, U.S. Patent 2,030,869, filed Oct. 12, 1934, and issued Feb. 18, 1936.

9. "Libbey Owens Acquires: Gets Rights to Double Glazed Window for Air-Conditioned Spaces," *Wall Street Journal*, July 27, 1934, 3.

10. C. D. Haven, Multiple Glazing Unit, U.S. Patent. 2,597,097, filed Jan. 11, 1943, and issued May 20, 1952.

11. The withdrawal of the product was a debacle that Libbey-Owens-Ford downplayed, but word of the failures was noted by professional journals such as *Architectural Record*. "A double glass which was on the market, advertised as effecting 40 percent savings in heat costs, has been withdrawn because of difficulties with condensation." Milton Lowenthal, "Trends in the Development of Building Materials," *Architectural Record* 85 (May 1939), 79–83.

12. Libbey-Owens-Ford's marketing materials gamely sold this older insulating method while it struggled to address problems with Thermopane: "You can enjoy eight more months of June! With Window Conditioning (Double-Glass Insulation). You insulate your windows by applying double glazed sash or modern winter windows of L-O-F Quality Glass. Here's what 'Window Conditioning' does for you—

1. Gives you greater comfort—better health
2. Cuts fuel bills 20 to 30%
3. Saves you more than any other single form of house insulation
4. Makes uniform temperatures easier to maintain throughout the house.
5. Lessens drafty danger zones near windows and floors
6. Makes healthful humidity possible without foggy windows, soiled draperies and moisture on window sills
7. Reduces cleaner's bills and even doctor's bills
8. Fuel savings help pay for a modern heating plant

'Window Conditioning' is a sound investment—fuel savings alone can pay for it in less than two winters. Dividends continue year after year. Financed under F.H.A.—no down payment." "L-O-F Sponsors Window Conditioning—Double Glass Insulation," advertisement, *Architectural Record* 84 (Aug. 1938), n.p. *Architectural Record* noted that such "double glazing" more than doubled the insulating value of a window because of the more or less dead air space between the two panes. See A. Warren Canney, "Effect of Air Conditioning on Building Design," *Architectural Record* 83 (April 1938), 91.

13. Today, glass block has an R-value of around 2.00, while 1/4-inch glass has an R-value of less than 1.00.

14. "Design for Light and Beauty with PC Glass Blocks," advertisement, *Architectural Record* 84 (Dec. 1938), 127.

15. Owens-Illinois featured the Bruning House in its own advertising campaign: "Owens-Illinois INSULUX Glass Block is a thoroughly modern building material, and yet, is as readily adaptable to the traditional as well as it is to modern architectural design. INSULUX Glass Block can be used excellently as a focal material—the dominant note in building design. 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* 84 (Oct. 1938), 143.

16. Charles D. Haven and John J. Hopfield, assignors to L-O-F Glass Company, Toledo, Ohio, Multiple Glass Sheet Glazing Unit and Method of Making the Same, U.S. Patent 2,235,680, filed July 14, 1937, and issued March 18, 1941.

17. Charles D. Haven and John J. Hopfield, U.S. Patent 2,235,680. Hopfield would go on to perform pioneering experiments in solar spectroscopy as a physicist with the rocket research laboratory at Johns Hopkins Univ.; "Dr. Hopfield; Physicist and Researcher," *Washington Post*, Jan. 10, 1953, 16.

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

19. Rear Admiral Richard E. Byrd to Frank R. Hawkins, L-O-F, Feb. 12, 1948, reprinted in brochure, "Thermopane" (Toledo: L-O-F Glass Company, 1945), L-O-F Company Records, folder 17, box 18, MSS-066, Ward. M. Canaday Center Manuscript Collection, Univ. of Toledo Libraries.

20. L-O-F publicized this retrofit in subsequent marketing material: "Excessive condensation on two large windows in the Library of Cranbrook School, Bloomfield Hills, Mich., prompted a test of a Thermopane unit during the winter of 1942 and 1943. Satisfied by the unit's performance in a north window, all regular glass in the library was replaced by Thermopane in August of 1943. John H. Buckberrough of the Cranbrook Foundation says: 'Thermopane has been installed in the large north window containing 60 lights, each measuring 29 1/2" x 30", and in a window on the south side of the building which has seven lights, each 58" x 27 1/2". Besides correcting our condensation problem, we find that Thermopane has great insulating benefits.' Eliel Saarinen, architect." L-O-F, *Thermopane: A Transparent Insulating Glass Unit for Homes and Other Types of Buildings* (Toledo: L-O-F Glass Company, 1946). See also Charlene Roise and Erin Hanafin Berg, "National Register of

Historic Places Registration Form, Farmers and Mechanics Savings Bank, 88 S. Sixth Street, Minneapolis, MN," July 2005.

21. "A New Outlook for the Modern Building," *New York Times*, Aug. 25, 1946, 67.

22. "GLASS Helps Bring the Stratosphere Down to Earth!," advertisement, *Nation's Business* 31, no. 1 (Jan. 1943), 6. "Glass Sandwich Takes Place of Storm Sash and Window Pane," *Popular Science* 145 (Sept. 1944), 167.

23. "Houses Warmed by the Sun," *New York Times*, April 15, 1945.

24. L-O-F, *Thermopane: A Transparent Insulating Glass Unit for Homes and Other Types of Buildings* (Toledo: L-O-F Glass Company, 1946).

25. Kenneth M. Wilson, "Plate Glass in America: A Brief History," *Journal of Glass Studies* 43 (2001), 152–153. "Double-Pane Glass Lowers Fuel Cost," *New York Times*, April 26, 1953.

26. "New Skyscraper in Boston Fully Air Conditioned," *Hartford Courant*, Oct. 2, 1949, B4. L-O-F, *Thermopane: A Metal-to-Glass Welded Insulation Unit . . .* (Toledo: L-O-F Glass Company, 1949), 6.

27. "Flat Glass Output Hits All-Time Peak," *New York Times*, June 18, 1948.

28. "Libbey-Owens-Ford," *The Analysts Journal* 13, no. 3 (June 1957), 170–171.

29. John J. Smith, assignor to Pittsburgh Plate Glass Company of America, Multiple Glazed Unit, U.S. Patent 2,303,897, filed May 28, 1941, and issued Dec. 1, 1942.

30. This advance was substantial enough to merit press coverage in *Scientific American*, among other outlets: "The hermetically-sealed, dead air in the space between the plates of glass is held at atmospheric pressure. It is dehydrated initially by means of a drying agent within the aluminum spacer tubing which has access to the air space. The drying agent remains in the unit and provides added insurance against vapor diffusion and helps considerably in meeting more than normal atmospheric changes." "New Products and Processes—Insulating Window," *Scientific American* 175 (Sept. 1946), 130.

31. "Equitable Builds a Leader," *Architectural Forum* 89 (Sept. 1948), 105.

32. Kenneth M. Wilson, "Plate Glass in America: A Brief History," *Journal of Glass Studies* 43 (2001), 152–153.

33. Meredith L. Clausen, "Belluschi and the Equitable Building in History," *Journal of the Society of Architectural Historians* 50, no. 2 (June 1991), 109–129.

34. "Note on Double-Glazed Windows," *Consumer Bulletin* 46 (1963), 24.

35. C. D. Haven, Multiple Glazing Unit, U.S. Patent 2,597,097, filed March 15, 1947, and issued May 20, 1952. Copies of standard Thermopane Warranty Certificates are held in the L-O-F Glass Company Records, MSS-066, Ward. M. Canaday Center Manuscript Collection, Univ. of Toledo Libraries.

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