FROM THE ARCHIVES

Windows and Glass in the Exterior of Buildings (1957)

Pages
200

Size
8.5 x 11

ISBN
0309361591

Building Research Institute; Division of Engineering and Industrial Research; National Research Council

WINDOWS and GLASS

IN THE EXTERIOR OF BUILDINGS

A research correlation conference conducted by the Building Research Institute November 14 and 15, 1956 at the Chamber of Commerce of the United States in Washingon, D. C.

Publication 478

NRC. BUILDING RESEARCH INSTITUTE.

Division of Engineering and Industrial Research

National Academy of Sciences • National Research Council

Washington, D. C.

1957

,\ʾ \

SPONSORS OF THIS CONFERENCE WERE:

Aluminum Window Manufacturers Association
Andersen Corporation
Arcadia Metal Products Company
Architectural Woodwork Institute
Breneman-Hartshorn, Inc.
Fenestra, Inc.
E. K. Geyser Company
Libbey-Owens-Ford Glass Company
The Kawneer Company
Kimble Glass Company (Owens-Illinois subsidiary)
Pittsburgh Corning Corporation
Pittsburgh Plate Glass Company
National Woodwork Manufacturers Association, Inc.

The Building Research Institute acknowledges with gratitude the services of the speakers, the chairmen of the respective sessions, and the program committee responsible for the organization of this conference. The latter, under the chairmanship of F. B. Zoll, Jr., were James Arkin, Robert Cutler, Julian Finkel, John P. Jansson, Alfred Jaros, Jr., Charles M. Judd, C. W. Kelly, H. F. Kingsbury, O. C. Lance, C. B. LeBon, Robert W. McKinley, Robert J. Offringa, W. F. Patman, R. F. Seery, C. H. Stark, E. C. Swanson and C. H. Thompson.

$5.00

Inquiries concerning this publication or the Conference on Windows and Glass in the Exterior of Buildings may be addressed to the

BUILDING RESEARCH INSTITUTE
Division of Engineering and Industrial Research
National Academy of Sciences — National Research Council
2101 Constitution Avenue • Washington 25, D. C.

Published in March 1957 Library of Congress Catalog Number: 57-60025

CONTENTS

FOREWORD

By WILLIAM H. SCHEICK

Executive Director
Building Research Institute

THE Building Research Institute's public conference on "Windows and Glass in the Exterior of Buildings" had as its primary objective discussion of the new and untraditional ways in which glass, windows and related products are being used today in buildings of all types. In addition, there was a need for an analysis of the problems posed by the use of large glass areas, and exploration of possible solutions from the viewpoints of architects, engineers, manufacturers of windows, glass and accessory devices, building owners and occupants.

An integral part of such a discussion is the effect of large glass areas on heating and air conditioning systems, on lighting and on ventilation. The problems encountered in a multi-story office building are entirely different from those experienced in a one-story school. The advantages and disadvantages of lavish use of glass in apartment houses vary considerably from those in single family homes.

When glass enters the picture in any quantity, it brings with it the need for control of the amount of light and heat transmitted to the building. The engineering and manufacture of such controls and the development of new control devices and techniques have a substantial bearing on future utilization of glass as a structural material.

Within the pages of this book, research directors detail some of their most recent findings in the field of daylighting; heating, air conditioning and ventilating engineers discuss problems and solutions; manufacturers describe new types of windows, new uses for glass; building owners relate their experiences with controls, and the reactions of occupants; control experts point out the benefits and detriments of interior and exterior control systems; architects mercial and institutional construction.

No attempt is made to determine whether or not there should be glass in a building, or how much of elaborate on design applications in residential, comit there should be. Rather, the entire subject of "Windows and Glass in the Exterior of Buildings" is placed under a microscope for examination by those interested in a major area of progress within the science of building. In conducting this conference, the Building Research Institute acted as a forum in which a balance of industry, professional and academic opinion was presented in the interest of the advancement of new research and development.

SYNOPSES OF CONFERENCE PAPERS

PRINCIPLES OF DAYLIGHTING FOR BUILDINGS

By J. W. Griffith (Southern Methodist University)

THERE are three basic sources of daylight which may be used for illumination in buildings; the sun, the sky and illumination from the ground and reflecting surfaces. Primary among these is the sun, the azimuth and altitude of which must be considered in any daylighting design. Calculators and tables have now been developed by means of which these two factors can be computed for a particular location at any time of the day and year.

The effect of sky brightness on daylighting illumination is normally taken into account by the incident illumination therefrom for both the direct component incident on the fenestration area and the reflected portion incident on reflecting areas, such as the ground. If the reflecting surface is above the horizon, the brightness must be considered as part of the sky brightness pattern.

All illumination from below the horizon can be considered as ground illumination. The brightness of the ground or such reflecting areas as concrete walks, light reflecting roofs below the fenestration area, etc., can be computed on the basis of incident illumination from the sun and sky. This source of illumination produces indirect lighting within the room, and may or may not be the major source of daylighting. Any shadow effect of the building on the immediate ground area must also be considered in computing such illumination.

Four fundamental factors are involved in visual tasks, all of which are affected by the amount of illumination available. These factors are: size of the task, contrast of the task (brightness or color contrast), brightness of the task, and time available for viewing the task. Research has indicated that relative visual performance increases with higher levels of illumination. Likewise, recent research has shown that where 30 footcandles may be adequate for some observers, others may require two to three times this level for equal vision.

Thus, recommended illumination practices based on minimums may be entirely inadequate and should never be incorporated as a code. By adopting minimum values of illumination based on artificial lighting alone, codes tend to produce poor lighting conditions. Performance type codes should specify illumination from both artificial and daylighting sources, and codes where no daylight is available should require considerably more artificial illumination for good visual environment.

There are three methods of calculating daylight distribution within buildings. The first and most economical is by computation using available prediction techniques. The second is by measuring the actual distribution of daylight in scale models of particular installations. This method is more expensive because the models must be to exact scale, and considerable equipment is required for testing. The third method is to measure the actual distribution in a room after it is completed, but this method also requires considerable equipment, and does not allow for alteration of the design to correct faulty conditions.

Daylighting design must also take into consideration the various types of fenestrations and controls. Venetian blinds properly adjusted can provide a high quality and quantity of light on the work plane, and can eliminate glare and redirect sunlight into the interior of the room. A properly designed overhang can provide adequate sun control and allow full utilization of reflected ground light. A louvered overhang on non-sun exposures can also reduce the shadow effect and redirect sunlight into the interior.

The diversity of illumination from daylight can be reduced by employing multilateral fenestrations. Bilateral and clerestory fenestrations can provide higher quantities of illumination with lower areas of brightness in the field of view. Consequently, where it is possible to use them, multilateral fenestrations and large fenestration areas will provide better quality and quantity of daylighting.

DESIGN OF GLASS FOR DAYLIGHTING

By Robert A. Boyd (University of Michigan)

DAYLIGHTING involves three sets of factors; the intensity and variability of the daylight sources, the overall design of the fenestration and the geometry and reflectivity of the interior to be daylighted. The visual environment that results can be evaluated on the basis of quantity of illumination and quality or control of brightness.

Fenestration materials are most readily separable into two groups, those which allow clear vision and those that are obscuring. The light incident on a glass unit is separated into a reflected component, an absorbed component and a transmitted component; the absorbed one being converted into heat. The percentage of transmission does not in itself predict the effectiveness of the material in providing adequate daylighting. With clear vision materials, the light reflected to the exterior, for direct sunlight at or near normal incidence, is 4 to 8 per cent. For obscuring materials this component may be as high as 60 per cent.

In clear vision materials the brightness of the view depends upon the absorption of the glass. However, these materials admit the light in a downward direction and thus a high percentage of it is absorbed by the floor, furniture, etc., with little or no diffusion of the transmitted light. Obscuring materials, on the other hand, provide a wide range of diffusion patterns. Single sheet obscuring materials scatter the transmitted light within a relatively small cone having the direction of incidence as an axis.

Of the various types of glass block used as fenestration materials, the prismatic glass block redirect transmitted light so that the major portion enters the interior above the horizontal plane. The diffusing type glass block transmits the light quite uniformly in all directions, and consequently is similar in performance to a perfect diffuser. Decorative glass block are manufactured with many different patterns. Unless used on non-sun exposures, they require some type of brightness control device.

The solar-selecting type of glass block incorporates an entirely different principle than the others. Through the use of prism combinations in the outermost layer of glass, it is capable of reflecting as much as 60 per cent of the sunlight away from the outside surface under certain conditions. This type of block is designed for use in wall fenestrations to discriminate against sun positions near 45 degrees altitude, and in roof installations against sun positions near 60 degrees altitude.

Tests show that the solar-selecting type of glass block with a uniform distribution of brightness, and the prismatic glass block with maximum brightness in directions toward the ceiling and upper walls give a higher quality of daylight than clear vision materials or typical obscuring glass. Also, the increase in illumination due to multiple reflections is greater in the cases of better diffusion.

In many single story buildings various types of secondary fenestration have been used to raise the minimum illumination and improve the quality of daylighting, such as clerestories, monitors, saw-tooth units and skylights. In the typical classroom, when the component due to multiple reflections from room surfaces is added to the direct light from the fenestrations, the total illumination may be less than the minimum required, and the ratio of source brightness to task illumination may be higher than recommended. Consequently, it has been general practice to utilize secondary fenestration, such as clerestories. More recently, because of lower costs and simpler construction, ceiling panels consisting of solar-selecting and diffusing glass block and skylights glazed with various types of obscuring glass have been used. These have several advantages over clerestories from a daylighting point of view.

Obscuring glass, heat-absorbing glass, clear vision materials and prismatic glass block are all commonly used in monitor construction. The prismatic glass block, in lighting the ceiling of the high bay, provides a higher percentage of scattered light than the obscuring glass. Diffusing glass block, obscuring glasses and clear vision materials are frequently used as fenestration materials for saw-tooth construction. Ceiling panels may be skylights utilizing wired, heat-absorbing glasses and obscuring glasses, diffusing glass block set into a reinforced concrete slab, or prefabricated panels of solar-selecting glass block. Such panels are often used in checkerboard pattern.

ASHAE RESEARCH AND HEAT TRANSFER THROUGH GLASS FENESTRATION

By Donald J. Vild (Libbey-Owens-Ford Glass Co.)

ABOUT a decade ago it became apparent that heat transfer through fenestration was often an important factor in the proper solution of air conditioning or heating problems. Lack of accurate information and research forced engineers to approximate this vital component. To fill this void, ASHAE set up a research program which since then has been expanded to investigation of virtually every type of daylighting fenestration. To date, ten papers have been published as a result of this research, including studies on flat glass, glass blocks, figured rolled glass, skylights, and the shading of sunlit glass, as related to heat transfer through fenestration.

In the majority of cases the factor of primary importance is the incident solar radiation, both the direct and the reflected or diffuse. The intensity of the direct component may vary from 0 to 350 btu/hr-sq. ft., but for design purposes a value of 294 is taken as standard. The diffuse solar radiation will have daytime values ranging from 10 to 100 btu/hr-sq. ft. depending on environmental conditions.

The intensity of the direct rays of the sun differs from one wave length to another. For average conditions, about 45 per cent of the total energy lies in the range of the visible portion of the solar spectrum. Diffuse radiation reaches fenestration by a number of paths. Building surfaces having high reflectances will increase the diffuse radiation, as will foregrounds such as smooth concrete and water.

Heat transfer through fenestration is also affected by low temperature radiation, outdoor air temperature, wind velocity and direction. It is only when the sky is overcast that the earth's atmosphere acts approximately as a perfect radiator. In addition, surrounding buildings, trees and ground may absorb energy during the sunlight hours and radiate at somewhat above air temperature during the latter part of the day. Outdoor air temperature is a factor in heat transfer by convection. The greater the difference between indoor and outdoor air temperatures, the greater the heat gain or loss by convection. High wind velocities, regardless of direction, will increase the convection heat transfer rates, with winds parallel to the surface producing slightly greater increases than those perpendicular to the surface.

The thermal behavior of glass is more difficult to analyze than that of opaque materials, since it will transmit solar radiation in varying amounts depending upon the type of glass and the characteristics of the solar radiation striking it. Many types of glass are color selective and will transmit one type of wave length more easily than another. For instance, the light transmittance of heat-absorbing glass is about 75 per cent, and that of a representative "gray" glass about 13 per cent. However, the total solar transmittance of each is about 40 to 50 per cent. This is due to the fact that the "gray" glass transmits more radiant energy in the non-visible portion of the spectrum. Solar transmittance values of common glasses vary from about 90 per cent for clear plate glass to about 14 per cent for hammered and etched heat-absorbing glass.

On a clear, afternoon in mid-summer at 40°N. latitude, with fenestration facing southwest, heat-absorbing glass will reduce the amount of transmitted solar energy by about 50 per cent from that transmitted by regular window glass. Double glazing employing heat-absorbing glass outside and regular plate glass inside will effect an additional reduction. Inside shading with light-colored venetian blinds is effective in direct relation to the amount of solar energy reflected back through the glass. ASHAE is presently engaged in making an analysis of heat transfer within a glass block panel so that its performance may be more accurately compared with other types of fenestration. However, it has been established that glass block greatly reduces total heat gain.

Engineers or architects can predict heat transfer through glass fenestration with a considerable degree of accuracy by consulting the tables published in the ASHAE Guide. Included in these tables are various types of glass and shading devices with information presented for winter conditions and for a summer design day. Through their use it is possible to determine the total instantaneous heat gain for any combination of orientation, time and latitude, and the heat transfer per square foot of fenestration under a variety of conditions.

DESIGN FOR THE CONTROL OF SOLAR HEAT GAIN AND LOSS

By Alfred L. Jaros, Jr., (Jaros, Baum & Bolles)

NO matter how desirable windows may be from all other aspects, their excessive use imposes a heavy tax on the cost and the space requirements for air conditioning. In figuring the cost of air conditioning a building serious attention must be given to the fact that one of the major causes of high air conditioning costs is the heat from the sun. It doesn't cost as much to operate air conditioning on a cloudy day as on a sunny day, but the plant must be designed for the sunny day. Ducts, fans and refrigerating machines must be large enough to cope with the worst conditions.

Within a modern multi-story office building, depending upon many factors of which size of windows is one, the cost of air conditioning may run from as little as $3.50 per square foot of usable floor area up to as much as $8.00 per square foot. An unshaded window of plain glass may transmit some 180 btu's of solar heat per square foot into the interior space. If the windows are large, this one factor may be greater than all of the other heat sources which combine to produce air conditioning load.

In designing windows of moderate size and in trying to find ways to shade and orient those windows, you can strike a happy medium between no windows at all and windows that are excessively large. Heat-absorbing glasses, glass block, etc., apparently transmit from one-half to two-thirds of the amount of heat that would come through an unshaded, clear glass window. Although research is not yet complete, it appears that if you also use venetian blinds, the heat-absorbing glass and other elements do not gain much more than the blinds alone can gain.

However, all of these considerations are insignificant compared to outside shading. With outside shading you may cut radiant heat from the sun down to one-fifth or even less, depending upon the efficiency of your shading schemes. One example of this is the projecting balcony, widely used in the tropics. Another is a scheme used in South America involving a series of concrete vertical louvers two or three feet out from the east and west facades of the building. As the sun comes around from the southwest arc, almost no sunshine strikes the glass, but the occupants of the building can look out freely to the northwest between the louvers, which are several feet apart. However, all such arrangements must be out in front of the glass to do their work properly; the farther out, the more effective.

A vast improvement over these fixed louvers is today becoming technically and commercially feasible for any exposure where you want to use vertical louvers. This is the use of light-sensitive amplifiers and mechanisms to make louvers swing around and adjust themselves automatically to the direction of the sun. One example of this technique is found in the new Reynolds Metals building in Richmond where practically the entire facade is covered by aluminum louvers which are pivoted on vertical spindles by means of photocells, amplifiers and controlled motors. Another is the building of the American Association for the Advancement of Science in Washington, D. C., which is almost entirely covered by such adjustable louvers.

In a building with 75 per cent glass in its facade, the total internal sensible heat load on the outside of the building for a one-foot wide band extending 15 feet into the building is not quite 800 btu/hr. The solar radiation on plain glass, unshaded, is over 900 btu/hr. With the use of venetian blinds of good reflecting quality, this 900 drops to about 500. If heat-absorbing glass is used, it drops to about 600 without blinds. Outside shading would drop it to 250 btu/hr instead of 900.

Figures quoted were prepared for the south side of a building only and do not reflect the fact that the sunshine is only on one face at a time. Therefore, the savings made possible either by small windows or shading devices are not as great in terms of the building as a whole as they are when considering only one side. This is true as concerns the total refrigerating capacity required. When the sun is shining on the east during the morning, it is not shining on the south and west. By proper design, the plant capacity can be shifted from one zone to another in the building so that the savings which can be made on the central refrigerating plant by cutting down solar heat are smaller than the examples given here indicate.

However, this is true only of the central refrigerating plant. It is not true of the air handling system, the fans, ducts, grilles, coils and filters. These must be designed for each zone of a building. In a typical job at present-day costs, the central refrigerating plant and accessories will cost $300-400 per ton of installed refrigerating capacity. The air handling system, depending upon type used, will cost from $900-$1,100 per ton of capacity, or about two-thirds to three-quarters of the whole cost of air conditioning a building. This system is affected simultaneously in the design of all sides of the building by excessive sun loads. Only the central part, representing about one third of the building, can take advantage of this diversity factor.

Therefore, it is important to give the utmost attention to minimizing solar heat radiation load, since without such attention it could easily become the most important factor in making air conditioning too costly.

NATURAL VENTILATION

By Bob H. Reed (Texas Engineering Experiment Station)

WITH all of the present-day improvement in the design and construction of windows, there still seems to be an almost total lack of concern for the fact that air flow is a prime function of the window. This may be due in part to lack of information on summer ventilation problems in warmer climates, and in part to the fact that most windows are manufactured in the east, where winter problems are paramount.

The physical effects of hot, humid weather on the occupants of a building are very much modified when accompanied by a brisk air movement. However, a low temperature which may even be stimulating in a calm, becomes unpleasant in windy weather. The chief difference, then, between winter and summer ventilation is that the current of air which is welcome in summer is unwelcome in winter. The variables involved in producing human bodily comfort or discomfort are: velocity of air stream, temperature of air stream, relative humidity of air stream, surrounding thermal conditions, duration of exposure, degree of exposure, and physical and physiological state of the individual.

A great many of our buildings are not air conditioned and must rely on natural air movement for summer cooling. Windows which are to be used for summer ventilation should be designed to permit the greatest possible use of natural wind forces. In addition to deflecting drafts upward in winter, they should also be capable of directing air currents downward through the living zone in summer. Some windows are limited in their ability to provide summer cooling, and probably should not be used where this is a major problem.

Virtually every window in any kind of building can be classified as one or a combination of three basic types: (1) simple opening, (2) vertical vane, or (3) horizontal vane. Generally speaking, air will flow in almost any direction through a simple opening, depending on the surrounding pressures at the various sides of the opening. Only when these pressures are symmetrical will air flow straight into the opening, perpendicular to the wall. On the other hand, in a plane perpendicular to the operating sash of vane type windows, the air generally flows parallel with the angle of adjustment of the operating sash.

While the importance of weather proofing, durability, strength, ease of operation, etc., in the design of windows is recognized, more consideration could be given to the air-control characteristics of the window to assure that the window will perform adequately when it is open, as well as when it is closed.

ENGINEERING PROPERTIES OF GLASS

By Leighton Orr (Pittsburgh Plate Glass Co.)

SINCE there are no particular problems with small plates of glass, this discussion refers to the use of larger size glass plates, often with special properties, where the stresses developed could possibly lead to failure of the plates. Wind loads and temperature difference where the sun is the usual heat source are the most common methods of stressing large glass plates.

The rate of applying the load or the length of time the load is held is important in determining the stress causing failure. An impact type of loading will withstand three times more stress than that developed from a constantly applied load held for a long period of time. Also, a failure always originates at some form of imperfection on the surface or the cut edge. Ordinary methods of calculating stresses and deflections due to wind loads are not valid with glass because of the extremely large center deflections. Pittsburgh Plate Glass Co. is therefore conducting experiments using equivalent static pressure loads on large glass plates.

Two separate series of tests have been conducted involving 20 plates tested to destruction. The variables included plate glass and Solex glass of several thicknesses, and of varying sizes and shapes. The range in center deflection at failure was between 1.0 and 1.6". The tests showed no significant effect of size or shape within the range used. The thickness was the most important factor controlling total load. Large size Twindow sealed, double glass units showed definite advantages as compared to single glass plates, since the deflection of one plate compressed the sealed air and transferred part of the load to the other plate. In tests of three different sizes, the increase in strength over single plate amounted to 50 to 80%.

In considering the effect of solar absorption on glass breakage, the type of glass and the thickness influence the amount absorbed. If the glass attained a uniform temperature rise over the entire area, no stress would result. However, where the edge is recessed in a frame and does not absorb energy, the edge temperature lags behind the normal temperature increase in the central area. This temperature difference produces tension stress all around the edge, where the plates are normally weakest. Painting solid designs on regular plate glass or applying decals would have the same effect as using heat-absorbing glass. Some of the darker colored opaque glasses or enamel coated glasses would be almost perfect absorbers where the only safe solution would be to partially temper the plates to allow greater resistance to temperature difference.

Tests conducted on heat absorption showed that stress reached a maximum after 30 minutes of exposure, and then decreased as the heat soaked into the edges. The investigation of breakage resulting from the heated plates suddenly being cooled by high winds or cold rain showed that the possibility of plates breaking from heat shock in service is very remote. Experiments on size effect, using ¼" Solex glass, showed that the possibility of breakage increases with the number of linear feet of edge, since there is more chance of a defect being present to start a break. The best safeguards against tension stresses on the edges of heat-absorbing glass are skillful, clean cutting, and the use of tape around the edges to prevent metal to glass contact.

Another factor which adds to edge stresses is the use of tightly closed venetian blinds or drapes close to the inside glass surface, which prevents loss of heat from the glass. Of all the shading devices tried, those with a shaded strip of various widths through the center section of a plate were the only ones which did not increase the tension stress on the glass edge. In using opaque glasses or enamel coated glasses, it is most important to know the solar energy reflectance, absorption and transmittance values. In general, the light colors reflect a high percentage of solar energy; the intermediate colors reflect about 50% and absorb about 50%; the darker colors reflect very little, and should all be "heat strengthened," regardless of method of installation, because of higher edge stresses.

WINDOWS IN MODERN ARCHITECTURE

By Bruno Funaro (Columbia University)

UP TO the time of the discovery of electricity and of the steel frame, windows were limited in size, shape and position by structural considerations. They were also performing a variety of functions such as letting in light and air, letting vision pass through, and still satisfying requirements of weather protection, privacy, heat and sound insulation. Often, the windows were the focal points of a vast composition which embraced the whole facade.

Jumping to the mid-20th century, we find windows completely free from control of the structural frame. As a means for new architectural expression, we find continuous horizontal bands of windows accomplishing the stratification of independent office areas placed one over the other. Vertical bands of windows emphasize vertical lines and contribute to the unity of the building. The climax of all this is reached when the whole building is sheathed in glass. With the all-glass wall, the window as an individual element ceases to exist.

In modern, air conditioned offices windows are no longer needed for light nor for ventilation and, when heavily tinted glass is used or shades are closed, they no longer provide a view. However, in the open areas such as cafeterias, rest lounges, etc., there is a real opportunity to open up. Here is where sunlight and fresh air should be provided. Why not place communication areas, elevator lobbies, reception rooms and corridors on the outer face of the building, so that people may enjoy the daylight there?

Current developments in single family homes seem to feature two main themes, the solar house and the air conditioned house. Development of the solar house has again called our attention to the fact that windows can serve many purposes; can become actual sun-traps and cut down heating bills. The design of glass areas has been removed from the purely aesthetic to a careful study and interpretation of conditions of geography, astronomy and climate, posing a challenge to both the architect and the glass manufacturer. Fenestration in houses has become so important today that the design of the whole house often revolves around it.

This, in turn, raises problems for the manufacturer, who must expand the variety of stock items to meet as many different situations as possible. The answer to this may be to provide separate components; hardware, frame and track profiles by the foot, glass sheets, all of which could be assembled by the dealer or on the job. Meantime, the future of window design remains closely tied with the kind of life we want to live in the rapidly changing world we have today.

WOOD WINDOWS

By James Arkin, AIA

THE form that stock windows take today is no longer bound by what the glass industry can supply, because the glass industry itself has become far more flexible in its output. Nevertheless, the form, style and sizes of stock wood windows are based at the present time entirely on the demands of the market for homes priced at $35,000 and under, and for light, utilitarian buildings.

The National Woodwork Manufacturers Association has carried on research programs aimed at the improvement of stock windows, including such projects as performance tests for use in developing standards for moisture content, materials, manufacturing processes, glazing and grading. This association has also been active in the initiation of Commercial Standards for windows produced by its member companies, of which five have now been issued. All of the standards call for windows made from carefully selected and properly kiln-dried wood, defect-free and chemically treated to permit easy operation under all weather conditions.

While the horizontal sliding wood window has been gaining in popularity, the double-hung window is still by far the most universally accepted. BLS statistics for 1955 showed that 55% of all windows installed in new non-farm dwellings during the first quarter of the year were wood. This is due in the main to the inherent advantages of wood as a material for window frames and sash, and also to constant technological improvements being made in their manufacture, such as the use of new materials and methods for weatherstripping, including vinyls and other synthetics as well as metal.

The NWMA has also developed standards for the chemical treatment of wood with water repellent preservatives which have now become standards for treating all forms of millwork, special as well as stock. The NWMA standards are administered through a "Seal of Approval" program based on rigid inspection of fabricators throughout the country, their methods and the chemicals used. Use of NWMA standards is implicit in U. S. Commercial Standards governing windows. They may also be applied to custom designed frames and sash if the architect so specifies.

A series of tests conducted by the ASHAE and the AIA pointed up the comparatively low infiltration of air through double-hung wood windows. Wood casement windows may be assumed to have the same unit leakage as the double-hung, when properly fitted. Wood windows also enjoy a relatively favorable position as compared to aluminum and steel in the matter of freedom from condensation on the surfaces, due to the high insulating qualities of wood.

In connection with reducing school maintenance costs, some architects have recently been specifying woods that do not require painting, or that will render good service with water-repellent treatment alone. The most recent standards of the Central Mortgage and Housing Corporation of Canada, which corresponds to our FHA, will accept treatment in lieu of priming for wood windows.

The special millwork industry is now organized to assist the architectural profession by providing technical information on the design and specification of wood frames and sash through the Architectural Woodwork Institute, which has members throughout the United States and Canada. Looking toward the future, the wood window wall and curtain wall remain to be developed to the fullest extent. The direction that window design will take in coming years is intimately related to the whole problem of architectural design.

STEEL WINDOWS

By William Gillett (Fenestra, Incorporated)

MODERN steel windows are manufactured from solid rolled sections for virtually all industrial types, and for casement and projected type windows for nonindustrial use. Cold roll formed strip is employed principally for double-hung steel windows. Advantages of steel windows not offered by other materials include fire resistance and detention. The strength of steel permits designs with a minimum of profile; lends itself well to rigid assembly; allows firm and permanent attachment of hardware and fittings. Steel is not subject to warping and, when properly protected, will last indefinitely.

Among its limitations are the fact that it is relatively difficult to shape, form and cut; it is not yet economically possible to provide steel extrusions for windows, and designs must be limited because of inability to provide certain shapes. Due to the high cost of basic equipment and rolls for forming, shapes must be substantially standardized as to types and sizes.

Today, steel window manufacturers have developed a process of hot dipped galvanizing plus a surface treatment that helps to protect steel from corrosion, makes it more pleasing to the eye without further coating, and permits satisfactory adherence of paint where colors are desired. Such a process must be applied to frames and ventilators separately with assembly of the two following, and is normally applied only to solid section steel windows. Those of cold roll formed strip start with a coated strip when galvanizing is desired. This new type of surface treatment represents the latest improvement in steel windows.

A problem confronting all window manufacturers today has to do with standardization of types and sizes. In the residential market there are literally hundreds of different types and sizes of windows, and in the non-residential field a large percentage of windows have no standardization whatsoever. If we, as an industry, are to give our customers improved products at lower costs, we must solve the riddle of varying extreme designs, even though window types and sizes are limited in number.

Another problem which calls for the attention of all segments of the industry including the designer, builder and material manufacturer is that of faulty installation and maintenance of operating windows.

To date, some limited use has been made of stainless steel for windows, but the present cost range of this material puts it beyond the reach of most building budgets. However, it would be remiss not to predict its increased use in the future. With a combination of new designs, improved protective and decorative finishes, and a higher degree of standardization, steel windows will continue to offer many advantages to future buyers.

ALUMINUM WINDOWS

By John P. Jansson (Aluminum Window Manufacturers Association)

THE first sizable installations of aluminum windows in hospitals, office buildings and schools were made in 1931. Since then, aluminum has proved by many examples that it is a good window material and will stand up under the most adverse conditions. One of the biggest reasons for its acceptance is the complete flexibility of design possible with aluminum. Architects can work out sections and details to suit their needs. Today, over 100 million pounds of aluminum go into prime windows every year, plus many millions of pounds used in storm windows.

Other advantages of aluminum are its low cost, light weight and low maintenance expense. Aluminum windows can be either of tubular or solid section design. The gauge is generally about .062 as a minimum, and it can be as thick as .188 or even 1/4" in some sections, depending on design requirements. It is possible to design a window out of light gauge which will be very strong structurally and have a good sectional module.

In 1946, with the formation of the Aluminum Window Manufacturers Association, standards were set up for strength of section, uniform and concentrated load tests and air infiltration tests, to make sure that the products being produced would satisfy requirements.

Aluminum windows can be screwed, riveted or welded together at the corner joints. The least expensive finish is the mill finish, which usually includes a coat of clear lacquer to protect the window against mortar action during construction. The more expensive finishes are the satin type, produced by etching, belt polishing, grinding or rubbing with steel wool or emery, a bright buffed finish, or an anodized finish which is a coated oxide covering on aluminum. Anodizing is generally recommended in cases where the windows are going to be maintained. If they are going to be allowed to accumulate dirt, then anodizing is not important, because the aluminum will continue to resist corrosion underneath the dirt.

Aluminum window manufacturers use a variety of hardware materials—bronze, aluminum, die-cast stainless steel. The only requirements here are that the hardware be structurally sound and tightly attached to the window. It is recommended that architects work with the manufacturers and use their accumulated experience to get the best results in designing aluminum windows.

GLASS BLOCK

By H. F. Kingsbury (Pittsburgh-Corning Corporation)

INTRODUCED in the 1930's, the early designs of glass block were mainly decorative in nature, and did not make use of the possibilities for light control inherent therein. As the need for better daylight controls was recognized, the design possibilities of glass block were investigated and today a variety of types is available in both decorative and functional patterns. And, it is not felt that the full range of design concepts has yet been explored, either in manufacturing or end usage.

Glass blocks are hollow, all-glass, evacuated units, made and sealed at high temperatures. They are non-load bearing, but have a compressive strength of about 500 lbs./sq. in. when uniformly loaded. Conducted heat loss or gain, depending on pattern and size of the glass blocks, ranges from approximately ½ to ⅓ that of single glazing, and instantaneous radiant heat gain is approximately ⅓ that of single glazing.

Glass block panels have a relatively high sound reduction factor, averaging 40 decibels, which is comparable to a 4" thick concrete wall, and are low maintenance installations. They are highly weather resistant, even in industrial atmospheres, and are difficult to break. In the field of light control, broad design possibilities exist with glass blocks, using prisms and lenses pressed in any or all of the four surfaces.

Blocks of light-directing design are available with varying degrees of brightness control. In addition, there are light-directing blocks which control both brightness and heat flow by means of a fibrous glass screen sealed into the block during manufacturing. For the control of extreme brightness or for use in areas where heat gain is a specific problem, there is a special block available. Various patterns of light-diffusing blocks help to control other situations.

Perhaps the biggest single usage of glass blocks today is in schools, where their properties of light control and low cost maintenance make them widely accepted as fenestration for classrooms, gyms, and other portions of school structures. Two styles are used for skylights, one in which the blocks are prefabricated in aluminum grids, and the other in which the blocks are cast directly in concrete. This type of panel is very flexible, can be used as sections of barrel roofs, pie shaped skylights, or in other forms.

By nature and design, glass block panels constitute a curtain wall type of construction. To overcome the monotonous appearance of an all-block wall, designers have combined them with inserts of tile and other materials for an interesting decorative effect. Future, broadened uses of this material are limited only by the imagination and curiosity of building designers.

FIXED GLASS INSTALLATIONS

By C. R. Sigler (The Kawneer Company)

THE modern era in fixed light design began with the use of lightweight, all metal glass-holding members which provide a resilient setting, are easy to install, and facilitate glass replacement. There is today universal acceptance of the modern design for store fronts and entrances of large, single or multiple fixed lights, which provide an open and welcoming atmosphere and open up expanded display areas. With today's trend toward more air conditioned buildings, the fixed light wall system is the simplest and most flexible. It is also more economical and forms a more positive weather barrier than operating sash. Fixed lights are also enjoying wider use inside the building as office or corridor walls, for borrowed light, or to separate and control traffic.

A fixed light may be of plate or sheet, or it may be a double glazed unit. Patterned and ornamental glass are also being used on exterior openings. Functionally, the requirements of fixed lights are to prevent air infiltration, prevent water leakage, and resist wind load. Air infiltration is prevented by the use of putty or gasket type materials applied continuously around the light and properly retained by the stops. Water leakage, on the other hand, is not so easily prevented. It may be due to a variety of factors including errors or poor workmanship in the installation, expansion and contraction of metal, warping, swelling or rotting of wood, or deterioration of the glazing compound. A weathered unit must seal the glass to stops, the stops to frame, and the joints in the frames. In this light it is better to assume that some water will enter, and to provide a system for collecting it and returning it to the outside. This can be done by a system of gutters and downspouts to contain any leaks within the frame members and prevent the water from entering the building. This solution requires only minor modification of the glazing or framing members and has proved very effective and economical.

Designing for wind load, especially on openings using large plates of glass with intermediate vertical or horizontal mullions, must be done meticulously. Engineering values for the strength of glass have not been defined to the degree that we could consider glass as a structural material, in this case. Therefore, tests have shown, the glazing members must be designed to contain the allowable deflection of the glass. Actually, in our designs, we allow the glazing member to deflect only $\frac{1}{3}$ the allowable deflection of the glass. On high, large lights where the design is sound from an engineering standpoint, with a rather lightweight vertical division bar holding the glass, the allowable deflection could be several inches. However, for psychological reasons, we arbitrarily limit this deflection, since the public would react unfavorably to glass movement as great as that.

Other specific considerations on particular jobs might include determination of twist in the member due to off-center placement of the glass, or location of the light where, due to surrounding buildings, air velocity on it may be a multiple of the open area velocity.

STANDARDIZATION OF WINDOWS

By William Demarest (National Association of Home Builders)

SUCH standardization of windows as we have today has been accomplished by the window manufacturers in an effort to hold down the delivered price of their products. The resultant economies (simplification of jigs, easier warehousing, simpler record keeping and catalogs, etc.) have contributed materially to reducing costs. As a result of more wide-spread research on the construction industry, the development of the "component concept" has pointed up the necessity for bringing building dimensions generally under control. Industrialization of home building has already begun with building materials, which raises the question of coordinating standardized unit sizes with each other. If the building is considered as the end-product of which the window is a component, it must not only be adapted to the structure, but coordinated with other related components.

Acceptance of modular dimensioning has been gaining in recent years, but has been hampered by the lack of modular coordinated material sizes available as stock items and priced accordingly. Coordinated standard window sizes are among the most urgently needed modular elements

There are several factors influencing the development of standard window sizes, including the aesthetic preferences of the building owner, anthropometric requirements, ventilation, insect screening, and even the use of blinds and window air conditioners, in addition to the problems of manufacturing, shipping and stocking.

To spur activity in this field, the NAHB Research Institute has tentatively suggested two widths and five heights of stock residential windows. The widths were based upon the established spacing of studs, and the heights were developed from considerations of eye height, furniture placement, and of exterior masonry and interior wallboard joints. The reason for choosing these particular sizes was to achieve ease and economy of installation and to reduce the number of stock residential sizes called for by home builders. Some manufacturers have already begun to produce stock sizes based upon this approach. While the basic stock sizes finally worked out between home builders and manufacturers probably will not be those originally proposed, at least steps are being taken cooperatively to solve the problem and to produce eventually at competitive prices a choice of sizes, materials and styles of windows best suited to the operations of the small volume home builder.

PROBLEMS REQUIRING CONTROLS: VIEWPOINT OF THE OWNER

By Harold S. Miner (Manufacturers Trust Company)

IT WAS the desire of the president of Manufacturers Trust to create a bank building that would be so appealing, so unusual and so inviting that it would compare favorably with the best of modern plants or commercial buildings. Because the exterior of the building is entirely of glass set in polished aluminum frames, it serves, in effect, as a giant showcase for banking. The 13,000 square feet of plate glass panes are sealed in place—the building is entirely windowless and completely air conditioned.

Through occupancy of the building and employee surveys, Manufacturers Trust has found that the sense of spaciousness imparted by the glass walls is restful and easy on the nerves. The fact that employees feel they are on public display has improved morale, personal appearance and efficiency. The openness of the structure has also improved customer relations, and the rate of opening of new accounts has increased nearly three-fold. Although the vault has been set on the main floor, only ten feet from Fifth Avenue, there is a rear door which is the only entrance for customer use, providing depositors privacy in going to and from safe deposit boxes. During banking hours, 32-foot translucent drapes are drawn to screen from view those officers seated next to the windows on the street floor. This offers sufficient privacy for them and their customers without destroying the "look-through" effect of the glass walls.

There have been two instances of breakage of tempered glass doors, when sharply struck, but no other difficulties have been encountered.

PROBLEMS REQUIRING CONTROLS: VIEWPOINT OF THE OWNER

By Herbert S. Greenwald, Builder-Developer

THE apartment house manager and owner encounters a number of problems in glass-walled buildings, first of which is consumer resistance. This is based on fear of falling out of the windows, fear that the glass will shatter in high winds, or neurotic fear of high places. In addition, prospective tenants worry about the problem of drapes and blinds for glass walls, and of furniture arrangement. They also worry about privacy, even though they are 30 stories up in the air.

Problems encountered in the structure itself have to do with extremes of weather, ventilation, and keeping the windows clean. In some cities, a problem arises where codes on fireproofing do not recognize glass as sufficiently fireproof for a spandrel wall.

As to the solutions for these problems, the first group seem to cure themselves. People learn to live with the glass walls and like them, as evidenced by the fact that occupancy is high, and that the value of the co-operative apartments in 860 Lakeshore Drive has increased as much as 200 to 300 per cent over the original purchase price. Further research by the glass industry could probably help to solve the privacy problem by producing a type of glass that would allow tenants to see and not be seen, at a price that would make it feasible for use on the outside of buildings.

Use of heating and air conditioning unit right at the glass has eliminated the problem of hot or cold walls. Use of gray-tinted plate with a tint of warm red added to prevent its being too gloomy on a cloudy day has proved quite satisfactory in some recently finished buildings. The aluminum industry provided information which allows control of hoppers so that ventilation problems have been overcome. We have also developed a good, economical system for washing the walls from the outside. There are still some problems connected with water infiltration that the glass industry could help to solve by developing more satisfactory calking compounds and putties. There is also a need for development of a glass spandrel containing fireproofing elements to satisfy local codes.

The advantages of glass buildings are many. They make for a greater feeling of spaciousness in the apartments. They produce a lighter building, and therefore, a cheaper building, which is also cheaper to maintain. The use of glass forces the builder to select a good site and to use only the best workmanship.

The glass industry faces a great challenge now to devise a way to put the air conditioning, the heating unit and the lighting in the glass itself, so that it can become a complete sheath for the building.

EXTERIOR CONTROLS

By Henry Wright, Architect

KNOWLEDGEABLE architectural design and careful orientation of buildings can reduce solar heat gain and thus minimize both air conditioning load and the need for external shading. Likewise, reduction of window sizes on some walls, and the use of all-glass walls on others can produce a dramatic effect without adding to air conditioning load. Changing the shape of high, narrow building windows to dispense with the upper half would afford savings and help keep heat load down.

For purposes of comparison, it can be said that an exterior louvered sunshade, completely closed, excludes about three-quarters of the heat which would otherwise enter an unshaded window. An overhang or hood above the window, and a partly open exterior louvered sunshade, may exclude slightly more or slightly less than two-thirds of the heat. An interior shade or blind, if white and if completely covering the window, excludes about one-half.

For any of these methods of solar heat control to have maximum effect on air conditioning costs, it is necessary that they reduce the over-all peak load, including ventilation and lamp loads. Otherwise they influence the cost of only part of the equipment and operating expense. As orientation of the windows approaches the worst possible, savings are at a maximum. To the extent that such orientation can be avoided, the magnitude of the saving due to control devices is reduced.

Fundamentally, exterior shading devices are an excellent way to correct design defects which have occurred because of our lack of experience with air conditioning. They are also an effective way to further reduce sun load when all appropriate steps have been taken in the design of the building to minimize solar heat gain. Granted that exterior shading devices can help to save money—money which can legitimately be applied to the cost of the shading device—this is still not economic justification for unnecessarily facing glass in the wrong direction, or of using more of it than necessary.

INTERIOR CONTROLS

By Sterling S. Bushnell (Breneman-Hartshorn, Inc.)

INTERIOR window coverings may be selected from one of five different types: spring roller shades, horizontal or vertical venetian blinds, draw draperies, various types of bamboo or woven wood coverings, or slatted interior wood shutters. Of these, the spring roller shade is the simplest to install and least expensive. In addition to the familiar materials, the industry is now offering shades in a number of textured fabrics and colors.

Venetian blinds, which permit greater flexibility of light control than shades, may be either of wood, metal or cloth. The vertical venetian blinds are easier to maintain, but more difficult to install, since they must be assembled on the job and have a more complicated operating mechanism. Draw draperies provide good opacity, but are more expensive than other types of window coverings due in part to their limited life in comparison with initial cost.

Advances have also been made in the design of woven wood and bamboo shades or blinds. Some manufacturers are now offering them in a range of colors with metallic or colored cords, etc. This type of shade can be installed with slats running horizontally and using spring rollers or lifting cords, or they may be hung with slats in a vertical position and be traversed like draw draperies.

Efforts are being made by shade and blind manufacturers to standardize on center to center dimensions for mounting holes for the various styles of brackets, so that metal windows could be prebored and tapped for easier installation of the blinds. Cost of installation could be considerably minimized by such a system, particularly in the case of panel walls delivered as a complete unit, since the shades or blinds could then be delivered directly to the job in correct size, and could be installed by unskilled labor, since no tools would be required.

Standardization of window sizes for residential construction would provide real economies for both builder and home owner on the cost and installation of blinds and shades as well as of windows.

ENGINEERING OF BALANCED CONTROLS

By E. F. Snyder (Minneapolis-Honeywell
Regulator Co.)

ONE of the advances in architecture which directly concerns the controls industry is the practice of using larger areas of glass in exterior walls. This practice means, first, that our heat transfer factors for exterior walls are different than those encountered in the past. Second, the surface temperatures on exterior walls are different. These two factors alone affect the choice of controls.

Because of the many other factors which contribute to environment in a given space, each room should be considered on its own merits. Anything less requires a compromise with results. In a broad sense, architects and engineers may choose today from pneumatic, electric and electronic controls. Each of these types has certain features which are desirable, but today's architecture has put the spotlight more squarely on the electronic types than on the others, because of the increased need to detect minute changes quickly. Large glass areas do not increase the thermal lag on the exterior wall, but rather tend to increase it. Changes in temperature outdoors are more quickly felt inside, and solar heat is transmitted very rapidly and in large volume through the glass. Such conditions may change the demand from heating to cooling within a single minute, and controls must keep up with these changes.

In addition, the use of larger glass areas causes a considerable variation in interior light levels, due to the variation in outdoor conditions. In order to maintain an optimum condition, it may be necessary during periods of low outside intensity to provide artificial lighting to bring the inside level up to the desired point. Therefore, the control system can not be considered balanced unless we also control interior light intensity. This has been done by means of individually controlled banks of lights parallel to the outside windows in some school rooms, arranged so that those farthest from the windows turn on first. Another method is to modulate the banks by means of saturable reactors so as to eliminate the step effect of the previous method. However, due to the additional cost, modulating control is at present economically practical only for large buildings in which a large number of lights can be regulated from a single control system.

Therefore, the two-position multi-stage control is preferable at this time. With this system, it is feasible to divide the building into zones selected according to exposure to outside light. A photo tube mounted externally facing the same direction as the zone it controls operates through its own independent panel to turn on the lights as required. Such a tube can be mounted internally, but exterior mounting has proven preferable.

In the modulating system, the photo tube located outdoors measures the average light intensity and pilots a saturable reactor or magnetic amplifier dimmer to reduce voltage on inside lamps as required.

A control system, to be complete, must consider and control on a balanced basis all phases of the interior environment. This can not be done economically in all cases today, but as knowledge increases we are drawing closer to perfection.

RESIDENTIAL DESIGN: ARCHITECT'S VIEWPOINT

By William Keck (George Fred Keck, William Keck, Architects)

FROM their crude beginnings as mere holes in the wall to admit light and air, windows have had a complex growth to the point where, today, we can carry our loads from floors and ceilings down on a skeleton type of framework, making the entire outside of the building an envelope of glass, if we so desire.

With the increasing use of glass, the problem of heating as well as comfort becomes an important one. Observations made of the Crystal House built for the Chicago World's Fair in 1933 were the beginning of considerable research by the writer's office on the subject of solar radiation which led to the conclusion that with proper orientation and protection, heating costs should be reduced in spite of increased heat loss through the glass. Thereafter, efforts were made to trap the sunlight and allow it to be converted into heat when it touched the floor or other objects in the house.

With the advent of double glazing in large pieces, it became possible to divorce the functions of light and ventilation for windows. Thus large areas of glass could be fixed and the ventilation supplied through adjacent areas. Glass can now be kept free of screening, and bedroom windows can be brought down to the ground with a reasonable sense of security. The larger windows also make it possible to open the end or side of a room visually, and give a feeling of more space to a relatively small room.

New developments in the future will be determined by the scope of materials available, as well as by the imagination of the designer. As new materials and methods develop, they will, in turn, change our basic planning as it is known today.

RESIDENTIAL DESIGN: RESEARCH VIEWPOINT

By James T. Lendrum, University of Illinois

THE three accepted functions of a window, to obtain light, to provide a view, and to provide ventilation, actually call for vastly different sized areas, located with different and conflicting orientations, and at quite unrelated heights from the floor. Because of our mechanical ingenuity, we have almost eliminated the window as a source of ventilation. While windows are important from a lighting standpoint, they are not indispensable, since they may be replaced entirely by artificial sources. Thus, we are left with only one real reason for using glass in a house, and that is for the vision which it allows.

There are a number of psychological problems connected with the use of glass in residential construction, among which is fear for personal safety, fear of breakage and falling glass. This is one reason many home owners hesitate to accept glass in large, unbroken areas. Window designs developed by the Small Homes Council provide a simple means of overcoming this fear by limiting the maximum piece of glass to approximately four feet wide. The addition of vertical divisions at spaces well within the reach of the outstretched arms of a falling person creates confidence in the mind of one walking near the window. Introduction of horizontal divisions at a point somewhere near the height of a chair seat makes it less likely that a chair will be accidently pushed through the window.

If we accept the premise that the primary purpose of glass areas in a house is for vision, then the problems involved with the interruption of that vision are extremely important. There is nothing more aggravating than a heavy, opaque interruption to the view at eye-level, whether this is a frame, sill, sash, transom bar or any other part of a window. Studies by the Small Homes Council staff established that there are apparently three ranges in which horizontal obstructions to the view are most objectionable. One is at the eye-level of persons standing relatively close to the window, the second of those seated in dining chairs, and the third of those seated in lounge chairs. For kitchen and bedroom windows, only the eye-level of the standing person is of significance, which permits the introduction of one or, if desired, two horizontal divisions without jeopardizing the view. A dining room window with a 2′ 6″ sill can have horizontal rails none of which fall within the limits of a seated person. In the family room or living room the only really satisfactory combination is that mentioned above.

Windows of the type described are finding high acceptance in custom built homes. They need not, of course, be all of fixed glass. The glass sizes are such that, with the exception of the upper section of the living room window, they might all be operated.

The use of building components, systems wherein the window is actually the wall even though it has opaque sections above and below, are the only feasible approach to truly integrated housing. As more and more manufacturers become conscious of the total approach to house assembly, costs can be reduced sufficiently so that every house can have major areas of unobstructed vision, as well as the incidental and collateral advantages of plenty of light and fresh air.

OFFICE BUILDINGS

By Bruce J. Graham (Skidmore, Owings & Merrill)

IN ARCHITECTURE, buildings are forms and structures conceived not by one man, but by many minds and techniques. The concept of the skyscraper has been applied to many functions; hospitals, office buildings, residences, churches, etc. Experience has shown that these functions are interchangeable and buildings first used as hospitals may later be used as office buildings, and vice versa. In any science today, the search for form must be a process of cooperative activity. An office building, then, is not designed for an individual function, since our clients themselves cannot predict what the function within its walls will be ten years hence. The problem of office buildings is primarily a problem of controlled, flexible environment for men.

The materials we use today are changing constantly as new ones make the older ones obsolete. We now have a gray glass to reduce glare, and in the making may be a glass which will also reduce heat loss, and yet be simply fabricated, a transparent reflector. This will change our form, however slightly. There are also many materials being developed for the opaque wall. These in turn must have the same characteristics we are requiring of the glass industry. We are experimenting with a sea of methods and materials for panel construction, such as precast concrete, aluminum, stainless steel, etc. It follows, then, that our building form can be reduced to three basic elements: sun control glass for habitable areas; opaque panels for areas of undesirable view; and structure. The task is one of developing these elements to perfection from the point of view of permanence and cost.

New air conditioning systems are being devised almost for each building. Every new structure is different than the one before it. Lighting is finally becoming a modulator in architecture. The use of lighting in office buildings is being thought of in the same terms as classroom lighting. The distribution of power in office buildings today makes them more than office buildings. There are very few functions that cannot be held within a building of this type. Elevatoring has also made a great contribution to the structures which form most of our cities. The primary limitation on the height of our buildings today is the ability to equip them with elevators. But as these machines develop, limitations of height will change, not because one individual wants to build a big building, but because technology makes this form possible.

By the process of conceiving of the industry as one which builds structures, and not as a group of specialists in a function, we are able to understand best those characteristics which all buildings have in common. And, by studying the various functions, we can develop an interchange of ideas to the benefit of all.

COMMERCIAL INSTALLATIONS

By Morris Ketchum, Jr. (Ketchum, Giná and Sharp)

THE exterior walls of commercial buildings have two functions: to enclose and protect the interior; to admit or exclude vision, light, air and the public. The over-all design of the exterior should, by its form, shape and color, create trade mark identification for the business itself. Another function that it must serve is that of advertising and display. Glass plays a vital part in both advertising and display by making the merchandise visible at the same time as it protects it; by making the store open and inviting; by providing for the admission of natural light in which to view the merchandise.

Transparent glass walls used in stores are usually a single thickness of $1/4''$ plate glass, when panel sizes are not over 12′ in any one dimension. In larger sizes, $3/8''$ or $1/2''$ may be required, which demands specially designed and fabricated glazing members at extra cost. Today, metal glazing members may be of steel, stainless steel, bronze or aluminum. Of these, aluminum is the most reasonable in cost and easiest to maintain, and therefore the most popular. To date the new finishes recently developed for aluminum have not been widely used for storefront design, but they could add much to the charm of the building and would not compete as strongly with the show window displays.

It is preferable to glaze a display case, show window or entire storefront from the outside so that display areas are not disturbed when glass is replaced. Applied glazing moldings for this use are essentially ornamental in character, whereas built-in glazing moldings are used to minimize visually the junction point of the glazed surface with an opaque surface. Flush glazing can be used successfully at the intersection of any glazed surface with an adjacent wall or ceiling, but is impractical for use at the floor line or around all four sides of a glazed opening.

By using a bulkhead combined with sidewall and ceiling glazing members, corner mitres can be avoided and the field assembly of the storefront immensely simplified. In a large, uninterrupted glass wall, it is necessary to use division bars to keep glass panels down to standard size. Vertical division bars in comparatively low storefronts can be kept small and inconspicuous, but where both vertical and horizontal bars must be used, both must be heavier in section and larger in over-all size—the horizontal bars in order to carry the weight of the glass panels; the vertical bars to carry the weight of both horizontal bars and glass panels. Door frames are actually division bars strong enough to take the weight of adjacent glass panels and of one or more doors. Built-in door checks plus a top or bottom pivot have superseded side hinges in the modern storefront design.

In multi-floor commercial buildings, typified by the department store, upper walls seldom need large glass areas. What fixed windows they have, however, should be able to follow changes in location of departments or service elements. To accomplish this, a modular panel wall system is preferable, so that any wall panel can be interchanged with any fixed window panel. This approach adds flexible glazing to flexible planning, to help meet the changing functional demands of merchandising.

SCHOOLS

By Alonzo J. Harriman, Architect-Engineer

LOCAL conditions must be considered in the design of school buildings—social, climatic, financial and other conditions. It is by the complete analysis of the problem through research that the amount of glass in schools should be determined. And, in this large country of ours, the amount and orientation of glass in schools should vary. There is no sense in putting large glass areas in schools where the sun only shines 40% of the time and the daylight hours are less than the school hours. It is equally bad to build an all-glass school in a glaring desert where relaxation comes from shade.

Since the last war, most states have modified formerly strict laws establishing the minimum amount of glass for schools, and today it is only necessary to have enough glass for a pleasant environment. This change in the rules has, of course, made material changes in the use of glass, and we now have some very good schools with interior classrooms.

We have found that the use of double glazing, insulating glass and glass block helps to reduce fuel bills, and that it pays the greatest dividends during the night hours. The hours that the school is unoccupied are apt to be those of greatest fuel consumption, since solar heat and body heat help to offset heat loss from the building during the time the school is in session.

Skylights are now being used successfully in schools, and safety glass has been introduced in a great many places where children and playthings come in contact with transparent or translucent walls. The type of glass varies with the architect and the use, but both safety and tempered are being used. We are now designing a school using tempered, colored, insulated glass for weather protection to replace enameled iron. The insulation is an aluminum coating on the back.

Colored glass is being used for two purposes in schools. One form is the use of glass tinted the color of sun glasses to reduce glare, and the other is the use of panels of colored glass to create colored patterns on the floors and walls of kindergartens and subprimary rooms.

SCHOOLS

By Thomas A. Bullock (Caudill, Rowlett & Scott & Associates)

FROM experience with educators, we know that an educational program cannot be "fenced in," it requires flexibility. The architecture of the school must help the child grow physically, mentally and socially. To do this, it must be healthful, functional, non-confining and colorful. With modern materials and methods we can allow for the fact that space is fluid. With glass and windows, we can provide the classroom with built-in outside learning environment without worry about the complexities of weather.

If we have really explored all the possibilities of this approach and have carried them through to the finished solution, we will have a school with all the advantages of the outdoors, and controls necessary to maintain the desired environment. A look at some of our solutions resulting from the spacial approach reveals a large, floating cover with vertical wall planes slipping into and projecting outside of the enclosed space.

Our experience with glass has been good, but we still have trouble integrating a good heating system in a glass school. The standard question concerning glass breakage has been pretty well answered by the use of tempered glass. We have reason to believe that the larger glass areas are less tempting to break, but the large panes are more difficult to replace in smaller communities. To meet the objections of visual education teachers to outside glass walls, we have designed a "room within a room" . . . a darkened area within the room itself.

When a classroom is a display case, the students' conduct is better, the teachers' morale is higher, and the opportunity for mutual observation helps build a fine competitive spirit between classes.

By Robert W. Cutler *
Skidmore, Owings & Merrill, Conference Chairman

MAN AND GLASS

Glass as a construction material has been closely associated with man's attitude toward his fellow men. In times of stress, little glass has been used. In times of enlightenment or new advancement, glass has been used extensively.

As man emerged from the cave to enjoy the sunshine and eventually find complete satisfaction out of his burrow, he found little use for glass, since the climate and the attitude of his fellow man were quite fulfilling. Barbarianism spread upon the land. Man returned to cavernous fortresses as overlord struggled with overlord for control of the serfdom. Missiles developed. Man crept deeper into the fortifications, which were devoid of all contact with the outside, since little or no friendliness prevailed. Christianity emerged from the catacombs. The printed word extolled the wonders of knowledge as man openly marveled at the magnificent storied windows of stained glass in the great cathedrals. Communication lines were extended. Travelers brought back new philosophies from fabled far-off lands, and a glorious enlightenment spread over the earth to launch the Rennaissance.

Friendly, open-minded man produced glass, a practical material as we know it today. The window became a component part of the monumental structures, and its periphery attained a high degree of studied ornamentation. Man enjoyed a new literary and political status which resulted in a formula for mutual preservation.

As the Nineteenth Century emerged, the industrial revolution quickened the pace. It is quite true that research in missiles produced new sources of human destruction, but men of good will persisted in their efforts to discuss their mutual problems, rather than betake themselves again into the caves.

Material comfort added to this process. The first glass structure heralded the fact that the industrial revolution was in full force, as Paxton built London's Crystal Palace in 1851. Simultaneous with even greater development in missiles, man, because he can look at his fellow man through glass, views with contempt the horrible destruction which may be wrought by the H-bomb. Glass has become a symbol of freedom, of neighborliness. It is quite fitting that the United Nations headquarters building in this time of stress is sheathed in huge expanses of glass. Man is determined that he will not return to the darkness of the cave.

Glass was developed over 3,000 years ago and has served man well in many ways. Because of its demonstrated performance and its unique properties, it will continue to be used in greater quantities, in more ways and in larger pieces than it has in the past.

Because of this evolution in glass, we are here to compare notes, to learn how to make the most satisfying use of this material and of the related accessories and devices. Surely many new ideas will be revealed and many new problems uncovered that will help us all to lift our sights even higher.

---

* Robert W. Cutler is a partner in the firm of Skidmore, Owings and Merrill, architects and engineers. He is an architecture graduate of Syracuse University and is President of the New York Chapter of the American Institute of Architects, a member of the Board of Governors of the Building Research Institute, the Board of Governors of the New York Building Congress, and a member of the American Hospital Association.

PART I

FUNCTIONS OF THE BUILDING ENVIRONMENT

Chairman

Otto F. Wenzler, AIA

Manager of Technical Sales,
Libbey-Owens-Ford Glass Company

By J. W. Griffith *
Southern Methodist University

PRINCIPLES OF DAYLIGHTING FOR BUILDINGS

This paper presents some of the basic principles of daylighting for interiors. Its purpose is to emphasize the available sources of daylight, the requirements of daylight illumination for interiors, and daylight distribution.

Interior lighting employing the use of daylight as a source is a dynamic process and is, therefore, more complex than a static condition. The principles discussed in this paper are primarily unique to the field of daylighting. It must be remembered, however, that the *basic* principles of light are applicable to daylight problems, in addition to the *unique* principles discussed in this particular paper.

SOURCES OF NATURAL LIGHT

The sun is the primary source of all daylight whether it is diffused by atmospheric conditions and referred to as sky light, or reflected from the ground or other areas and called reflected light. The illumination distribution of daylight in buildings varies considerably with both the solar altitudes and the azimuth with respect to the fenestration area. Consequently, the sun azimuth and altitude must be considered in any daylighting design. The sun altitude and azimuth for a particular location at any time of the day and year can be computed by the use of such devices as the Libbey-Owens-Ford sun angle calculator or by tables. (RL20).†

Tables for computing the average solar illumination as a function of altitude are available in the IES Handbook (RL21) and generally the effect of sun azimuth and altitude can be taken into account by the cosine law. Naturally, where the azimuth of the sun is such that no sun is incident on a fenestration area, the only necessary consideration for the effect of the sun is that due to reflected illumination. This effect can also be taken into account by application of the cosine law. For installations where the sun is incident on the fenestration, it generally contributes the greater portion of daylighting on the interior directly. Under such conditions it is difficult to locate the illumination incident on the fenestration from the sun alone and take into account the excessive sky brightness immediately surrounding the sun. Consequently, it is advisable to consider this excess sky brightness as part of the incident illumination from the sun.

The secondary source of daylighting is the sky. It may be an overcast sky, a clear sky with or without sun on the fenestration, or a partly cloudy sky. Typical clear skies are approximately three times brighter at the horizon than at the zenith, while typical overcast skies are just the opposite. The uniform overcast sky has been used in the past for comparison purposes and care should be taken to assure proper usage of this hypothetical condition. Equivalent sky brightness for clear days and average overcast days, as well as typical illumination values for various sky conditions as a function of solar altitude, can be obtained from tables and curves in the IES Handbook (RL18,19). The atmospheric conditions in a particular locality may be such that it would be necessary to take observa-

* James W. Griffith is Assistant Professor of Engineering Research and Director of the Daylight Research Laboratory at the Southern Methodist University School of Engineering. Professor Griffith has degrees in electrical engineering and illuminating engineering. He is a member of the Illuminating Engineering Society and of its Daylighting Committee. He is the United States nominee to the Daylight Working Committee of the International Commission on Illumination and is also a member of the American Society of Electrical Engineers.

† *For Bibliography of Selected References see page 169.*

tions of daylighting conditions rather than typical data. At the present time the actual availability of daylighting on an hourly basis throughout the year is known for very few locations. There is a task group of the IES Daylighting Committee working on this problem and computational techniques or data are forthcoming.

The effect of sky brightness on daylighting illumination is normally taken into account by the incident illumination from the sky brightness for both the direct component incident on the fenestration area, and the reflected portion incident on reflecting areas such as the ground.

Partly cloudy skies are generally taken care of by daylighting designs that are adequate for both overcast and clear sky conditions. If specific consideration is given to partly cloudy skies, computations should be made for combinations of conditions where the sun may or may not be incident on the fenestration and where the sun may or may not be incident on the ground immediately adjacent to the sun fenestration area.

The third source of daylight is the illumination from the ground and reflecting surfaces. If the reflecting surface is above the horizon, the brightness must be considered as part of the sky brightness pattern and diffuse illumination from above the horizon follows a similar distribution pattern.

All illumination from below the horizon can be considered as ground illumination since diffuse illumination from below the horizon follows a similar distribution pattern within the interior. The brightness of the ground or reflecting areas such as concrete walks, light reflecting roofs below fenestration areas, etc. can be computed on the basis of incident illumination from the sun and sky. This source of illumination produces indirect lighting within the room and may or may not be the major source of daylighting. The illumination from the ground may be only a small percentage for bright overcast sky conditions, whereas in the case of clear skies with no sun on the fenestration, bright ground areas can produce considerably more incident illumination on the fenestration area than the clear sky. The immediate ground area adjacent to the fenestration is the most effective portion of the area below the horizon for producing illumination within a building.

Except for the ground area, which is partially shielded by the sill, the closer an area is to the fenestration the more effective it will be in producing illumination within a room, if areas being compared are of equal brightness. In making such computations, it is necessary to consider any shadow effect of the building on the immediate ground area. For overcast sky conditions, or clear sky conditions with no sun on the fenestration, the most effective ground area will be from the fenestration at a point where the shadow effect is adequately reduced.

ILLUMINATION FOR INDOOR SEEING

There are four fundamental factors involved in all visual tasks. These are: size of the task, contrast of the task (brightness or color contrast), brightness of the task, and time available for viewing the task. All of these factors are affected by the amount of illumination on the task. Consequently, in recommending any level of illumination for a task, each of these factors must be considered. It must be remembered that the effects of these four factors are not controlled solely by the physical limits of the task. It is possible to change the size of a task by viewing it at a different angle or to change the contrast by viewing from a position where shadows or specular reflections will either increase or decrease the contrast of a task. It is also possible to decrease the brightness of a task by veiling shadows such as the shadow cast by the individual. Any change of these three factors will affect the time required for vision.

It is obvious that, except where an extensive lighting survey can be made, it is impractical to study each task individually to determine the proper lighting condition for good vision. It is necessary, however, to design a lighting system that permits the worker to perform his visual tasks safely, efficiently, and as comfortably as possible. To insure safety and a minimum level of illumination, many states and counties have adopted performance type codes. Since the requirements for vision vary considerably with different types of tasks, the IES Handbook lists several hundred tasks with levels of illumination that were considered good current practice at the time of printing (RL22).

In using such a table as a guide, one must remember that good current practice does not necessarily mean adequate levels of illumination. Under the section for homes, a footcandle level of forty is recommended for study. If you compare this with the recommended level for study halls and classrooms, you will find that thirty footcandles are considered good current practice. It is rather obvious that students spend much more time studying in schools and there appears to be a discrepancy in the table. This apparent discrepancy is due to the fact that these recommended levels apply only to illumination from artificial sources. The properly designed schools of today are provided with much higher levels of illumination throughout the school day due to the added illumination from daylighting. It is unfortunate that most recommendations are based on artificial lighting alone. Such recommendations are unrealistic and should be considerably higher to conform with good current practice and higher yet for optimum lighting conditions.

Research (RL34) has indicated that relative visual performance increases with higher levels of illumination. This relative performance approaches a logarithmic curve when plotted against illumination in footcandles over a range of one to five hundred footcandles for contrasts of thirty to fifty per cent. More recent research (RL13) has shown that where thirty footcandles may be adequate for the average observer, some observers will require two to three times this illumination level for equal vision. This research also pointed out that people in the age bracket of fifty-six to sixty-five require two to three times as much illumination as a group in the age bracket of sixteen to twenty-five for equal vision. It further shows that people with only a slight degree of subnormal vision (20/25) require a forty per cent increase in the level of illumination to equal the visibility of the so-called normal group with 20/20 vision. People with 20/40 vision required over four and a half times as much illumination for equal visibility with the 20/20 vision group.

It is rather obvious that good visual environment requires much higher levels of illumination than are presently considered as good current practice. It must be remembered that recommended practices are based not only on good current practice, but on what can be obtained at the present time. It would be far more realistic to recommend the levels that would produce efficient, safe, and comfortable accomplishment of visual tasks, rather than abide by current limitations. Since recommended levels of illumination at the present time are generally based on artificial lighting alone, and since most installations throughout the working day have added illumination from daylighting, many so-called thirty footcandle installations appear adequate.

PERFORMANCE TYPE CODES

Recommended practices based on minimums that should be maintained in service may not be adequate for the normal task and should never be incorporated as a code. They are not designed for use as codes, but only as recommendations. By adopting minimum values of illumination based on artificial illumination alone, codes tend to produce poor lighting conditions rather than good illumination. Performance type codes should specify illumination from both artificial and daylighting sources where possible. Codes for conditions where no daylight is available should require considerably more illumination from the artificial sources for good visual environment.

Since World War II performance type specifications have become increasingly popular. Where performance type codes are being designed, it must be remembered that such codes become part of law and should be based on proven facts rather than extrapolated data. It is quite obvious that illumination levels alone are not the basis for good illumination design. However, to date there has been no basis for evaluation of good quality lighting that is applicable to all conditions. It is also obvious that quality and quantity cannot be separated. The so-called good quality of a one-to-one brightness ratio can be obtained with total darkness.

If a glare rating system is being considered in a recommended practice or code, it should be limited to those conditions upon which it was based. To date most glare rating systems are based on small area brightness sources. Glare is a function of the adaptation level, and where large areas of brightness are in the field of view producing higher levels of illumination on the task, the glare rating systems for small area sources are not applicable. At this time, it is premature to try to incorporate a glare rating system into a performance type code.

Naturally, performance type codes are desirable as far as the purchaser is concerned, because it places the responsibility of performance on the designer and builder. It is unjust to saddle a designer or builder with performance type codes that are not practical or proven. Consequently, the old specification type codes, with proven results, are more satisfactory at the present time.

Recommended practices are designed for the use of experienced illuminating engineers and should not be used as "do-it-yourself" instruction manuals. It is quite easy to see where a person inexperienced in the field of illumination might take the school lighting recommended practice of the IES and surmise that since thirty footcandles of illumination are adequate for classrooms, and since classrooms of a particular school are designed to be used only in the daytime, the daylighting should be designed to provide all of the required illumination. The illuminating engineer knows that these recommendations are based on artificial lighting alone, that school tasks need additional illumination from daylighting, and consequently designs installations with this in mind. Mistakes could be eliminated if recommended practices gave not only minimum levels of illumination based on artificial lighting, but minimum levels for daylighting based on the service period of the room and standard, or minimum, daylighting conditions.

DISTRIBUTION OF DAYLIGHT INDOORS

There are three methods of calculating the daylight distribution within buildings. The first and most economical method is by computation using available prediction techniques (RL29,10,9,3,4,30). The second method is measuring the actual distribution of daylight in scaled models of a particular installation under either artificial or natural conditions. This method is more expensive, because the models must be exact scales of the full size room, and it requires considerable equipment for testing. It is the best means for obtaining daylight distribution in rooms that are beyond the scope of prediction techniques, and can be obtained from daylighting laboratories at several universities. The third method of determining daylight distribution is to measure the actual distribution in a room after it is completed. This procedure requires considerable equipment and does not allow for alteration of the design where necessary.

The primary purpose of a prediction technique is to permit the architect and illuminating engineer to compare and study alternative types of daylighting design while the plans are on the drafting table. A few hours of consideration to a particular design can show the advantages and disadvantages of various types of controls, room sizes, reflection factors, and fenestrations. Such studies can produce adequate daylighting design and enable the engineer to design compatible artificial lighting systems.

Regardless of the method used to determine the distribution of daylight within a room, it is usually obtained for evaluation purposes. Before any daylight distribution is used for evaluation, proper consideration should be given to the exterior of the building. The following exterior data should be either measured or computed:

(1) The total incident illumination measured in the plane of the fenestration area or in a parallel plane at the outer edge of any exterior control device. (Recorded simultaneously with each interior reading.)

(2) The incident illumination from the sun only, its altitude and azimuth.

(3) The incident illumination from above the horizontal excluding sun.

(4) The incident illumination from below the horizontal.

(5) The total incident illumination measured in a horizontal plane at an unobstructed position.

(6) Brightness measurements of the sky vault visible from the fenestration.

(7) The average brightness of large area surfaces visible from the fenestration such as ground, concrete areas, or buildings.

Where prediction techniques or model tests under artificial conditions are used to obtain the daylight distribution, the exterior conditions should be computed as nearly as possible to that expected on the particular installation. This includes the orientation of the building and its geographical location, so that several conditions for various times of the year can be considered. Extreme care should be given to the exterior terrain. If proper consideration is not given to the daylight from below the horizon, gross errors may appear in both computation and measurements (RL25). The variability of daylighting necessitates this consideration for each installation. It would be improper to compare overhangs or horizontal louvers for northern latitudes and southern latitudes with the same exterior conditions.

DAYLIGHTING AND CONTROLS

There is no one best daylighting design that fits all conditions. Consequently, it is necessary to analyze various types of fenestrations and controls to arrive at the best daylighting design for a particular installation. In this way the advantages and disadvantages of various designs and controls can be weighed.

Horizontal adjustable louvers such as venetian blinds with clear glass fenestrations provide a high quality and quantity of light on the work plane. They can eliminate direct glare and redirect sunlight into the interior of the room, giving a good distribution of daylight. Indirect illumination from the ground further increases the quality and distribution with properly adjusted louvers. Venetian blinds have a further advantage in that on dark days they may be raised to permit higher levels of daylight illumination. Where horizontal adjustable or fixed louvers are used as an exterior control, they effectively reduce the heat loads for warm climates.

The overhang is a very useful daylighting control device and, like the exterior louver, greatly reduces the heat load for warm climates. A properly designed overhang can provide adequate sun control and allow full utilization of reflected ground light. Solid overhangs, either sloping or flat, provide weather protection in addition to sun control. The louvered overhang is advantageous for non-sun exposures to reduce the shadow effect and redirect sunlight into the interior.

Figure 1.1 shows the comparison of various fenestrations with several types of control. The vertical scale has been expanded for ease of reading. These curves are based on computations for a 30′ x 30′ room with a 12′ ceiling height and a ceiling reflectance of

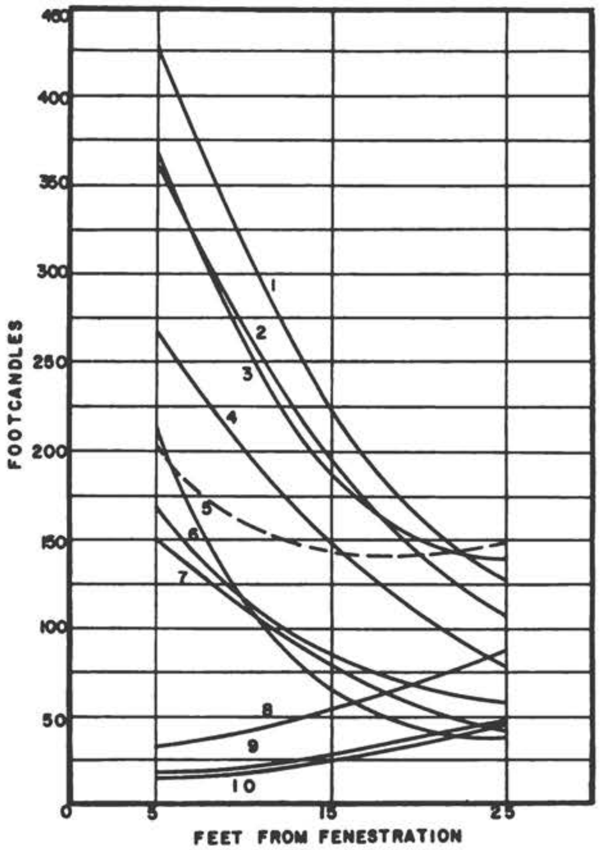


Fig. 1.1—Daylight distribution curves on a thirty-inch work plane.

80 per cent, a wall reflectance of 70 per cent, and a floor reflectance of 30 per cent. Computations were made for a maximum 5 feet in from the fenestration, a mid-point in the room, and a minimum 5 feet from the wall opposite the fenestration area. All of the distribution curves were computed for sky conditions at 11:00 a.m. and 1:00 p.m. on March and September 21st at a 42° latitude with a ground reflection of 20 per cent.

Curves 1, 2, 3, 4, and 7 in Figure 1.1 were computed for a south elevation with a sun at 45° altitude and for window wall fenestrations from a 3′ sill to the ceiling. The sun control in curve 1 was a diffusing shade with 20 per cent transmission. Curves 2, 4, and 7 are for typical venetian blinds adjusted at 30°, 45° and 60° with the horizontal. Curve 3 is for a room with a 9′ solid, horizontal overhang extending out from the top of the fenestration. Curve 6 is the distribution for a north window wall fenestration with the same sun condition and no control. This is a typical clear sky test with no sun on the fenestration. Curve 5 is the distribution for a typical overcast sky with five hundred footcandles incident on the window wall fenestration from the sky and 100 footcandles from the ground. Curves 8, 9 and 10 are for 2′9″ bilateral fenestrations measured down from the ceiling and running the entire length of the room. Curve 8 is the distribution for a south bilateral window for the sun condition with a diffuser of 15 per cent transmission. Curve 9 is the distribution for a north bilateral window with the 45° sun and has no control on the fenestration. Curve 10 is the distribution of an overcast sky with no control on the bilateral fenestration. By adding the effect of the proper bilateral fenestrations to the main fenestration distribution, the total distribution of the multilateral daylighting design can be obtained as shown by the dashed curve for a north window wall and a south bilateral with clear sky condition.

The diversity of illumination from daylight in interiors can be reduced by employing multilateral fenestrations. Bilateral and clerestory fenestrations can provide higher quantities of illumination with lower areas of brightness in the field of view. Consequently, where possible, multilateral fenestrations and large fenestration areas should be employed for better quality and quantity of daylighting.

By Robert A. Boyd *
University of Michigan

DESIGN OF GLASS FOR DAYLIGHTING

The purpose of this paper is to present a complete review of the various types of glass and glass products used in windows, walls or roofs to provide and control the quality and amount of daylight for various purposes and various building types. In doing this it will be necessary to review briefly the various factors associated with the daylighting of buildings.

In any daylighting problem one is involved with three sets of factors; the intensity and variability of the daylight sources, the overall design of the fenestration and the geometry and reflectivity of the interior to be daylighted. The visual environment that results can be evaluated on the basis of quantity of illumination, and quality or control of brightness.

The daylight that is incident upon the exterior surfaces of a building may come from three sources; the sun, the sky and by reflection from the ground and surrounding areas. Generally speaking, however, in daylighting design, major consideration is given to two extreme conditions; sun and clear sky, and an overcast sky. The reason for this is that for sun and clear sky one is principally concerned with control of brightness, whereas, for overcast sky one is concerned with quantity of illumination.

As an illustration of the intensities involved, Figure 1.2 shows a typical variation in normal sun intensity with solar altitude due to atmospheric absorption and scattering. This variation when combined

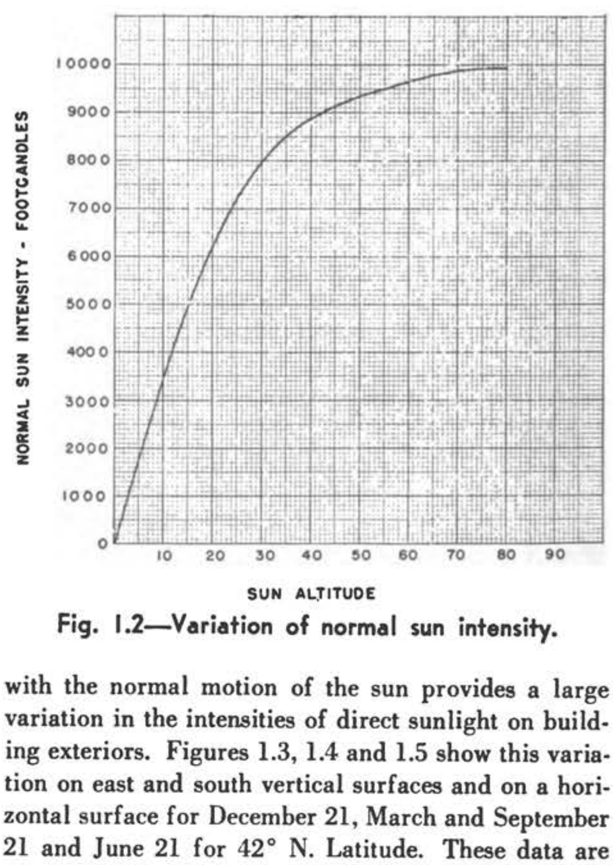


Fig. 1.2—Variation of normal sun intensity.

with the normal motion of the sun provides a large variation in the intensities of direct sunlight on building exteriors. Figures 1.3, 1.4 and 1.5 show this variation on east and south vertical surfaces and on a horizontal surface for December 21, March and September 21 and June 21 for 42° N. Latitude. These data are presented in this form because the intensities for direct sunlight and the corresponding sun positions are directly involved in any daylighting problem. Of course, one must also consider the supplementary intensities due to light from the sky and the surroundings, but they are of secondary importance from a brightness standpoint.

Figures 1.6 and 1.7 show typical exterior illumination conditions for over-cast sky as recorded for Ann Arbor, Michigan, on February 23, 1951. In these cases

* Robert A. Boyd has been a research physicist at the University of Michigan since 1940. He is a graduate of Carleton College, holds a Masters degree from Washington University and a Ph.D. from the University of Michigan. He has also been an instructor in physics at Western Reserve and Cleveland Universities, and is a member of the Illuminating Engineering Society and the Optical Society of America.

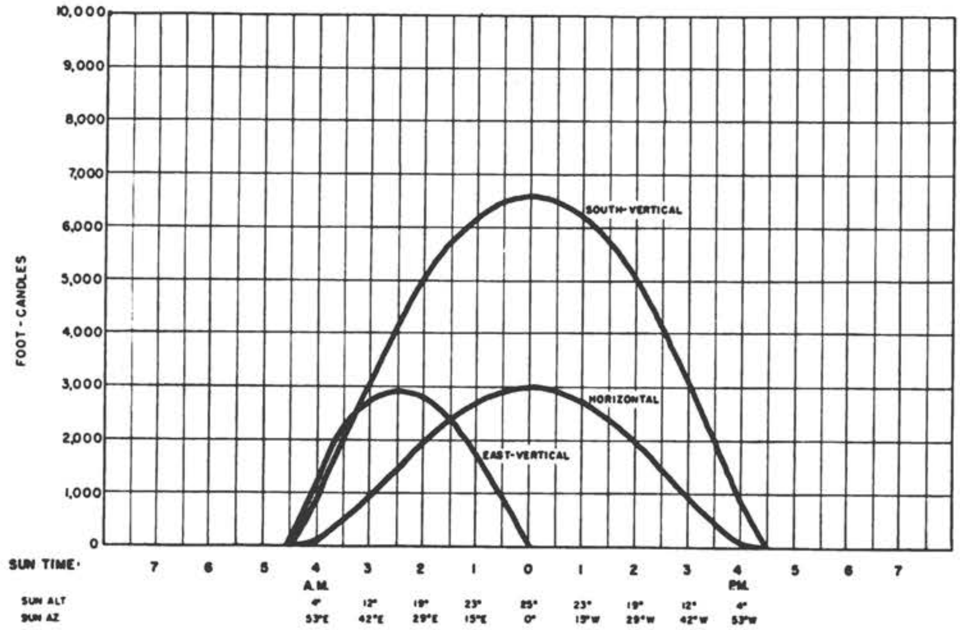


Fig. 1.3—Direct sunlight incident, 42° N. latitude—December 21.

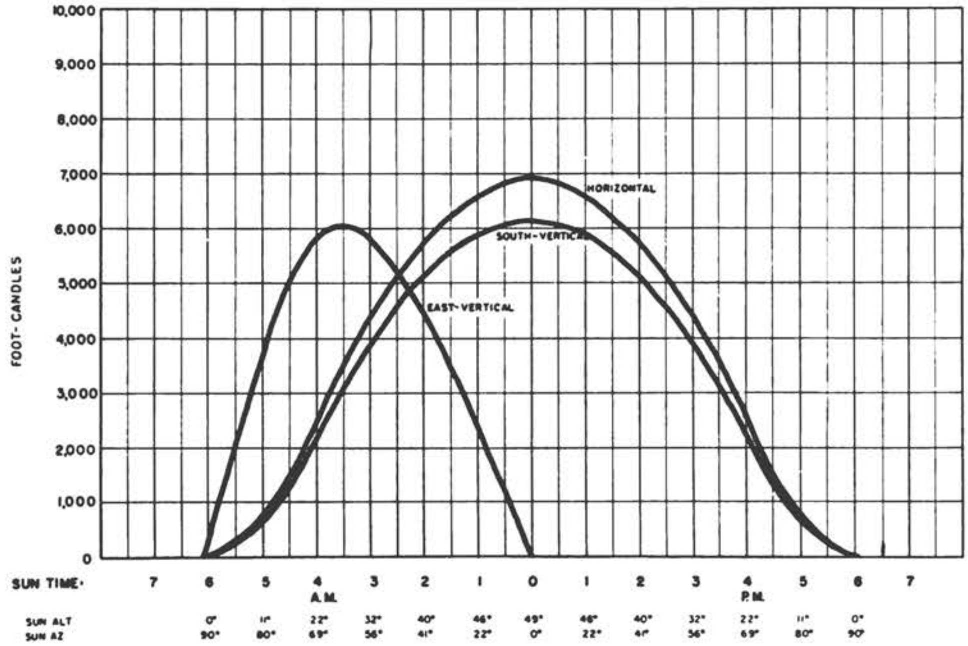


Fig. 1.4—Direct sunlight incident, 42° N. latitude—September 21 to March 21.

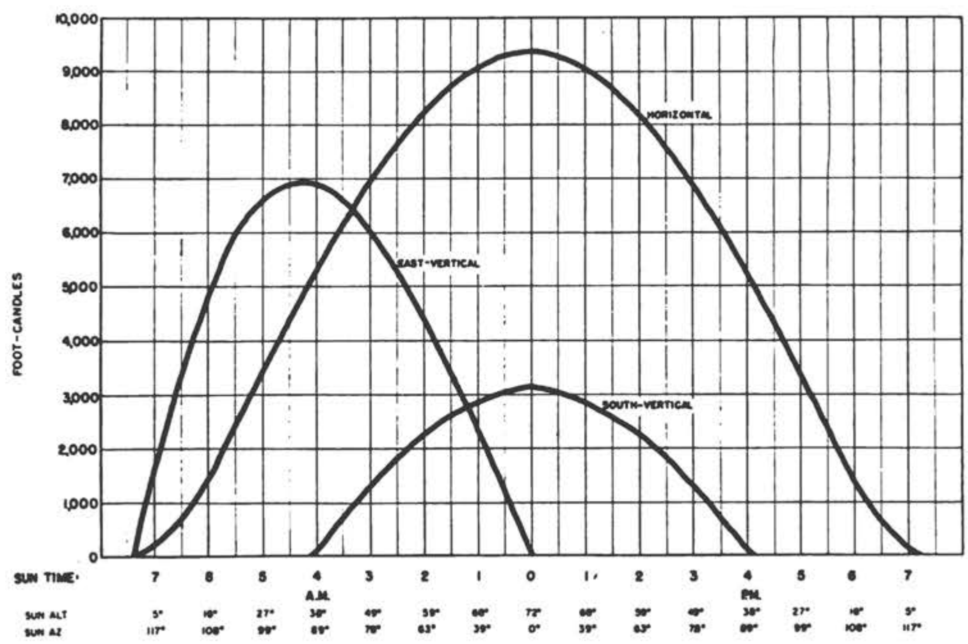


Fig. 1.5—Direct sunlight incident, 42° N. latitude—June 21.

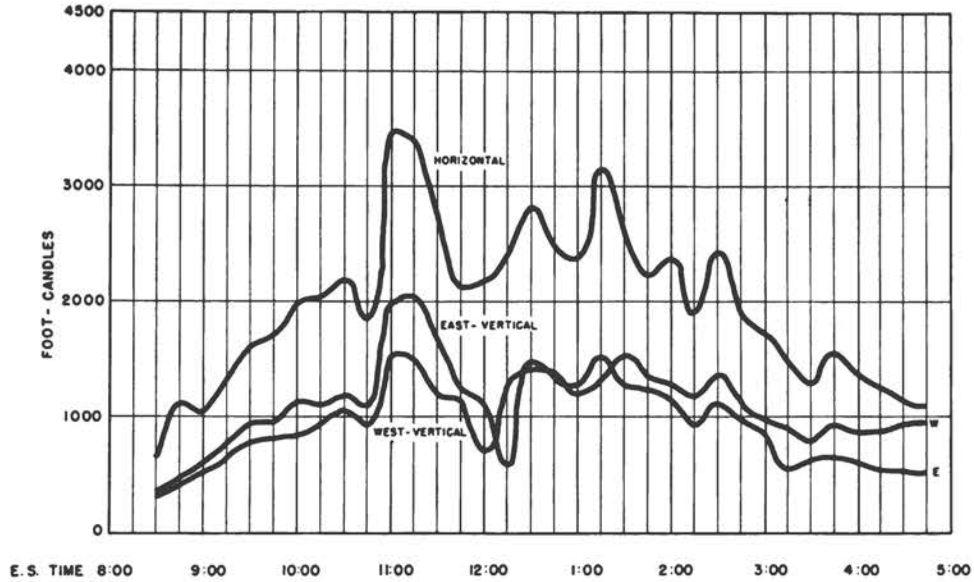


Fig. 1.6—Exterior illumination, east-vertical, west-vertical, overcast sky, foreground reflectance 20%—Ann Arbor, Michigan, February 23, 1951.

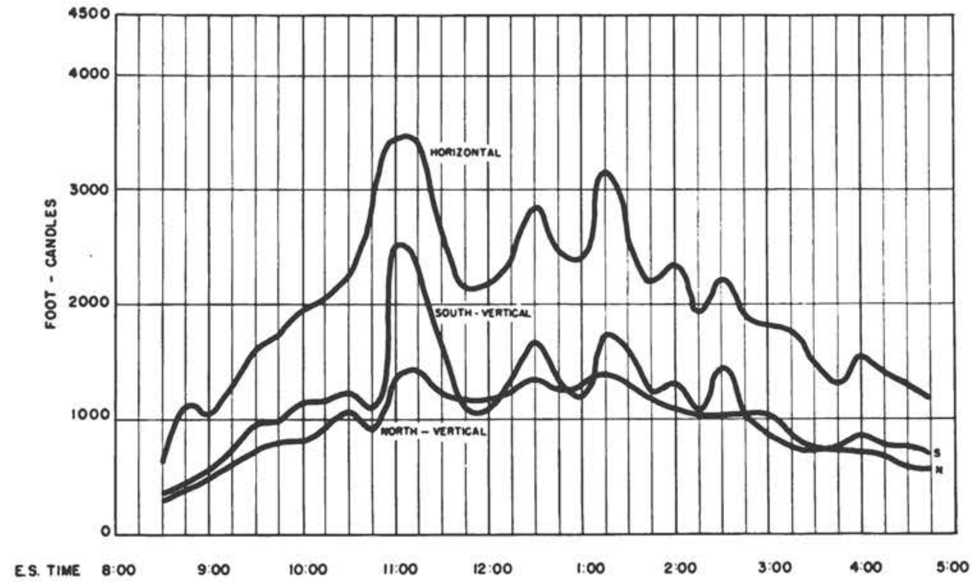


Fig. 1.7—Exterior illumination, south-vertical, north-vertical, overcast sky, foreground reflectance 20%—Ann Arbor, Michigan, February 23, 1951.

the illumination component due to ground reflected light has been included.

These data are given only as a guide in the discussion of fenestration materials. More extensive and detailed meteorological data are contained in the literature (RL41,7,40,42,39,6,12,35,8).†

Fenestration materials are most readily separable into two groups, those that allow clear vision to the exterior and those that are obscuring; Table 1 shows the representative materials constituting these two groups and where they are most frequently used in a building.

The light that is incident on a glass unit is separated into a reflected component, an absorbed component and a transmitted component; the absorbed one being converted into heat. It is difficult to refer to a single transmission figure for fenestration materials since the percentage transmission, in general, depends upon the angle of incidence of the light. It is general practice, however, to give one figure for a collimated beam of light incident normally, this figure being representative for direct sunlight, and a second figure for light from a diffuse source such as an overcast sky. Table 1 also gives a range of percentage transmission for a collimated beam of light, for the materials in each group. The percentages of transmission for light from an overcast sky may be as much as 20 per cent lower than those for a collimated beam, depending upon the structure of the material.

For clear vision materials the light reflected to the

† *For Bibliography of Selected References see page 169.*

TABLE I

Fenestration Materials	Use *	Range of Transmission **
A. Clear Vision		
1. Clear Window Glass	W	90–92
2. Polished Plate Glass	W	90–92
3. Tempered Plate Glass	W	90–92
4. Heat Absorbing Glass	W, S, C	75–83
5. Glare Reducing Glass	W, S, C	45–68
6. Glass Block	Wa	81-85
7. Double Glazing Units	Wa, W	81-85
8. Triple Glazing Units	Wa, W	73–78
9. Wired Glass	W, S, C	72–84
10. Filter Glass	W, V	12½–35
B. Obscuring		
1. Hammered Frosted Heat Absorbing Glass	W, C	36-58
2. Hammered Heat Absorbing Glass	W, C	53-63
3. Wired Heat Absorbing Glass	W, S	— —
4. Frosted Glass	W	63–76
5. Patterned Glass	W, C	52-92
6. Double Glazing Units	Wa, W	56–76
7. Patterned Sandblasted Glass	W	36–77
8. Prismatic Glass Block	Wa, C	40–50
9. Diffusing Glass Block	Wa, C, R	40–50
10. Decorative Glass Block	Wa	70–80
11. Solar Selecting Glass Block	Wa, Rs	20–40

*Code: W —Windows
Wa—Walls
C —Clerestories, monitors and saw-tooth
S —Skylights
R —Roof-panels
Rs —Prefabricated roof-panels
V —Vision strips

** Per cent—Normal Incidence

exterior, for direct sunlight at or near normal incidence, is 4 to 8 per cent. For obscuring materials the reflected component may be as high as 60 per cent for direct sunlight having angles of incidence 0 to 60 degrees. The difference between 100 per cent and the sum of the reflected and transmitted components is, of course, the absorbed component.

The percentage transmission does not in itself predict the effectiveness of the material in providing adequate and acceptable daylighting. In addition it is necessary to have information on the diffusion of light and brightness of the material, or of the views through the material.

In the case of clear vision materials the brightness of the view depends upon the absorption of the glass. Typical maximum exterior brightnesses are; up to 7,000 footlamberts for clear sky in the vicinity of the sun, an average of about 2,500 footlamberts for an overcast sky, up to about 7,000 footlamberts for a white-sunlight building, and the sun has an actual brightness of several hundred million footlamberts. Reference to Table 1 indicates that these brightnesses will be reduced from 10 to about 90 per cent depending upon the material used. However, these materials, because they allow clear vision to the exterior, admit the light from the sun and sky into the interior in a downward direction. This is inefficient from a lighting point of view, since a high percentage of the light is absorbed by the floor, furniture and room occupants before it is scattered about the room and, in addition, high intensities on some of the room surfaces may cause reflected glare.

Whereas clear vision materials provide little or no diffusion for the transmitted light, the obscuring materials are designed to provide a wide range of diffusion patterns. In these cases, since the brightness relates to the material rather than the exterior view, it is necessary to refer directly to the amount of light incident on the exterior. Reference to Figures 1.3, 1.4 and 1.5 indicates that exterior intensities due to direct sunlight may be as high as 6,900 footcandles for a vertical surface and 9,000 footcandles for a horizontal surface. The supplementary illumination due to light from the sky will be of the order of 1,000 to 2,000 footcandles.

As an illustration of how increase of diffusion reduces maximum brightness, consider two sheets of obscuring material, one being a perfect diffuser and the other an average obscuring material, each transmitting 55 per cent of the light that is incident normally in a collimated beam. The brightness distribution of each material, per 1,000 footcandles of incident illumination, is shown by Figure 1.8. It is apparent that the smaller the angle of scattering the greater the maximum brightness per lumen of transmitted light. One observes that the ratio of maximum brightness of the average obscuring material to that of the perfect diffuser is about 8.4 to 1. The perfect diffuser is simply used to show the extent to which brightness can be reduced by an increase in diffusion; actually there is no material manufactured that can be classified as a perfect diffuser, although solid opal glass and diffusing glass block are "near" perfect diffusers. As regards the magnitude of the brightness for direct sunlight, for an incident illumination of 9,000 footcandles a brightness of 40,000 footlamberts is easily obtainable with some obscuring materials. For prismatic glass block incorporating specific control prisms a maximum brightness of 2,000 footlamberts is typical.

It is characteristic of single sheet obscuring materials to provide scattering of the transmitted light within a relatively small cone having the direction of incidence as an axis. This, since the direct sunlight on the exterior is incident from directions above the horizontal plane, means that the direction of maximum brightness is one easily encountered by the observer. On the other hand, as a class of fenestration materials, prismatic glass block have been designed for use in walls of buildings which redirect the transmitted light to such an extent that the major portion of the light enters the interior above the horizontal plane. Thus, with the

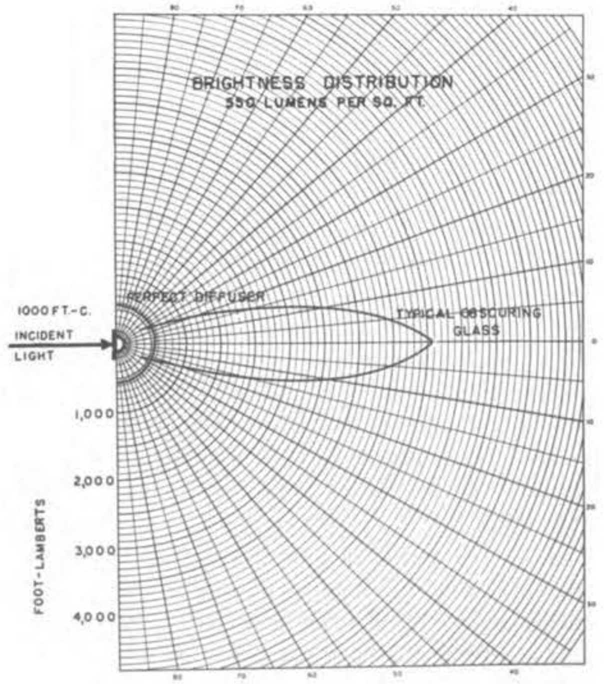


Fig. 1.8—Brightness distribution, 550 lumens per sq. ft.

directions of maximum brightness being above the horizontal, the higher brightnesses are not usually encountered by the observers when the block are installed above eye-level.

The diffusing type glass block belongs to this same class of fenestration materials. Through the use of prisms and diffusing ribs the light is quite uniformly transmitted in all directions, consequently in performance it is similar to a perfect diffuser.

Decorative glass block are manufactured with many different patterns and are suitable for use on non-sun exposure. When used on sun exposure, they usually require some type of brightness-control device.

The fourth type of glass block has been designated as solar-selecting. This type should be considered separately since as a fenestration material it incorporates an entirely different principle than is employed in single sheet obscuring materials and prismatic glass block. Reference to Figures 1.3, 1.4 and 1.5 indicates that there are two major variations in the intensity of direct sunlight. The first is the daily variation for any particular surface as shown by all of the curves and the second is the yearly variation of the daily maximum values for a particular surface. As an example of this latter variation, one can observe from Figures 1.3, 1.4 and 1.5 that for a horizontal surface the daily maximum value varies from 3,000 footcandles on December 31 to 9,380 footcandles on June 21, whereas, for a south vertical surface it varies from 6,600 footcandles on December 21 to 3,140 footcandles on June 21. To a large extent, with clear vision materials and obscuring materials, except solar-selecting glass block, these variations are retained in the amount of light transmitted by the materials and in the brightness of the materials. In addition to these variations in the daylighting being somewhat undesirable, the high illuminations and brightnesses corresponding to the maximum exterior intensities are unnecessary, since there is more than enough light at these times. Increasing the density of the materials to reduce the transmission and brightness for the maximum conditions to desirable values would not alter the variations and, in addition, would reduce the transmission of daylight for the less severe exterior conditions to undesirable levels.

The fourth type of glass block, through the use of prism combinations in the outermost layer of glass, is capable of reflecting as much as 60 per cent of the sunlight incident from particular directions away from the outside surface. For other sun positions the reflection is considerably less. This type of glass block is manufactured for use in wall fenestrations to discriminate against sun positions near 45 degrees altitude, and for use in roof installations to discriminate against sun positions near 60 degrees altitude. Due to

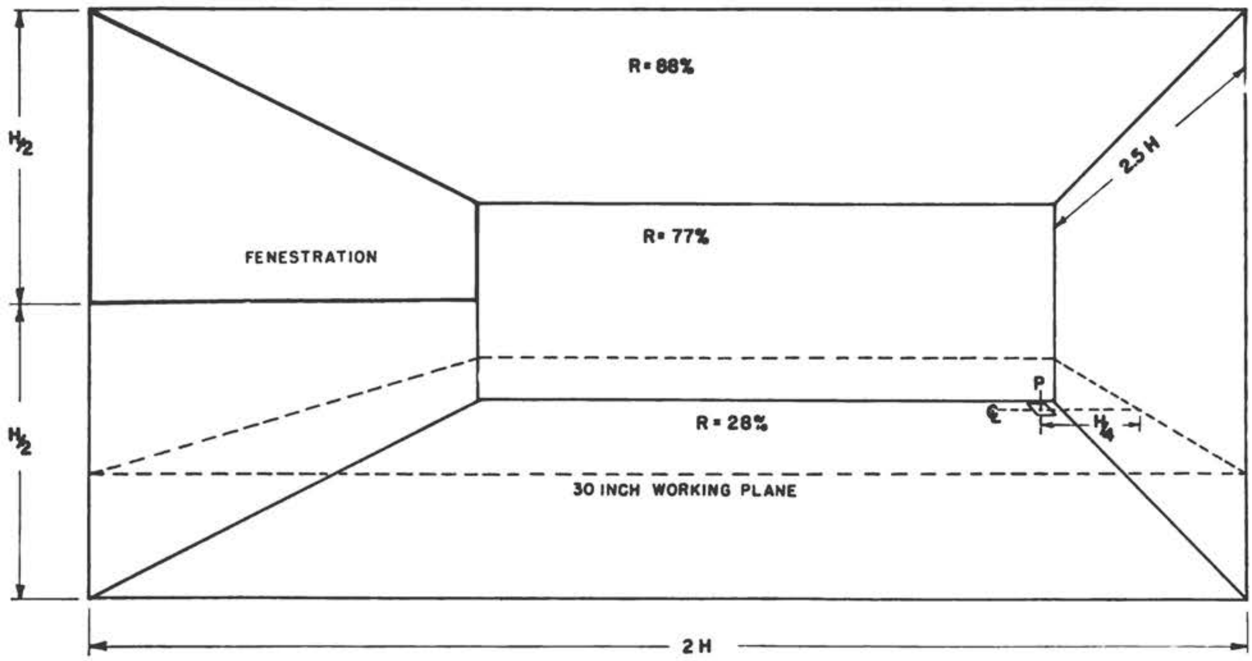


Fig. 1.9—Unilaterally daylighted room.

this type of reduction in transmission the maximum "observer" brightness for the most severe sun conditions is about 2,000 footlamberts. For the majority of sun conditions the brightness is considerably less.

Having briefly reviewed the transmission characteristics of the various types of fenestration materials, the next step is to consider the quality and quantity of daylighting when the materials are used in various types of interiors. The materials have actually been divided in three more or less separate classes depending upon the type of diffusion; little or no diffusion for clear vision materials, moderate diffusion for typical obscuring materials and extensive and particular diffusion as shown by functional glass block.

It is impossible in a paper of this length to give detailed information on the daylight that results when each of these materials is considered in connection with the many different fenestration arrangements employed in the various types of buildings. One way to present the relative performance of the three types of materials is to consider each of them as constituting a fenestration in a particular building type.

Possibly the most common type of interior, when all buildings are considered, is the unilaterally daylighted room. Such a room is shown by Figure 1.9 where the fenestration is considered to occupy the upper half of the outside wall and the room depth is equal to twice the ceiling height. For any type of fenestration material the amount of daylight reaching any point on the working plane can be considered in two parts; the direct light from the fenestration and the light multiply reflected from the room surfaces. Methods have been developed that allow the calculation of each of these two components (RL5,14-16,23, 24,26-28,31). In the Daylighting Laboratory at the University of Michigan models have been used with an artificial sun and sky, as well as with natural sources, to collect such data.

In any daylighted interior reference is usually made to the poorest lighted task and the brightness of the fenestration as viewed from that task. In Figure 1.9 consider that P is such a task. According to the theory of surface sources, if the fenestration has an average brightness of B footlamberts and all the remainder of the room surfaces above the working plane have an average brightness of B′ footlamberts, as viewed from P, then the illumination at P is given by $E = 0.025\,B + 0.975\,B'$ (Ft.C.).

Some evaluation of the quality of the daylighting can be obtained from the ratios B/E and B/B′; the lower the ratios the higher the quality of the lighting. In giving the comparative figures for the three general types of fenestration materials, and for a "near" perfect diffuser, it has been assumed that the average value of B is the same for each, namely 1,000 footlamberts. On this basis, the results are as follows:

Material	0.025B	E	B′	B/E	B/B′
Clear Vision	25 Ft.C.	65 Ft.C.	41 Ft.L.	19	31
Typical Obscuring	25	45	21	28	60
Prismatic Block	25	105	82	10	12
"Near" Perfect Diffuser	25	95	72	13	17

For single sheet materials requiring window frames it has been assumed that 80 per cent of the entire fenestration area is free glass. The figures for the clear vision materials are typical for exterior conditions not involving direct sunlight. The remaining figures are typical for direct sunlight. With direct sunlight on the clear vision materials the interior illumination is considerably higher than indicated, but some type of brightness control is usually required. Most obscuring materials with no direct sunlight will perform similarly to clear vision materials with no direct sunlight. Prismatic glass block, by virtue of the design, provide the same type of performance for all exterior illumination conditions.

Since the "observer" brightness is the same in each case, these data serve to show the effect that the brightness distribution pattern of the fenestration material has on the quality of the lighting; the "near" perfect diffuser with a uniform distribution of brightness and the prismatic glass block with maximum brightness in directions toward the ceiling and upper walls giving the higher quality daylighting. It will also be observed that the increase in illumination due to multiple reflections is greater in the cases of better diffusion.

Unilaterally daylighted rooms similar to the one shown by Figure 1.9 are common for multi-story office buildings, single story and multi-story schools and similar structures.

In many single story buildings various types of secondary fenestrations have been used to raise the minimum illumination and consequently improve the quality of the daylighting. It is impossible to discuss in detail the complete fenestration systems utilizing the various types of secondary fenestrations, such as clerestories, monitors, saw-tooth units and skylights. However, two general types of interiors will be discussed briefly.

Figure 1.10 indicates a common classroom interior wherein the room is square and has a depth equal to 2.5 times the ceiling height. The specific dimensions given can, for the most part, be ignored in this consideration. The room surface has been divided into specific sections, as designated by A, B-I, and a factor has been calculated for each section which is the ratio of the illumination at P (Ft.C) to the average brightness (Ft.L) of the section as viewed from P. Generally sections A and B constitute a main fenestration. In some cases B is a glass block panel and A is a vision strip glazed with clear flat glass or a filter glass, while in other cases both A and B are clear flat glass.

In any case, if both A and B are assumed to have an average brightness of 1,000 footlamberts the direct light reaching P is only 16.5 footcandles and, when the component due to multiple reflections from room surfaces is added, the total illumination may be less than the minimum required and certainly the ratio of source brightness to task illumination will be higher than is recommended. Consequently, it has been general practice to utilize a secondary fenestration in such a case. Clerestories have been used, having a position such as section F, or a position with opposite exposure such as between E and D when E is at a greater height. More recently, because of lower costs and simpler construction, ceiling panels consisting of solar-selecting and diffusing glass block and skylights glazed with various types of obscuring glass have been used in areas similar to section E. From a daylighting point of view, ceiling panels have several advantages over a clerestory arrangement.

Clerestories receive their light from only half the

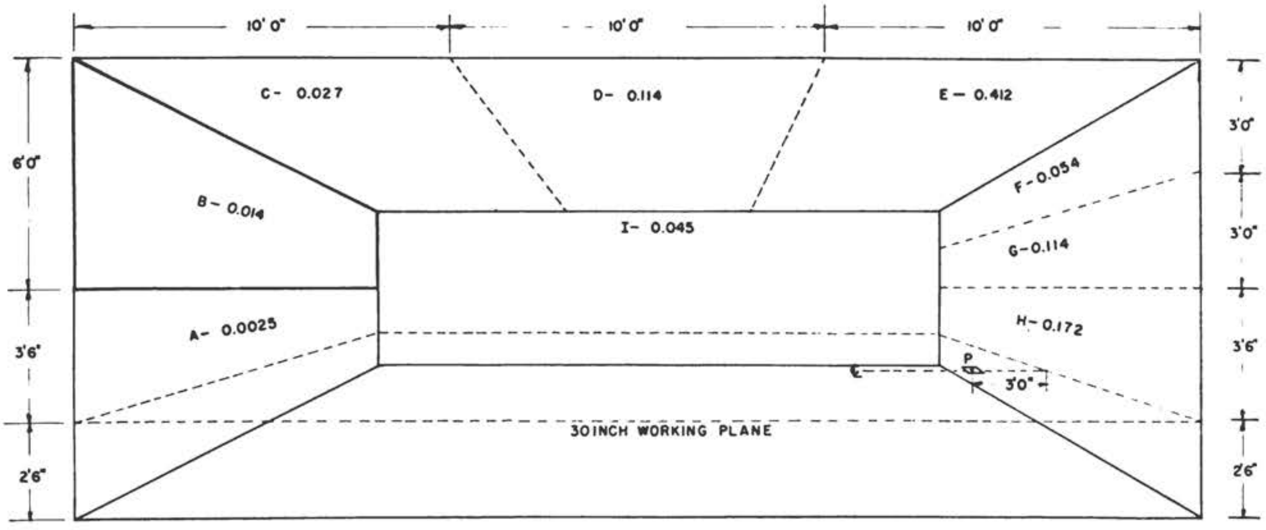


Fig. 1.10—Common classroom interior.

total sky, whereas, ceiling panels are exposed to the entire sky. Thus, the transmission of light through the latter is much more uniform, in general, over a period of one day or one year. This uniformity is further increased when solar-selecting glass block are used since they are designed to have an unusually low percentage transmission when exterior intensities are at a maximum. On an overcast day, as shown by Figures 1.6 and 1.7, the exterior illumination of a horizontal surface is about twice that of a vertical surface. In a consideration of adequate interior illumination for times when the exterior illumination is low, this is of major interest.

As can be seen from Figure 1.10, there is another disadvantage of the ceiling panel in that the illumination factor for section E is substantially larger than for section F. In fact, the illumination factor for section E is too large, so in practice, only a por-

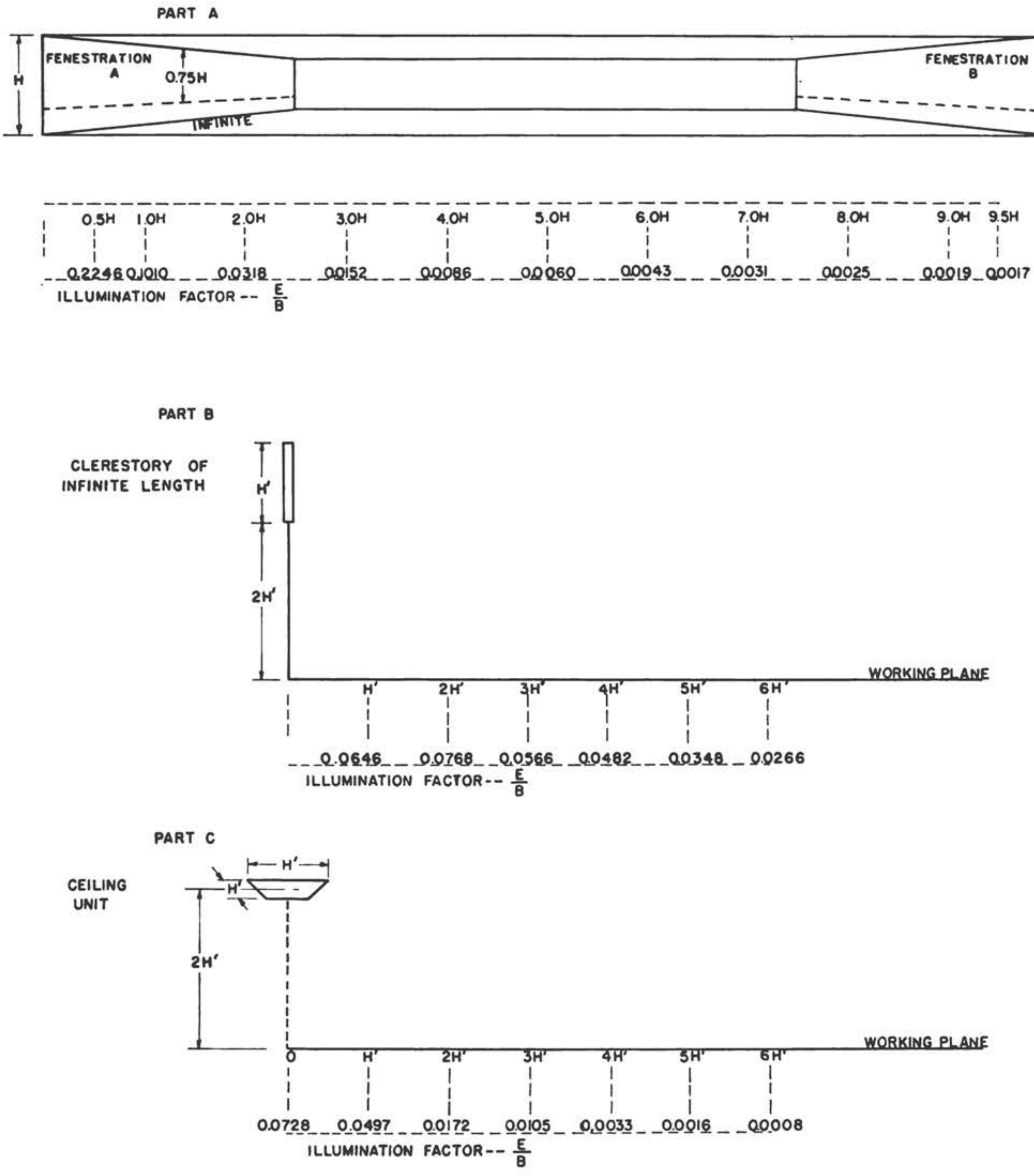


Fig. 1.11—Factory type interior.

tion of E is used as a ceiling panel. As an illustration of the effectiveness of such a secondary fenestration in improving the quantity and quality of the daylighting, consider that only one-quarter of section E is a ceiling panel or skylight, that the illumination factor is 0.103 and that the brightness from P is 1,000 footlamberts. Then the supplementary direct light at P is 103 footcandles or, with the direct light from sections A and B, the total direct illumination at P is 119 footcandles. Consequently, the ratio of brightness to illumination, even without taking into account the light due to multiple reflections, is adequately low.

This type of classroom is associated with both single and double-loaded corridor arrangements. Many times in double-loaded corridor situations, sections F and G consist of clear glass or obscuring glass in order to daylight the corridor by borrowing light from the classrooms.

The second general type of interior to be discussed is the one shown by Figure 1.11, where the distance between outside walls is large compared to the ceiling height. Part A shows how the illumination factor decreases with increase of distance from fenestration A. In calculating these factors it has been assumed that the length of the room is infinite; this does not introduce an appreciable error for a large room. These factors indicate that when the distance from fenestration A is more than two or three times the ceiling height, or the distance between fenestrations A and B is more than five to six times the ceiling height, supplementary daylighting is required.

The secondary fenestrations, when the structure of the building will allow, are represented by Parts B and C of Figure 1.11. In Part B the clerestory, saw-tooth or half-monitor is considered to be infinite in length, since they usually extend the full length of the building, and the illumination factors were calculated accordingly. In Part C the ceiling panel or skylight is shown to be square; the illumination factors being for the finite size.

It is common practice in monitor construction to make the high and low bays the same width, the width being one to two times the ceiling height of the low bay. Obscuring glass, heat-absorbing glass, clear vision materials and prismatic glass block are frequently used in these cases. The prismatic glass block, in lighting the ceiling of the high bay, provides a higher percentage of scattered light than the obscuring glass.

In saw-tooth construction, which is frequently used on north exposure, the spacing is one to two times the ceiling height. Diffusing glass block, obscuring glasses and clear vision materials are frequently used as fenestration materials in these cases.

Ceiling panels fall into three distinct classes; skylights utilizing wired heat-absorbing glasses and obscuring glasses, diffusing glass block set into a reinforced concrete slab and prefabricated panels of solar-selecting glass block. Such panels are many times used in a checker-board pattern with the total area equal to 10 to 20 per cent of the floor area.

To a large extent the uniformity and intensity of the interior daylighting for a proposed fenestration arrangement can be estimated by using the data given by Figure 1.11. The added illumination resulting from multiple reflections will be approximately the same for all areas of the working plane and, in the case of a well-decorated interior, may equal 60 per cent of the direct light.

As mentioned previously, the quality of the daylighting is dependent upon diffusion and control of brightness. More specific information on the properties of the glass can be obtained from the manufacturers.

Discussion Period—DAYLIGHTING

MR. WENZLER: What was your source material for the effect of lower intensity illumination on loss of the tension, the effect on the heart action and the effect on blinking of the human eye?

PROFESSOR GRIFFITH: That material was based on research that has been done at General Electric, I think by Syl Guth. The slides were furnished me by Walker Sterling of General Electric.

MR. WENZLER: With human specimens?

PROFESSOR GRIFFITH: I'm not sure. I made reference to the actual paper I took that from, and I'm not sure they mentioned in that the exact number they used in that demonstration. It was published in the IES under the title, "Footcandles for the Forgotten Man."

R. L. CLINGERMAN (William Bayley Co.): For the benefit of those who are not IES members, explain the difference between footcandles and footlamberts.

DR. BOYD: This question always comes up, of course, when you're talking to people who are not versed in our terminology. If you take one footcandle of illumination and reflect it from a perfectly diffuse surface, that is, having a reflectivity of 100 per cent, and it is reflected in such a way that the brightness of the surface is the same for all directions and view, then that brightness will be one footlambert. Likewise, in transmitting one lumen per square foot through a surface if it is transmitted so as to have perfect diffusion, then the brightness of the surface will be one footlambert.

M. D. FOLLEY (Architect): Diffusion-type materials transmit only a fraction of that of clear glass or even of an unglazed area. But does not the glare factor increase with diffusion type of materials?

DR. BOYD: That was one thing that I tried to point out. If you think in terms of a ratio of brightness to illumination as it is provided in an interior, then the ratio for a diffusing type of material would be higher than for clear-vision materials for the same footcandle illumination incidence.

Now, of course, that answer has to be modified a little bit on the basis of how wide a diffusion you have. Obviously, if you go to something like a perfect diffuser, then eventually you will get to the other side where your brightness ratios are better. But for the most part, with the obscuring materials available today, the first answer is correct, and that is that your ratios will be higher.

J. R. BEAUJON (Procter & Gamble): What is the importance of interior decorations to the quality and quantity of daylighting? Can one design for this?

PROFESSOR GRIFFITH: The interior decorations, the reflection factors on the walls and any equipment in the room necessarily determine the brightness in the field of view. In designing prediction techniques we have taken into account and applied the techniques over a wide range of brightness conditions, or rather reflection factors, in the room, which in turn cover a wide range of brightness conditions. You can design for it by using the variations of wall reflectances on your room surfaces and compute the incident illumination on the work plane with the various reflectances. As yet we have not designed a prediction technique that covers all of the room surfaces, so that the entire field of view cannot be predicted at this time.

W. H. SCHEICK (Building Research Institute): Are the speakers willing to comment on reasons for obtaining visual levels by daylight, rather than solely by artificial illumination?"

DR. BOYD: In talking about daylighting, the question always comes up; What are the advantages of daylighting? I think the first one is the variability of daylight. All of us are averse to stacked conditions, and I believe we feel that way with regard to lighting. We like the variability of illumination that results from daylighting. The second is that as yet the electric lighting people have not developed an artificial lighting source that has the same color, temperature, or the same spectral distribution as daylight. In using daylight you see colors, and the reflection from objects is much more realistic than it is with the use of comparable electric lighting sources.

PROFESSOR GRIFFITH: I agree completely with Dr. Boyd. Dr. Weston over in England brought this out about two years ago in a paper before the IES in which he posed the problem to the artificial lighting people asking them to see if they could design artificial lighting so it would have this built-in variability. He thought it would appeal more to the individuals in the room. Also, in using daylighting, you normally have clear-vision strips, and these strips allow the eye to become rested when it is fatigued from close work. As you work with close objects the curvature of the lens in your eye is tightened so that the muscles holding this curvature become fatigued over a period of time. You can get away from this fatigue by shutting your eyes and letting your muscle tension relax. This takes a little longer, though, than if you look at a far-off object outside a window or something twenty to forty feet away.

A. L. JAROS (Jaros, Baum & Bolles, Consulting Engineers): Do you have data as to ratio of reflected visible light and reflected infra-red heat from ground surfaces?

PROFESSOR GRIFFITH: I don't have this information with me, and I'm not sure that it is available. It could be obtained, but just at the present time I can't think of a source where it is available.

H. E. TWIETMEYER (Johns-Manville Corp.): What method of brightness control do you recommend for partly cloudy days when the sun comes out from behind the clouds and is again obscured?

DR. BOYD: This, as far as fenestration design is concerned, can only be done on the basis of design for direct sunlight and design for diffused light. The work that we have been doing at the laboratory in recent years is involved with prismatic design that discriminates against certain sun positions; that is, by prism control it is possible to reflect the direct sunlight, and consequently to direct solar heat away from the outside surface. This same design that discriminates against direct sunlighting also increases the transmission of light from other portions of the sky, as well as light reflected from the ground. By design the materials have a different transmission for direct sunlighting and for light from some of the outlying portions of the sky and light reflected from the ground.

ASHAE RESEARCH AND PRINCIPLES OF HEAT TRANSFER THROUGH GLASS FENESTRATION

By Donald J. Vild *
Libbey-Owens-Ford Glass Company

The proper solution of any air conditioning or heating problem depends upon accurate prediction of the cooling and heating loads likely to be encountered. Often an important factor in this evaluation is the heat transfer through the fenestration. For many years air conditioning engineers were forced to approximate this vital component. With the advent of increased use of air conditioning this situation constituted a major deterrent to correct design. About a decade ago, as a major step in its policy to assist the air conditioning industry, the American Society of Heating and Air Conditioning Engineers instituted a research program to obtain information to fill this void. This program was initiated by the ASHAE Technical Advisory Committee on Heat Transfer through Fenestration, whose purpose is to guide the research. All research has been executed at the Research Laboratory of the ASHAE in Cleveland, Ohio. Financial support of the program has come from glass-producing firms, membership dues, and manufacturers, consultants and others directly interested in particular phases of the research.

Initially the research was to cover the more common types of flat glass and glass block. Since its beginning, the scope has expanded to the point where virtually every type of day-lighting fenestration is planned for investigation. The ultimate goal is to provide air conditioning engineers with reliable design data for all types of fenestration.

Below is a list of past ASHAE research on fenestration:

(1) Heat Transfer through Flat Glass (2 papers).
(2) Heat Transfer through Double Flat Glass.
(3) Over-all Coefficients for Flat Glass.
(4) Solar Energy Transmittance of Glass Blocks.
(5) Solar Energy Transmittance of Figured Rolled Glass.
(6) Shading of Sunlit Glass (3 papers).
(7) Heat Transfer from Skylight Fenestration.

Presently, canvas awnings are being studied and shading devices between two lights of glass are planned for the near future. Subsequent research will be dictated by the needs of industry. In all, there have been ten research papers dealing specifically with heat transfer through fenestration. The information in these papers has been reviewed and condensed by the Technical Advisory Committee and compiled into convenient tables in the ASHAE Guide. These tables enable the air conditioning engineer to predict quickly the total instantaneous heat transfer for combinations of fenestration design, climatic conditions, orientation and location.

PRINCIPLES

Heat transfer through fenestration is dependent upon a combination of meteorological conditions, fenestration design and orientation, the nature of the surroundings and, to some extent, the indoor conditions. The indoor air temperatures for an inhabited structure are generally assumed as 80°F. for summer and 75°F. for winter. It is further assumed the surfaces that the inside of the fenestration "sees" are perfect radiators at the temperature of the indoor air

---

* Donald J. Vild is Technical Service Engineer for the Libbey-Owens-Ford Glass Company. He was formerly associated with the American Society of Heating and Air Conditioning Engineers' laboratory, and The Austin Company of that city. He has a Bachelor of Science degree in Mechanical Engineering from Case Institute of Technology and is a Registered Professional Engineer in Ohio. He is also a member of the Illuminating Engineering Society and the American Society of Mechanical Engineers.

and only natural convection occurs at inner surface.

METEOROLOGICAL CONDITIONS

In the majority of cases the meteorological factor of primary importance is the incident solar radiation. This is especially true during the cooling season. Solar radiation consists of two portions, the direct solar radiation and the reflected or diffuse solar radiation. The diffuse radiation is that which is reflected from water vapor, gases, and dust particles in the atmosphere surrounding buildings and the ground. The intensity of the direct component may vary from 0 to 350 btu/hr.-sq. ft. at sea level, depending upon the clearness of the atmosphere and the altitude of the sun. For design purposes a value of 294 btu/hr.-sq. ft. is taken as a standard, with the sun directly overhead. It is only occasionally that this value is exceeded. The diffuse solar radiation will have daytime values ranging from 10 to 100 btu/hr.-sq. ft. depending upon the environmental conditions encountered. (RL 32).†

As illustrated in Fig. 1.12, the intensity of direct rays of the sun differs from one wave length to another. This spectral energy distribution curve is for a solar altitude of 30°, average atmospheric conditions for a clear day and at sea level. Changes in these conditions will cause marked changes in the energy levels and the distribution of the solar energy. Note the narrowness of the visible portion of the solar spectrum. For average conditions about 45 per cent of the total energy lies in this range.

The various paths by which solar radiation reaches a fenestration are shown in Fig. 1.13. The radiation is depleted passing through the earth's atmosphere

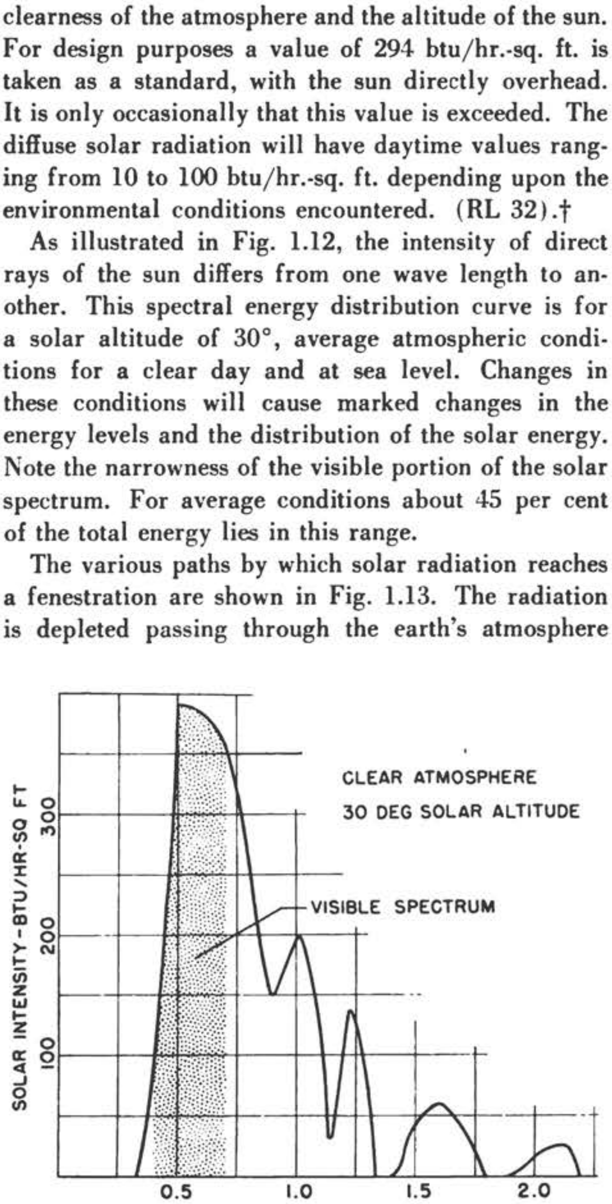


Fig. 1.12—Spectral energy distribution of direct solar radiation at sea level.

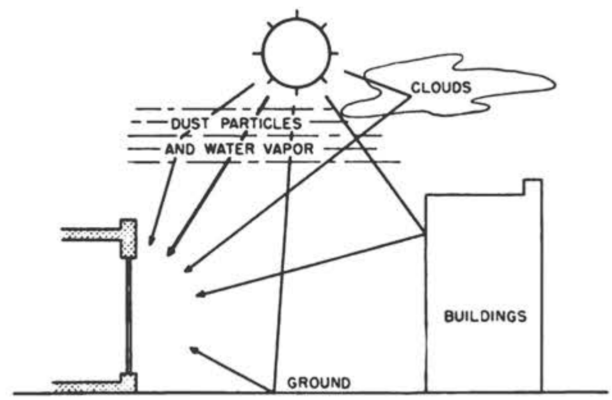


Fig. 1.13—Paths of solar radiation.

and in some cases may be reduced nearly 100 per cent. As seen, the diffuse radiation reaches a fenestration by a number of paths and its value is dependent, to an extent, on the nature of the surroundings. Building surfaces having high reflectances will increase the diffuse radiation, as will foregrounds such as smooth concrete and water.

Heat transfer through fenestration is affected by a number of other meteorological factors besides solar radiation. These are low-temperature radiation, outdoor air temperature, and wind velocity and direction. Previous to studies (RL33) at the ASHAE research laboratory, it had been customary to treat the earth's atmosphere as if it were a perfect radiator at ambient air temperature. This has been proven invalid for a number of cases. When atmosphere is clear and relatively free of dust particles, gases and vapors, a fenestration will have a low-temperature radiation exchange, largely with the upper layers of the atmosphere, which may be as much as 40°F. cooler than the ambient air. This effect is most pronounced in skylights and other fenestration that "see" a large part of the sky.

This phenomenon is of sufficient magnitude in most cases to warrant consideration in predicting the rate of heat transfer. It is only when the sky is overcast that the earth's atmosphere acts approximately as a perfect radiator at air temperature. The overall low-temperature radiation exchange is significantly altered by the nature of the surroundings, such as buildings, trees, and ground. These may absorb energy during the sunlight hours and radiate at somewhat above air temperature during the latter part of a day.

Outdoor air temperature is a factor in heat transfer by convection. The greater the difference between indoor and outdoor air temperatures, the greater the heat gain or loss by convection. This means of heat transfer is also affected by the outdoor wind velocity

† *For Bibliography of Selected References see page 169.*

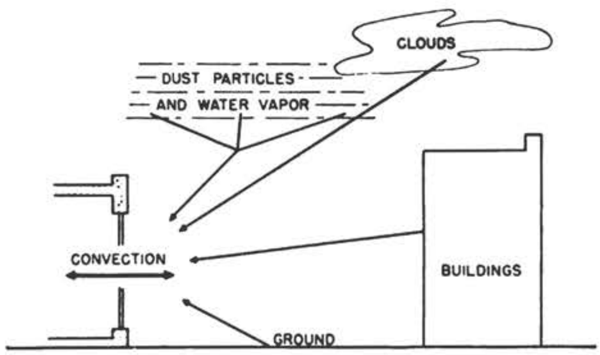


Fig. 1.14—Convection and low-temperature radiation.

and direction. High wind velocities, regardless of direction, will increase the convection heat transfer rates. Wind parallel to a surface generally produces slightly greater convection rates than wind perpendicular to a surface.

In Fig. 1.14 are shown the convection and low-temperature radiation exchanges between a fenestration and its surroundings. These exchanges, along with those attributable to solar energy, constitute the whole of the outdoor environmental conditions affecting a fenestration.

Fig. 1.15 shows the complete heat balance between any type of fenestration and its environs. Although the interchanges within the fenestration itself may vary considerably, the exterior exchanges are qualitatively identical. As seen, the solar energy is divided into three parts; the transmitted, absorbed and reflected radiation. The transmitted portion is realized as an instantaneous heat gain to the inside. The absorbed energy increases the temperature of the fenestration which in turn contributes to a heat gain by convection and reradiation. The time lag involved in this gain is

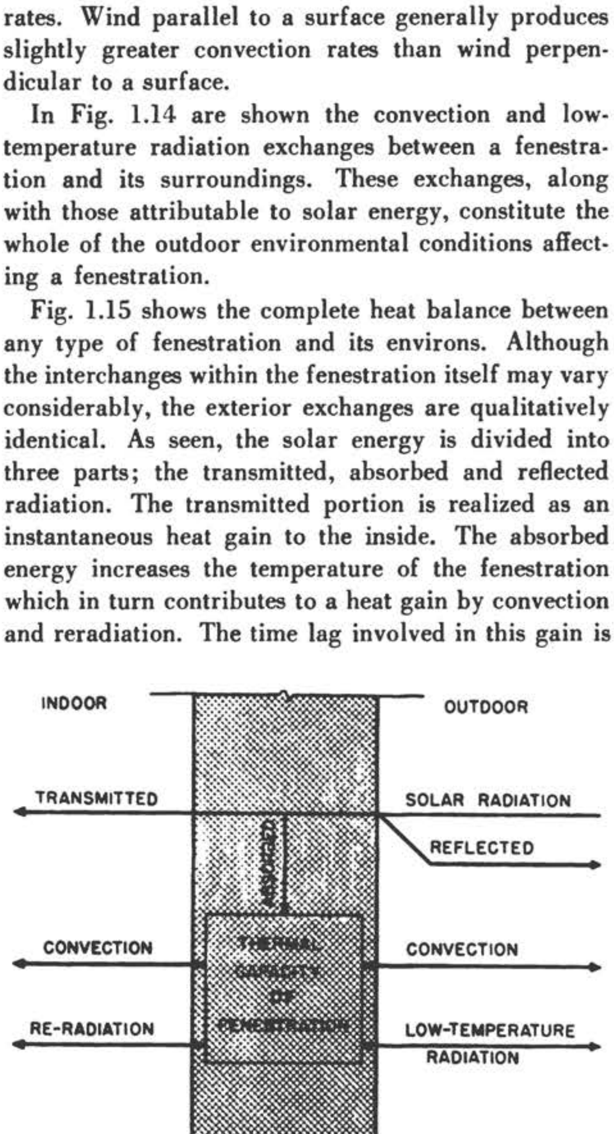


Fig. 1.15—Instantaneous heat balance for any fenestration.

dependent primarily upon the heat capacity of the fenestration. The reflected energy, of course, is expelled and does not contribute to the heat gain. Superimposed upon the gain due to solar energy are those due to convection and low-temperature radiation exchanges between the glass and its outdoor environs. None of this energy is transmitted directly through the glass, but is absorbed by it and convected and reradiated at the inside face.

PRINCIPLES AFFECTING FENESTRATION DESIGN

Glass possesses characteristics that make an analysis of its thermal behavior more complex than opaque materials. As is well known, glass will transmit various amounts of solar radiation depending upon the chemical and physical make-up of the glass, and upon the characteristics of the solar radiation striking it. Glass, however, as previously pointed out, is opaque to low-temperature radiation. This latter phenomenon occurs up to temperatures of about 450°F., above which increasing temperature is accompanied by increasing transmittance.

Not all types of glass will transmit with equal ease all wave lengths within the solar spectrum. Many types are decidedly color selective in that they may transmit the wave lengths constituting the "greens" or the "blues," or some wave lengths in the invisible part of the spectrum with greater ease than the remainder of the spectrum.

In Fig. 1.16 are shown three typical curves of normal-incident solar transmittance versus wave

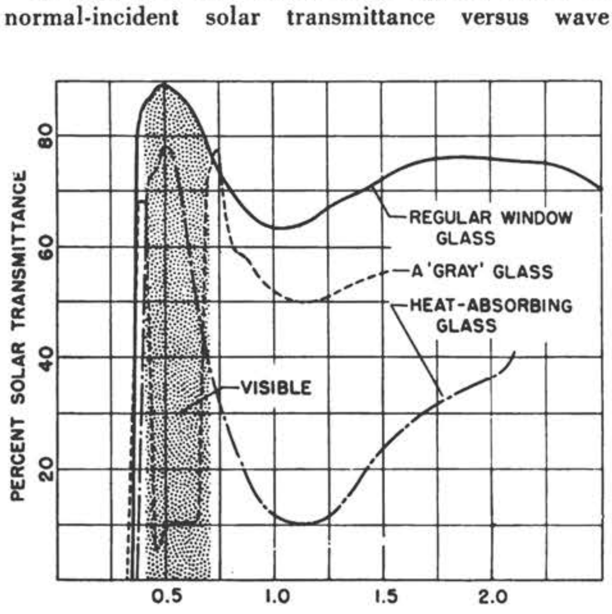


Fig. 1.16—Spectral transmittance of various flat glasses.

length. Each of the many types of glass has its own characteristic curve. From this figure and the curve of solar energy distribution, it can be seen that solar transmittance and light transmittance will not be the same and are likely to differ quite widely. A good example of this is the case of the heat-absorbing glass and a representative "gray" glass. The solar transmittance curves are those shown in Fig. 1.16. The light transmittance of heat-absorbing glass is approximately 75 per cent and the "gray" glass, approximately 13 per cent. However, the total solar transmittance of each is of the order of 40-50 per cent. This is due to the fact that the "gray" glass transmits a greater portion of the radiant energy in the non-visible portion of the solar spectrum than the heat-absorbing glass. For typical atmospheric conditions, the two glasses will have equal total heat gains.

The solar transmittance values of common glasses vary from about 90 per cent for color-clear plate glasses to about 14 per cent for hammered and etched, heat-absorbing glasses. Some special types have lower transmittances but are presently not widely used as daylighting fenestration.

A fenestration may be in the form of flat glass, figured rolled glass, corrugated glass, glass block or shading devices singly or in combination. The design, if properly developed by the architect, will be an optimum combination of heat exclusion, ventilation, proper daylighting, aesthetic appeal and economics. This discussion, however, will deal only with the heat transfer through various common types of fenestration. From the standpoint of heat transfer, factors such as orientation and prevailing climatic conditions should be considered.

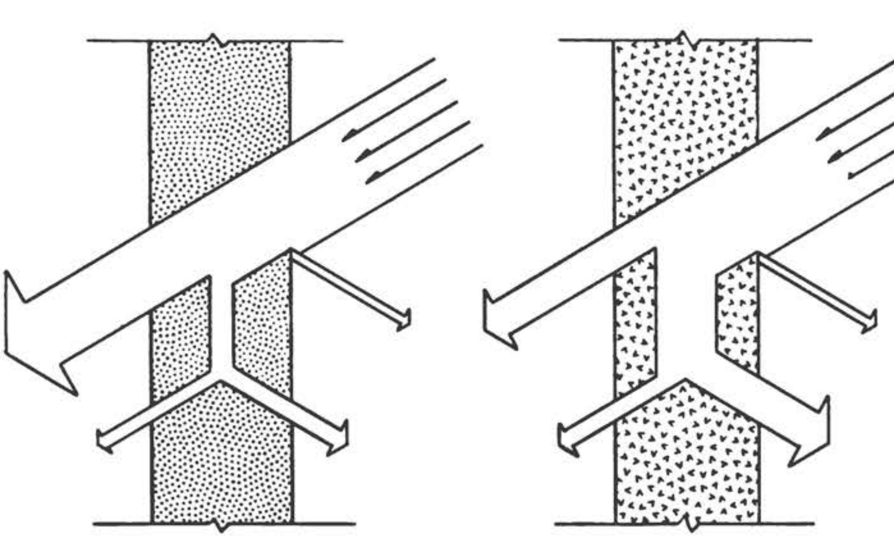
COMPARISON OF VARIOUS FENESTRATIONS

To illustrate the thermal behavior of various fenestrations, four common types will be compared with regular window glass. Conditions are a typical, clear afternoon in mid-summer at 40° north latitude, fenestration facing southwest. It should be emphasized that these comparisons hold only for the conditions indicated and not necessarily for any others. However, these are typical severe conditions.

Heat Absorbing Glass—Fig. 1.17 is a graphic comparison of the heat transfer through regular window glass and standard heat-absorbing glass. The heat-absorbing glass reduces the amount of transmitted solar energy by about 50 per cent. This reduction is partially offset by a large absorption of solar energy (indicated by the vertical portion of the arrow). This raises the temperature of the heat-absorbing glass, causing an increased gain by convection and low-temperature radiation exchanges to the interior. The total heat flow is, nevertheless, much less for the heat-absorbing glass. This illustration points out the variation in heat transfer due to differences in the chemical properties of the glass.

Double Glazing—In Fig. 1.18 is shown the heat gain for a double light having heat-absorbing glass outside and regular plate glass inside. A considerable reduction in heat gain is achieved. As in the case of heat-absorbing glass alone, the convection and reradia-

REGULAR WINDOW GLASS — HEAT-ABSORBING GLASS



183 BTU/HR-SQ FT — 126 BTU/HR-SQ FT

Fig. 1.17—Comparison between regular window glass and heat-absorbing glass.

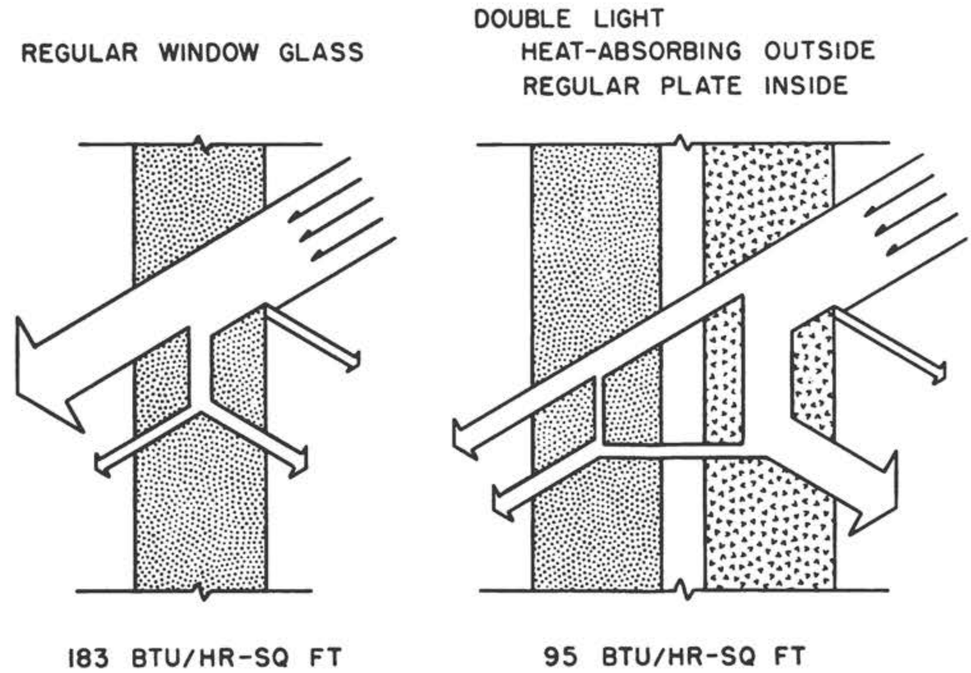


Fig. 1.18—Comparison between regular window glass and a double light.

tion gain is slightly increased, offsetting a portion of the reduction in transmitted solar energy. A fenestration of this type also provides a greater barrier to heat transfer during periods of negligible incident solar radiation.

Inside Shading Devices—The thermal interchanges within a fenestration consisting of a single sheet of glass and inside horizontal louvers are shown diagramatically in Fig. 1.19. Incident solar radiation is partially absorbed by both the glass and the louvers. The portion ultimately transmitted through the slats depends upon slat geometry, solar absorption of the louver surfaces, as well as the characteristics of the glass. The reflection from the slat surface may be specular, as shown here, or it may be diffuse. If it were diffuse the rays would scatter upon striking the surface. Recent research (RL37) has shown that there is negligible convection heat transfer between the glass and the louvers, and each operates independently with the indoor air. The paths of air movement are shown by the dashed lines. Radiation exchanges take place between the glass, the louvers and the indoor surfaces due to differences in temperature caused principally by the absorption of solar energy. These are represented by the short arrows. This diagram is simplified since the actual case would involve numerous inter-reflections between the glass and louvers, especially in the case of diffuse-reflecting louvers.

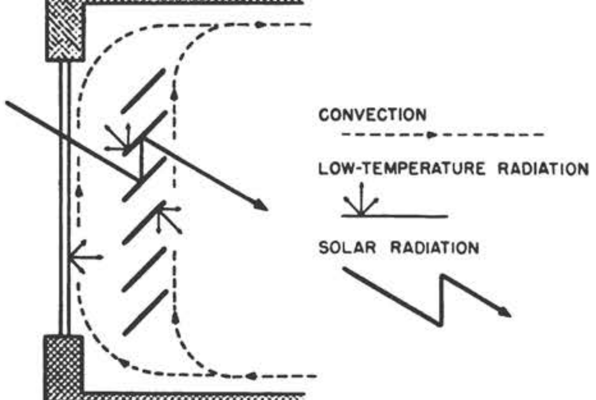


Fig. 1.19—Heat exchanges within a flat glass-venetian blind assembly.

Fig. 1.20 indicates the reduction in heat gain due to the addition of light-colored inside venetian blinds. The effectiveness of louvered devices of this type is directly related to the amount of solar energy reflected back through the glass.

Glass Block—The thermal interchanges within a glass block panel are complex. Fig. 1.21 shows a simplification of the heat flow paths involved. Not shown are lateral heat flow components and the numerous inter-reflections within the block. An analysis of the heat transfer within a glass block panel is presently being made at the ASHAE research laboratory. (RL1). The results will enable an accurate prediction of the complex thermal performance. Fig. 1.22 compares a typical glass block panel with regular window glass. Glass blocks gain their effectiveness by reflecting and refracting energy back to the outdoors and by

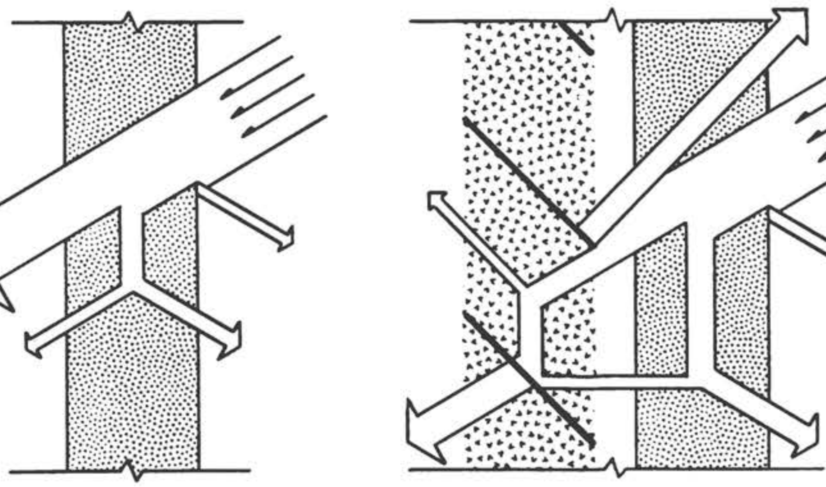


Fig. 1.20—Comparison between regular window glass with and without inside venetian blinds.

absorbing solar energy. This absorption takes place almost exclusively in the web (or non-face) portion of the block. The example indicated here is for a time after the glass block had been subjected to considerable solar radiation. The heat storage within the panel is therefore greater than it would be earlier in the day. This causes the relatively high convection and reradiation gain. The total gain, as seen, is greatly reduced.

DESIGN DATA

Faced with the complexities of predicting heat transfer through glass fenestration, an engineer or architect is apt to consider accurate determinations as an impossibility. It is here that the information compiled by the research laboratory staff of the American Society of Heating and Air Conditioning Engineers comes to his aid. In the ASHAE Guide are convenient tables to enable the prediction of the total heat transfer through numerous types of flat glass, figured rolled glass, glass block and shading devices. Information is presented for winter conditions and for a summer design day, which is the basis for determining air conditioning loads and comfort conditions. When information for other climatic conditions is desired, there are methods described for obtaining it.

The vast amount of information on heat transfer through fenestration compiled as a result of ASHAE research is prohibitively large to be included here in its entirety. However, information will be presented for predicting the total heat transfer for a number of flat glasses and regular window glass with various shading devices.

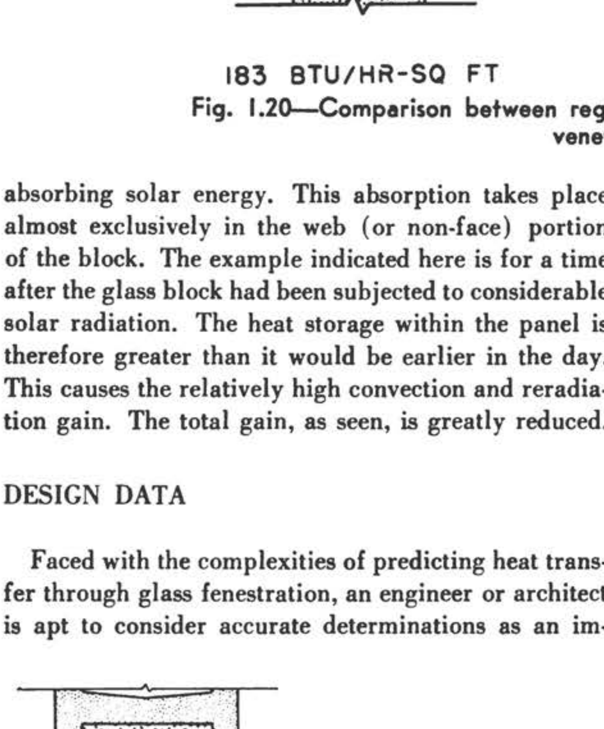


Fig. 1.21—Heat exchanges within a glass block panel.

AIR CONDITIONING LOAD

All data for heat gain determinations is related to that for regular window glass on a summer design day. The summer design day is a typical clear August 1 with a maximum outdoor temperature of 95°F. Table 1 is a compilation of the transmitted solar energy through regular window glass for the design day. Table 2 indicates the convection and reradiation gain from the inside surface of regular window glass and Table 3

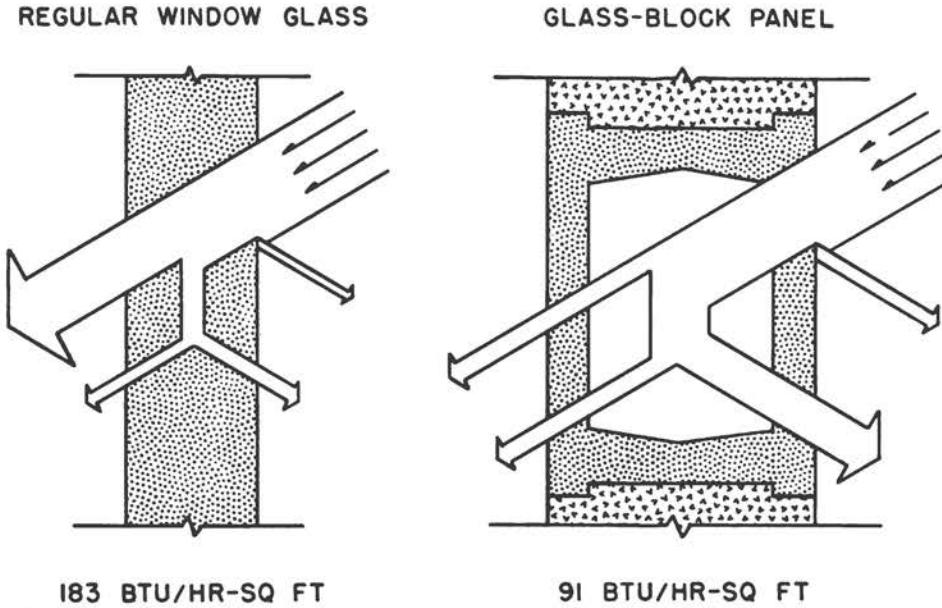


Fig. 1.22—Comparison between regular window glass and a glass block panel.

TABLE I *

A VALUES

(Instantaneous Rates of Heat Gain Due to Transmitted Solar Energy by a Single Sheet of Unshaded Regular Window Glass)

For A Summer Design Day

	Sun Time		Instantaneous Heat Gain in Btu Per (Hr.) (Sq. Ft.)								
	AM		N	NE	E	SE	S	SW	W	NW	Hor.
30 Deg. North Latitude	6 a.m.	6 p.m.	25	98	108	52	5	5	5	5	17
	7	5	23	155	190	110	10	10	10	10	71
	8	4	16	148	205	136	14	13	13	13	137
	9	3	16	106	180	136	21	15	15	15	195
	10	2	17	54	128	116	34	17	16	16	241
	11	1	18	20	59	78	45	19	18	18	267
	12		18	19	19	35	49	35	19	19	276
40 Deg. North	5 a.m.	7 p.m.	3	7	6	2	0	0	0	0	1
	6	6	26	116	131	67	7	6	6	6	25
	7	5	16	149	195	124	11	10	10	10	77
	8	4	14	129	205	156	18	12	12	12	137
	9	3	15	79	180	162	42	14	14	14	188
	10	2	16	31	127	148	69	16	16	16	229
	11	1	17	18	58	113	90	23	17	17	252
	12		17	17	19	64	98	64	19	17	259
50 Deg. North	5 a.m.	7 p.m.	20	54	54	20	3	3	3	3	6
	6	6	25	128	140	81	8	7	7	7	34
	7	5	12	139	197	136	12	10	10	10	80
	8	4	13	107	202	171	32	12	12	12	129
	9	3	14	54	176	183	72	14	14	14	173
	10	2	15	18	124	174	110	16	15	15	206
	11	1	16	16	57	143	136	42	16	16	227
	12		16	16	18	96	144	96	18	16	234
		PM	N	NW	W	SW	S	SE	E	NE	Hor.

* Reprinted by permission from *Heating Ventilating Air Conditioning Guide*, 1956, Chapter 13.

TABLE 2*

B VALUES

(Instantaneous Rates of Heat Gain by Convection and Reradiation from a Single Sheet of Unshaded Regular Window Glass)

For A Summer Design Day

Sun Time	Dry Bulb Deg. F.	North Latitude Degrees	Instantaneous Heat Gain in Btu Per (Hr.) (Sq. Ft.) N	NE	E	SE	S	SW	W	NW	Hor.
5 a.m.	74		—6	—6	—6	—6	—6	—6	—6	—6	—6
6	74		—5	—4	—4	—5	—5	—6	—6	—6	—5
7	75		—5	—2	—2	—3	—5	—5	—5	—5	—3
8	77		—3	0	1	0	—2	—3	—3	—3	0
9	80		0	2	4	3	1	0	0	0	3
10	83		3	4	6	6	5	3	3	3	8
11	87		8	8	10	11	10	9	8	8	13
12	90	30, 40, 50	12	12	12	13	14	13	12	12	16
1 p.m.	93		15	15	15	16	17	17	17	15	20
2	94		16	16	16	16	18	19	19	17	21
3	95		17	17	17	17	19	21	21	19	21
4	94		16	16	16	16	17	20	20	19	19
5	93		15	15	15	15	15	18	19	18	17
6	91		13	13	13	13	13	14	15	15	13
7	87		8	8	8	8	8	8	8	8	8
8	85		6	6	6	6	6	6	6	6	6
9	83		3	3	3	3	3	3	3	3	3

* Reprinted by permission from *Heating Ventilating Air Conditioning Guide*, 1956, Chapter 13.

provides a correction factor for the convection ad reradiation gain for fenestration having greater absorption of solar energy than regular window glass. The procedure for determining the total instantaneous heat gain for any combination of orientation, time and latitude is outlined below:

(1) In Table 4 find the proper fenestration and coefficients x, y and z.

(2) From Tables 1, 2 and 3 determine the A, B, and C values for the orientation, time and latitude under consideration.

(3) Multiply the above values by their proper coefficients thusly: $xA + yB + zC$. This summation equals the total instantaneous heat gain in btu/hr.-sq. ft. for the specified conditions.

HEATING LOAD

The heat transfer per square foot of fenestration is dependent upon the overall coefficient of heat transmission (U value) of the fenestration and the air-to-air temperature difference. Generally the U value is for an outdoor wind velocity of 15 mph. Variations in U values for wind velocities other than 15 mph are shown in Fig. 1.23. Following is a list of U values for a number of fenestrations.

U Values of Common Vertical Fenestration
(15 mph wind outside: still air inside)

Btu/hr.-sq. ft./F.	U Value
Any single glass	1.13*
Any double glass—¼" air space	0.61*
½" air space	0.55*
Glass block	
Nominal 6" x 6" x 4" thick	0.60
Nominal 8" x 8" x 4" thick	0.56
Nominal 12" x 12" x 4" thick	0.52

The total heat transfer when negligible solar radiation is present is:

$$Q = U \times A \times (t_i - t_o)$$

Where: Q = total heat transfer—Btu/hr.
U = overall coefficient of heat transmission—Btu/hr.-sq. ft./F.
A = face area—sq. ft.
t_i = indoor air temperature—F.
t_o = outdoor air temperature—F.

* A lowered shade or closed venetian blinds will reduce the U value approximately 20 per cent.

TABLE 3*

C VALUES

(Heat Absorbed in Glass. Used in Determination of Instantaneous Rates of Heat Gain Due to Convection and Reradiation Gain for Various Fenestration)

For A Summer Design Day

Sun Time		Values of C in Btu Per (Hr.) (Sq. Ft.)[a]								
		N	NE	E	SE	S	SW	W	NW	Hor.
5 a.m.		0	0	1	0	0	0	0	0	0
6		4	16	18	9	1	1	1	1	3
7		2	24	30	20	2	2	2	2	11
8		2	22	33	25	2	2	2	2	21
9		2	16	30	29	8	3	3	3	32
10		3	5	25	27	14	3	3	3	37
11	40	3	3	12	21	18	3	3	3	42
12	Degrees	3	3	3	15	19	12	3	3	45
1 p.m.	North	3	3	3	3	19	22	10	3	44
2	Latitude	3	3	3	3	16	27	24	4	41
3		3	3	3	3	10	30	31	15	35
4		3	3	3	3	4	29	36	26	26
5		2	2	2	2	2	23	34	27	17
6		4	1	1	1	1	14	24	21	6
7		0	0	0	0	0	2	3	3	1

Sun Time	Latitude	SE	S	SW	Sun Time	Latitude	SE	S	SW
5 a.m.		0	0	0	5 a.m.		2	0	0
6		7	1	1	6		13	1	1
7		18	2	2	7		22	2	2
8		22	2	2	8		28	3	2
9		24	3	3	9		30	13	3
10		22	5	3	10		31	20	3
11	30[b]	16	7	3	11	50[b]	27	25	5
12	Degrees	6	9	4	12	Degrees	20	27	17
1 p.m.	North	3	9	14	1 p.m.	North	9	25	26
8	Latitude	3	6	21	2	Latitude	3	22	32
3		3	5	27	3		3	16	33
4		3	3	26	4		2	7	31
5		2	2	21	5		2	2	26
6		1	1	11	6		1	1	17
7		0	0	0	7		0	0	7

* Reprinted by permission from *Heating Ventilating Air Conditioning Guide*, 1956, Chapter 13.

[a] Values of C for 8 and 9 p.m. are zero.

[b] For N, NE, E, W, NW and horizontal use 40 deg. North Latitude values.

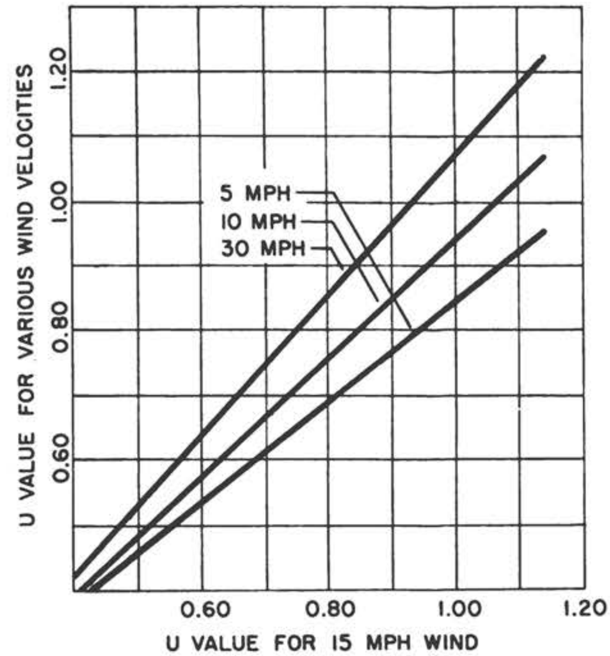


Fig. 1.23—Variation in U value versus wind velocity.

TABLE 4

Coefficients to be Used with Values from Tables 1, 2 and 3

Fenestration	Coefficients x	y	z
Single regular window glass	1.00	1.00	0
Single regular plate	0.87	1.00	0.25
Single heat-absorbing plate	0.46*	1.00	1.00
Double regular window glass	0.85*	0.60	0.10
Double regular plate	0.66*	0.60	0.55
Double light			
Heat-absorbing plate outside			
Regular plate inside	0.37*	0.60	0.75
Single regular window glass and:			
Inside Venetian blinds, light, 45° slat angle	0.56	1.00	0
Inside Venetian blinds, dark, 45° slat angle	0.75	1.00	0
Outside Venetian blinds, light, 45° slat angle	0.15	1.00	0
Outside green-tinted aluminum sun screen	0.22	1.00	0
Outside dark bronze sun screen	0.15	1.00	0

* Increase values by 10 per cent when glass is in shade.

Derived from Tables 15 and 24 of the *Heating Ventilating Air Conditioning Guide*, 1956, Chapter 13; and unpublished data.

NOTE.—*Values for the various glass-shade combinations may be used only in cases where no direct sunlight passes between the slats. The coefficients for the glass-shade combinations will yield accurate total heat gains but will not give correct values for the two components; i.e., the transmitted solar radiation and the convection and reradiation gain.*

By Alfred L. Jaros, Jr.*
Jaros, Baum & Bolles,

DESIGN FOR THE CONTROL OF SOLAR HEAT GAIN AND LOSS

Since our basic subject is "Glass and Windows," and I am to discuss their effects on air conditioning quantities and costs, we will devote particular attention to the subject of solar heat and how to keep it out. For (in most buildings) the radiant heat from the sun entering through windows is one of the major determinants as to how large and costly the cooling system must be. Even more important, it is the largest such factor readily amenable to preventive treatment. And it is usually much cheaper to *keep heat out* initially than to remove it *after* it gets *in*.

This being the case, we shall consider at length the two major questions in controlling this sort of heat:

(a) How large (or small) can the windows be?

(b) How can we best shade them and thus keep the solar radiation out, especially if the architecture requires that they be large?

I have been asked to discuss this phase of our subject, because as a designer of air conditioning systems I am in frequent contact with these problems. Since most of the audience, however, is engaged in very different areas of the building industry, much confusion and misunderstanding could arise if I used without explanation terms which had a different meaning (or perhaps *no* meaning) for many of you. Therefore, it seems important first to define enough about air conditioning itself—its vocabulary, the principal systems in common use, and how their size and capacity are determined—so that we may, together, discuss the effects and control of solar heat with complete understanding.

Since heating and air conditioning (now considered almost essential in making a modern building livable, rentable, and useful) usually represent from 15 to 20 per cent of the entire construction cost, sound design must provide not only functional completeness, proper coordination of the mechanical work with other trades and with the available space, and proper zoning and control, but also the lowest cost, both of installation and operation, consistent with good results.

This is where the skilled engineer most needs the understanding cooperation of the architect and owners for his greatest study and care cannot secure good results if the building design provides inadequate or badly-arranged mechanical spaces, nor economy if it necessitates extravagant quantities of cooling and heating. Harmonizing all of these requirements calls for imagination, experience, initiative and real coordination in which the fact must be faced that the high unit cost of air conditioning puts great emphasis on methods of reducing summer heat gains from sunshine, heat conduction and humid air infiltration.

QUANTITIES

The air conditioning equipment must provide capacity sufficient to care for the maximum requirements that occur often enough to matter (perhaps 50 hours in an average summer). It must automatically and

---

* Alfred L. Jaros, Jr., has been a partner in Jaros, Baum and Bolles, Consulting Engineers of New York, since 1916. He is a mechanical engineering graduate of Columbia University, has taught engineering at the New York University School of Engineering, and has lectured at Columbia University Schools of Architecture and Engineering.

During World War II he was a Technical Advisor to Contruction, Quartermaster General, United States Army, and in World War I was a Project Engineer in the Power Plant section of the United States Navy, Bureau of Yards and Docks.

Mr. Jaros is a Member of the American Society of Mechanical Engineers, American Association for the Advancement of Science, the United States Naval Institute, the Institute of Navigation, and is Past President of the New York Association of Consulting Engineers.

dependably adjust its output to the needs of the occupants, and to the effects of changing outdoor temperature, sunshine, wind, etc.

A good air conditioning system must:

(a) Maintain suitable air temperatures, automatically controlled to suit varying population, outdoor temperature, sunshine, etc.

(b) Maintain about 45 to 50 per cent relative humidity at all temperatures.

(c) Circulate enough conditioned air (usually a mixture of outdoor and recirculated air) to accomplish the above, and to produce adequate but not too great air motion. The delivered air must be at a lower temperature and humidity than those to be maintained, to the degree needed to remove the heat and moisture liberated within the room.

(d) Remove objectionable dust from the air being supplied.

(e) Introduce outdoor air (cooled and dehumidified in summer) at such a rate as to prevent odors, or "fouling" of coils and ducts, etc. A needlessly large quantity of outdoor air is a simple but extravagant way to improve air quality. In summer, it requires more refrigeration, and in winter more fuel, than to recirculate reconditioned return air. 0.3 to 0.4 cfm/sq.ft. of net floor area is an acceptable range of outdoor air supply for office buildings. Suitable rates for other types of buildings will vary with population and usage.

(f) Extract used air from rooms in such a manner as to remove smoke, odors, or other objectionable constituents. Part of this used air will be filtered, reconditioned, deodorized chemically when necessary, and reused.

COMPUTATION METHODS

The rate of supply of conditioned air is based upon the acceptable temperature differential between room and delivered air and the internal sensible load (Btu/hr. to be removed) including:

(a) Conducted heat through walls, windows, etc., due to temperature difference between outdoors and indoors.

(b) Heat given out by people, lights and any hot equipment.

(c) Heat radiated by the sun or reflected from the sky, entering mainly through windows.*

In a typical office building with about 100 sq. ft. of floor per occupant and about 5 watts/sq. ft. of electric consumption for lighting and office equipment, the sensible cooling load for interior zone space all the year around may approximate 20 Btu/sq. ft./hr. Cooling load due to occupants and electric equipment will not be too different in other types of buildings devoted primarily to human occupancy (except auditoriums or other crowded spaces). However, in exterior zone spaces (considered as about 15 ft. in from windows), windows with blinds or shades equal in size to 25 per cent of the total facade area, will increase the maximum sensible cooling demand to about 40 Btu/sq. ft./hr. on the south side, and at least 45 on the east and west. For windows equal to 50 per cent of the facade, these figures will approximate 55 and 60 Btu/sq. ft./hr. respectively; for 75 per cent windows, 70 and 75 Btu/sq. ft./hr.* All of these values are for approximately 11½ to 12 ft. floor-to-floor height, and 40° north latitude. The values for southern exposure will vary considerably in other latitudes.

The proportion of the various factors will naturally vary with the size, usage, location, and design of the building, but:

(a) In any particular case, population will be a fixed design quantity.

(b) Lighting intensities will also be fixed, but the cooling load can be substantially reduced by more efficient types of lights, by the use of radiant ceilings with cooled lighting fixtures, by using ceiling spaces when practical as a return air plenum, as well as excluding from the conditioned spaces as much as possible of power and industrial heat sources.

(c) Good thermal insulation will pay its way in roofs, and in *large* areas of *thin* outside walls. We have found both glass fiber blankets and foam glass blocks excellent if of adequate thickness (4 inches is desirable). A good vapor barrier on the indoor side of glass fiber blankets is most important in winter. Where windows are large, the thermal resistance of walls becomes relatively unimportant, since they represent no more than 2 per cent of the *total* cooling load.

(d) Heat gain due to solar radiation is one of the largest variable factors. To limit this, windows should either be well shaded, or their areas should be the smallest acceptable, since every square foot of *unshaded* window may admit five to eight times as much heat from the sun's radiation as it conducts from the hotter outside air. An "all window" building, inherently, causes very extravagant air condi-

* (See Appendix II.)

tioning design. Even with blinds or shades, every needless square foot of glass except on the north will probably add $10.00 to $15.00 to the cost of installing good air conditioning.

In a typical case, computation gave the following subdivision of the maximum simultaneous cooling demand:

(a) People, Lights, Office Equipment.... 37%
(b) Conduction (through walls and roofs). 1%
(c) Conduction and Solar Radiation (through windows)................ 27%
(d) Dehumidification of outdoor air supply. 24%
(e) Miscellaneous (including heat from fans) 11%

This was a building whose windows approximated 40 per cent of the facade areas and were equipped with venetian blinds.

Obviously, the only important ways of reducing total cooling capacity in this building would be either to reduce the proportion of outdoor air or size of windows, to use heat-absorbing glass, or more effective shading. In the example quoted, 25 per cent windows would have reduced the total refrigerating demand by about 10 per cent, whereas 70 per cent windows would have *increased* it by at least 20 per cent! *

In the above example with 40% windows, complete outside shading of the south, east and west windows, if it could have been done, would probably have reduced the refrigerating demand by about 20 per cent—twice as much reduction as by using 25 per cent windows.**

SHADING

Much emphasis has been given recently to heat-absorbing types of glass, but recent research indicates that, while this glass will substantially reduce solar heat input through an entirely unshaded window, its net advantage is negligible when light-colored venetian blinds (or any still better method of shading) are used.

By now, it should be clear that the most effective way to save on the cost of air conditioning and still have an adequate, efficient, and satisfactory plant is to keep the sun out of the windows *entirely*, if that is possible, or as nearly so as other considerations will permit. This was a common practice in the tropics, and in other very hot countries, during the centuries before air conditioning was developed. But, for some reason, American habits, municipal building laws in some cases, and the usual architectural concepts of our builders have quite generally accomplished little or nothing with such shading in our large, modern air conditioned buildings. Substantial savings could be made by a widespread change in our practices.

Various factors have a bearing on which method of shading to employ:

(a) The old fashioned canvas awning on the outside of the building can do more to reduce cooling demand than most combinations of heat-absorbing glass and venetian blinds.

(b) The performance of such awnings can be further improved by making them light in color on the outside and by providing a ventilating slot at the top of each awning. The light color reflects more of the sun's rays outward and the ventilating slot permits hot air accumulating under the awning to escape, instead of increasing heat conduction through the window.

(c) Modern types of ventilating awnings, built of aluminum or plastics, will do as good a job as the canvas awning.

(d) Unfortunately all of these, as well as the old fashioned wooden slat shutter outside of the window (also quite effective), suffer from a common and grave defect. They must be manipulated, perhaps at several hundred distinct points in a building, and to do this the windows must be opened and closed. Because of the nuisance, all of these older methods have largely fallen into disuse.

(e) On orientations where the sun is quite *high* in the sky (in the northern hemisphere, the south facade, and in the southern hemisphere, the north facade) projecting balconies or cornices can be arranged to do as effective a job as any sort of awning. However, this method of shading is less useful on easterly exposures, and almost useless on westerly exposures, because the solar heat radiation is greatest on a west window late in the afternoon, as the sun sets *low* in the sky.

(f) For these directions, the best shading methods are fixed (or movable) metal or concrete jalousies, several feet out from the building (which introduces a serious problem in supporting them, unless projecting vertical "fins" are used for this purpose), or various schemes of vertical louvers, either fixed a little way out from the windows or pivoted so that their angulation can be adjusted to the changing direction of the sun's rays.

(g) The latter method is especially valuable on exposures somewhat to the south of true east or

* (See Appendix II.)
** (See Para. I-3, Appendix I.)

west; the spaces between such louvers should then look northward rather than southward.**

Each building, and to some extent each different facade (depending on its orientations), deserves special study for the best results. In different cases, various combinations of these methods work out best. It requires rather bold initiative, an adventurous outlook on the part of the architect, and, of course, the cooperation of the builder and owners in accepting such design, to secure all the saving which solar shading can provide.

DISTRIBUTION SYSTEMS

While a detailed discussion of air conditioning distribution systems is outside the scope of this paper, it is necessary to point out that buildings with any considerable amount of heat intake through glass windows require zoning. They must have systems so arranged that the amount of heating or cooling effect can be independently controlled in the several differently oriented outside zones, separately from the interior zone. The need to do this, and as economically as possible, has largely dictated the development in recent years of:

(a) Subdivided Conventional Systems—Sometimes used for new buildings, but more applicable to old ones; subdivision of conventional systems (each caring for one floor, or at most two or three) into several separate zones, selected as to exposure to sunshine, wind, and the like.

(b) Peripheral Systems—The outer zones (areas extending from 12 to 15 feet inward from the windows) are cooled or heated by means of compact local units located in metal cabinets under the windows or in a continuous metal sill construction. Each unit circulates, locally, as much conditioned air as will serve the outer zone space bounded by the one window; while the inner zones of the building are conditioned by separate ducted air-supply systems. Frequently, the units under the windows receive primary air (about 25 per cent of the total to be circulated in the room) from a remote primary fan-room, through small, high-velocity conduit ducts, usually run vertically near each outside wall column. The primary (largely or entirely *outdoor*) air is filtered, cooled and dehumidified as necessary, and delivered at considerable pressure to the acoustically baffled under-window units where, by means of ejector nozzles, it aspirates several times its own volume of air into the room from the unit, mixes with it, and delivers the mixture back into the room in such a manner as to give good local distribution. The aspirated room air passes through a finned coil in the unit, and is cooled in summer or heated in winter by water circulated from piping connecting to each unit, and distributed much as is the primary air ductwork.

(c) Another somewhat similar scheme uses small motor-driven fans in the units to handle the recirculated room air, while the primary air may either enter the unit (at lower pressure) for mixing or be delivered to the room through separate outlets.

(d) Double-Duct Systems—A single, central high-pressure system utilizes *two* supply ducts, with air at two different temperatures (one very low, the other moderately high). Mixing dampers, thermostatically controlled, deliver the correct temperature of air to the "control box" supplying the outlets for each individual zone (or room). This system gives excellent control, and can be applied to mixing boxes under windows (as well as in ceilings). It requires larger ducts than peripheral systems.

(e) Radiant Heating and Cooling—By the circulation of cooled "secondary" water through coils, which extract heat from an aluminum ceiling attached under the coils, and exposed to the room to be thus cooled. The same equipment gives very effective winter heating by *warming* the circulated water. To absorb heat, the ceiling must be appreciably colder than the air or than other surfaces in the room. For example, a suitable surface, about 15°F. cooler than the room air will absorb at least 20 Btu/hr./sq. ft. of sensible heat. It will be recognized that this is just about the differential between typical inside and outside zone demands, *if* windows are smaller than 25 per cent of the facade, or else very well shaded. This in turn means a large reduction in the amount of conditioned air required and usually makes it possible to combine outside and inside zones into a *single* system of fans and ducts, supplemented by small convectors under windows for winter use only, and obtaining their zone control entirely by means of the water supplied to the radiant ceiling.

There is no standard or routine method for selection of the best scheme to use. Study and experience, the geometry of the building, the quality of results considered appropriate, the relative importance of initial versus operating costs, whether or not the space can be modified to accommodate a particular system, these and many other considerations should guide. However,

** (See Para. 1-3, Appendix I.)

it may be stressed that some schemes are feasible and economical *only* when windows are quite small or very well shaded.

The accompanying photographs, as well as Appendix I, give further examples of methods of solar shading. An example may emphasize its value: A building with about 250,000 net square feet of usable floor area, with typical construction and 40 per cent windows, might require about 1,000 tons of air conditioning. Such a plant might add about $1,800,000 to the total construction cost, of which about $1,500,000 or less would be in the mechanical contract, and about $110,000 per annum would be the operating and maintenance costs including labor, but not fixed charges.*

Reducing the windows to 25 per cent of facade would reduce the maximum air conditioning demand to about 900 tons; this would reduce the initial investment to about $1,250,000, and the per annum cost of operation and maintenance to about $95,000.

But *complete* solar shading, even *without* reducing the size of windows, would reduce the air conditioning plant to 800 tons and simplify its zoning, and therefore its unit cost. The initial investment might approximate $1,050,000, a saving of about 30 per cent, and the per annum expense should be about $85,000 to $90,000, a saving of over 20 per cent. So you can see that keeping the sun out can pay handsome dividends.**

APPENDIX I

SOLAR RADIANT HEAT REDUCTION

I-1. Inside Shading: The simplest way of reducing solar heat loads is to use the smallest acceptable windows, especially on east, southeast, south, southwest, and west facades. Additional reductions can be had (effective only in windows not otherwise shaded) by using heat-absorbing glass or by combining one pane of heat-absorbing with one pane of plain glass. The advantages of heat-absorbing glass approach the vanishing point, however, when effective shading devices are used. Results of recent ASHAE research indicate that, whereas (under typical conditions of time and orientation) light colored venetian blinds inside the room reduced the solar radiant energy transmitted with plain glass to 56 per cent of what such an unshaded window would admit, with good heat-absorbing glass, using the same blinds, the solar heat gain was 55 per cent of that with the unshaded plain glass. The heat-absorbing glass with blinds produced a net reduction of only about 1 per cent in solar heat gain.

I-2. While research on double and triple panes is as yet less complete, it seems most probable that these also are of little added value when proper inside shading is employed.

I-3. Outside Shading: An attack upon solar heat gain, basically different from the use of small windows, is to so design the building as to shade all or most of the glass during the hours of most intense insolation (which vary with orientation, latitude, and time of year). The earliest such attempts long antedated air conditioning. Manually operated awnings and the newer, more efficient designs of aluminum slats arranged to ventilate the space under the awning are widely used on south-facing windows.

I-4. A light colored outside awning, especially if properly ventilated, can be much more effective than the best inside shades or blinds, because it intercepts a major part of the sun's radiation *before* it can enter the building. Inside devices can only intercept radiant energy *after* it has passed through the glass, and they actually eliminate only that percentage which they can reflect out through the glass. Much of the radiant energy striking an inside blind is absorbed, converted into sensible heat, and converted to the air within the building.

I-5. These factors, plus the fact that heat-absorbing glass functions by converting *within* the glass solar radiation into sensible heat, part of which is conducted outward and part inward, account for the facts brought out in Par. 1 of this Appendix. While heat-absorbing glass refuses to pass inward a considerable fraction of the energy radiated from the sun, it likewise refuses to pass outward a similar or greater fraction of the energy reflected from blinds.

I-6. Manually operated outside devices, however, are cumbersome and undependable, especially for large buildings with thousands of windows. They pose a major maintenance problem, and are not readily applicable to very large windows. In recent years, a number of inherent or built-in solar shading schemes have been used. Among these may be mentioned:

(a) For south windows in the northern hemisphere—also southeast and southwest windows—projecting eaves or balconies on every floor, casting a shadow in summer as far down as the window sill. (Figs. 1.24 and 1.25). This scheme is of little value on west facades, because the rays of the late afternoon sun are too horizontal to be intercepted by horizontal projections.

(b) An eqivalent scheme is the use of external

* (See Par. III-5 and Notes, Appendix III.)

** (See Para. III-6, III-7, and III-11, Appendix III.)

Fig. 1.24—Overhanging balconies, etc., on the southeastern exposure of an apartment house in Havana, Cuba.

Fig. 1.25—Projecting balconies to southeast and louvers to the northeast in an office building in Havana, Cuba.

inclined louvers or fixed metal awnings supported by a projecting structure at such a distance out from the wall as to shade the south windows effectively from above, while allowing upward ventilation of space behind the louvers and permitting a horizontal outward view. (Fig. 1.26).

(c) Either scheme can also be designed to exclude the midsummer sun, while admitting a considerable amount of welcome heat from the lower-altitude sun of midwinter months.

(d) East windows are not a serious problem for office buildings, because:

(1) Solar radiation on these windows is most intense from about 6 to 9 A. M. (when the building is untenanted) and practically vanishes by about 10:30 or 11:00 A. M., before the real heat of the day.

(2) During these morning hours, the outdoor air is usually cooler and drier than at midday or in the afternoon, so that the conditioning plant then has *surplus* cooling capacity. At such times, inside shades or blinds are adequate.

For residential buildings, hospitals, etc., however, the east window problem is more important than for business buildings.

(e) West windows are the most severe problem of all because of the low sun and high outdoor temperatures in late afternoon. Some unconventional buildings (especially in the tropics) have met this problem by the use of vertical louvers such as concrete panels a few feet apart, projecting several feet out from the building facade. (Fig. 1.27). These panels are not set perpendicular to the wall, but are slanted at such an angle as to shade the windows until about 5:00 P. M. while permitting a diagonal view out.

(f) A still more recent adaptation of the same basic idea uses vertical metal louvers perhaps 2′ in width mounted on pivots, which can be adjusted either individually or in groups to suit the changing "angle of attack" of the sun as the day passes.

Fig. 1.26—Horizontal louvers set out on the western exposure; balconies on the southern exposure of an office building in Havana, Cuba.

Fig. 1.27—Vertical concrete inclinded louvers on the western exposure of an apartment house in Havana, Cuba.

(g) The latest development of this scheme adjusts the vertical louvers in groups mechanically, the mechanism being controlled either by timing devices or by "electric eye" photo-electric devices, so mounted as to come into play whenever the sun starts to creep around the louvers. (Fig. 1.28).

I-7. Inclined Windows: A recent idea (valuable on a South facade, especially) is to incline windows, top outward, somewhat as in an airport control tower, thus reducing the effective cross-section perpendicular to the sun's rays. A detailed study of this scheme was based upon various combinations of glass types and of angles of inclination: vertical windows, windows at various specified angles of inclination outward, plain glass unshaded, or plain glass with inside venetian blinds. In all cases, it was assumed that the interior would be 15° cooler than outdoors and the heat transmission was included, as well as the solar radiation entering through the glass. The heat transmission at 15° is a fixed quantity (approximately 17 Btu/hr./sq. ft., whether or not the sun hits the glass) and is not affected by the inclination. This study was made for true south, not the "New York south," which is about 208° true instead of 180° true.

I-8. An example will show typical results of this study: For a typical office building, the cooling load for all interior factors (occupants, lights, electric typewriters, etc) plus the dehumidification of outdoor air brought in for ventilation will approximate 315 Btu/hr. of sensible heat (which affects the cfm of air to be supplied) plus 30 to 40 Btu/hr. conducted through the wall, say 350 total Btu/hr. of internal sensible heat, for a strip 15 feet deep and one foot wide along the periphery of the building. Humidity given out by occupants plus the dehumidification of outdoor air will account for approximately another 250 Btu/hr. of latent heat. This will *not* affect the cfm of air supply.

I-9. As against this, a continuous window 6 feet high would impose an additional sensible heat load (in the middle and latter part of August, the time usually assumed) of about 720 Btu/hr. if *not* shaded, or about 510 Btu/hr. if shaded with venetian blinds. If venetian blinds are used, very little additional is

Fig. I.28—Movable vertical louvers as used on the American Association for the Advancement of Science building in Washington, D. C.

gained by using heat-absorbing glass, double glazing, or any combination thereof.

(a) Thus, with the usual vertical window, the solar radiation (at this time of year) adds about 120 per cent to the summation of all other sensible heat loads, and a corresponding amount to the cfm of conditioned air that must be supplied.

(b) Since the refrigerating tonnage (as distinguished from the air quantity) includes also the outdoor air and latent loads, the solar radiation at this time and on these windows adds about 80 per cent to the tonnage required for this *outside* zone, not for the whole building.

(c) While this addition is the only increase in refrigerating plant, the local air handling equipment (for the South zone only) really should be sized for the lower sun and more intense sunshine in mid-October. This almost doubles the amount of solar heat through any vertical window on the south facade, so that the air quantity is tripled (rather than doubled) as compared to loads *other than* sunshine.

I-10. The above example was worked out for vertical glass 6 feet high. However, in mid-August a window inclined outward approximately 20°, unshaded, will only admit about *one-half* as much solar radiation per square foot of glass as a shaded vertical window, and a window inclined outward at 30°, only about *one-fourth!* Such inclined windows should nonetheless be provided with venetian blinds. These are not too important in mid-summer, but will become important during September and October as the sun goes lower.

APPENDIX II

TYPICAL ANALYSIS, COOLING LOAD "OUTSIDE ZONE"

II-1. Assumptions:

Outdoor Condition, 95° Dry Bulb, 75° Wet Bulb

Indoor Condition, 77° Dry Bulb, 50 per cent Relative Humidity

Outside Zone, per 1 ft. wide, 15 ft. deep

South Exposure, August mid-day

(Note: 8:00 A.M. *East,* 4 P.M. *West* or *October Noon South,* will increase solar inputs about 60 per cent.)

Persons, one per 100 sq. ft., light activity

Electric Usage (lights, etc.), 5½ watts/sq.ft.

Wall Construction, 12 ft. floor to floor, U=0.3

Ventilation, 0.4 cfm outside air/sq.ft. (75° to 64° Wet Bulb)

II-2. Comparisons:

Per Cent Glass in Facade	25		50		75	
Lat. and Outs. Air Load, btu/hr.†		275		275		275
Sens. Load, Cond. Sing. Glass, btu/hr		61		122		183
Sens. Load, Cond. Double Glass, btu/hr	*30		*61		*91	
Sens. Load, Cond. Wall, btu/hr		48		32		16
Sens. Load, Occupants, btu/hr		35		35		35
Sens. Load, Elec. Equip., btu/hr		280		280		280
Total Sens., Excl. Solar	*668	699	*683	744	*698	789
Solar, Unshaded, Plain Glass		306		612		918
Solar, Unshaded, Double Glass	*276		*552		*827	
Solar, Unshaded, Heat-Ret. Glass		224		448		672
Solar, Unshaded, Glass Block	*84		*168		*252	
Solar, Inside Blinds, Plain Glass		171		342		513
Solar, Inside Blinds, Double Glass	*147		*294		*440	
Solar, Inside Blinds, Heat-Ret. Glass		168		346		504
Solar, Outside Shading, Plain Glass		84		168		252

* Based on conduction for double glass. All other figures are for single glass.

† For 15′ x 1′ floor strip with 1′ side parallel to wall.

Per Cent Glass in Facade	25	50	75
Cfm/Sq.ft.,* Unshaded, Plain Glass	2.3	3.3	4.5
Cfm/Sq.ft., Unshaded, Double Glass	2.1	3.0	3.9
Cfm/Sq.ft., Unshaded, Heat-Ret. Glass	2.0	2.8	3.7
Cfm/Sq.ft., Unshaded, Glass Block	1.5	1.8	2.1
Cfm/Sq.ft., Inside Blinds, Plain Glass	1.9	2.5	3.2
Cfm/Sq.ft., Inside Blinds, Double Glass	1.7	2.2	2.7
Cfm/Sq.ft., Inside Blinds, Heat-Ret. Glass	1.8	2.4	3.1
Cfm/Sq.ft., Outside Shading, Plain Glass	1.6	2.0	2.4

* Cfm/Sq.ft. for 15′ x 1′ floor (based on all-air system with 20° F.T.D.).

Per Cent Glass in Facade	25	50	75
Tons/1000 Sq.ft.,* Unshaded, Plain Glass	6.00	7.45	9.65
Tons/1000 Sq.ft., Unshaded, Double Glass	5.30	6.95	8.55
Tons/1000 Sq.ft., Unshaded, Heat-Ret. Glass	5.15	6.55	7.70
Tons/1000 Sq.ft., Unshaded Glass Block	4.25	4.75	5.30
Tons/1000 Sq.ft., Inside Blinds, Plain Glass	4.95	6.05	8.30
Tons/1000 Sq.ft., Inside Blinds, Double Glass	4.60	5.50	6.35
Tons/1000 Sq.ft., Inside Blinds, Heat-Ret. Glass	4.75	5.90	6.60
Tons/1000 Sq.ft., Outside Shading, Plain Glass	4.40	5.15	5.85

* Tons/1000 Sq.ft. for south outside zone.

APPENDIX III

TYPICAL INSTALLATION AND OPERATING COSTS

III-1. The installation cost of air conditioning in multi-story buildings logically falls under three major heads:

(a) Central Refrigerating Plant—Refrigerating machines, "drive" and accessories, cooling towers or other source of condensing water (or air-cooled or evaporative condensers), condensing-water piping and pumps, chilled-water piping and pumps, steam, drain and fresh-water connections (also thermal insulation).

(b) Floor Work or Distributing Systems—Fans and drives, coils, cooling and heating and connections, ducts, filters, grilles and outlets, automatic controls, exhaust ventilation, steam, drain, and fresh-water connections (also thermal and acoustic insulation).

(c) Other Trades—Electric power supply and wiring beyond what the building would require if it were not air conditioned, foundations, sill enclosures for units, supports for cooling towers, etc.

III-2. For this paper, costs have been approximated for three types of central refrigerating plants generally used in large and moderately large buildings:

(a) Motor-driven centrifugal compressors, (1) in basement, (2) in penthouse.

(b) Steam turbine-driven centrifugal compressors, (1) in basement, (2) in penthouse.

(c) Steam-operated absorption refrigeration in penthouse.

III-3. For similar buildings, five basic floor work schemes have been estimated:

(a) Ejector type units under windows for exterior zones, plus a single-duct system for interior zones.

(b) Fan-coil type units under windows for exterior zones, plus a single-duct system for interior zones.

(c) Metal radiant ceilings for cooling and heating exterior zones, plus a single-duct system for all parts of the floor.

(d) Single-duct systems (all air) separately zoned for interior and for the several exterior zones, plus heating convectors under windows.

(e) A double-duct system (all air) for each floor, with mixing boxes under windows for exterior zones, and mixing boxes in ceilings for interior zones.

III-4. In considering all these alternatives, it must be understood that the choice cannot be based solely on relative initial cost. The nature, size, location and usage of the building, available space, operating and maintenance features, all must be considered—from the viewpoint of both imagination and ample experience—to arrive at the most satisfactory and (in the long run) most economical scheme for each particular project.

III-5. Typical Cost Estimates * (Dollars/Ton)
Notes:

(a) Cost of steam supply source (boiler plant or outside steam connection) not included; steam piping to turbines, coils, heat exchangers, etc., is included.

(b) Electric power supply costs include no power generating equipment, but do include additional cost of basic electric power supply in building, as well as wiring to motors, installation of starters, interconnections to pneumatic control equipment, etc.

(c) The item for sill enclosures is the estimated difference between otherwise normal treatment of sills and walls at windows, and extended-sill continuous enclosures for peripheral units (or double-duct mixing boxes and their connections.

* For New York City (1956-1957). These are comparative costs for similar buildings, with high grade commercial mechanical plants.

CENTRAL PLANT

Item	Motor-Centrif. in Bsmt.	Motor-Centrif. in Penthouse	Steam-Centrif. in Bsmt.	Steam-Centrif. in Penthouse	Steam-Absor. in Penthouse
Refrigerating Equipment	175	175	155	155	145
Cooling Towers	55	55	65	65	75
Condensing Water System	110	45	130	50	55
Steam Piping	...	...	45	80	90
	$340	$275	$395	$350	$365
Electrical Wiring and Other Trades	50	100	25	45	50
	$390	$375	$420	$395	$415

(d) Other building construction items have been included (such as foundations, duct and pipe shafts, furring at columns, and construction of machine rooms) under General Contract Items, at about 15 per cent of mechanical items.

(e) These figures are the writer's estimates for an assumed "average" new building during the coming year, and would vary widely with shape, size, use and location of building, calibre of mechanical plant considered desirable, etc.

FLOOR WORK

	Ejector	Fan-Coil	Radiant	Single Duct	Double Duct
Air Handling Equipment	120	150	100	160	225
Controls	100	100	90	90	125
Chilled-Water System	350	400	300	150	150
Steam Equipment	35	35	35	65	35
Ductwork	275	165	165	225	400
Insulation	150	125	150	150	200
Exhaust Ventilation	30	30	30	30	30
Grilles and Outlets	35	45	45	85	85
Plumbing and Miscellaneous	20	45	20	20	20
Radiant Ceiling	...	...	500	...	...
	$1115	$1095	$1435	$975	$1270
(Credit) Acoustical Ceiling	...	...	—225*	...	...
Net/Ton	1115	1095	1210	975	1270
Electrical Wiring and Other Trades	150	200	125	150	200
	$1265	$1295	$1335	$1125	$1470

OTHER TRADES

	Ejector	Fan-Coil	Radiant	Single Duct	Double Duct
Sill Enclosures	100	100	...	40	100
Other Construction	250	250	250	200	250
	$350	$350	$250	$240	$350

* If good acoustic ceilings would otherwise be provided, the radiant metal ceiling (which is acoustically at least as good) should be credited for their omission.

III-6. Electric Requirements: Based on a typical, modern, fairly large office building of normal construction, usage and orientation in New York City or similar climates. All quantities are given per ton of refrigerating capacity (equivalent to approximately 250 to 300 sq. ft. net usable area), with ejector type peripheral units and separate interior zones.

Note: In Southern climates (e.g., Dallas, New Orleans, Phoenix) annual use of power for cooling will be much higher, aggregating perhaps 2 to 2½ times as high for compressors and cooling towers, and 1½ to 2 times as high for fans, due to longer operating hours in most months.

BREAKDOWN

	Compressor	Pumps and Cool. Towers	L.P. Int. Zone Fans	H.P. Int. Zone Fans
Demand	0.95KW (max)	0.35KW (max)	0.40KW (max)	0.60KW (max)
Consumption	645. KWH	305. KWH	865. KWH	1370. KWH

ELECTRICAL SUMMATIONS

	L.P. Int. Zone		H.P. Int. Zone	
	All-Electric	Stm. Driven Refrig.	Electric	Steam
Demand	1.70KW (max)	0.75KW (max)	1.85KW (max)	0.95KW (max)
Consumption	1810. KWH	1170. KWH	2310. KWH	1675. KWH

III-7. Steam Requirements (Pounds per Ton)—based on typical degree day heating year for New York and similar climates, and on 18 lbs./ton hr. average refrigerating consumption.

STEAM REQUIREMENTS

	Refrig. Mach.	Tempering and Reheat	Space Htg. and Hot Water	Totals (Lbs./Tons) All-Electric	Totals (Lbs./Tons) Steam Driven Refrig.
Total	13,650	9,200	12,700	21,900	35,550

III-8. This table makes it clear why steam-turbine drive for refrigerating compressors has become so popular. For a 1,000-ton plant, approximately 13½ million pounds of steam (at a cost probably not much over $16,000) will deliver the same amount of cooling effect as 650,000 KW Hrs., with an increased demand charge, also, for about 950 KW. A saving in electric power installation cost of $25,000 to $50,000 will result; whereas, the boiler plant or other source of steam-supply, whose capacity must otherwise be based on the coldest midwinter day plus a fair surplus for "heating up" and "breakdown protection," will need little if any increase in capacity to operate the refrigerating plant in summer.

III-9. With purchased steam, in some localities a markedly lower all-year rate is available for all-year power service; with a boiler plant, better operation and a better satisfied crew are the usual result.

III-10. Other Costs—Operating and maintenance labor may currently be expected to approximate $20,000 to $30,000 per year for a plant of a few hundred tons—up to $45,000 for a plant of 2,000 to 5,000 tons—figures which will vary considerably with hours of operation, calibre of management, etc. With a competent crew, maintenance supplies may average $3.00/year/ton; water make-up and chemical treatment may approximate 75¢/year/ton currently in the New York area.

III-11. Total Cost of Air Conditioning—From data similar to the above, an approximate analysis may be made of the cost of providing good air conditioning under any given set of conditions. As a sample, in New York or equivalent climate, with a 1,000-ton plant, in a building with about 250,000 net sq. ft. usable area, steam-driven compressors, purchased steam and current:

TOTAL COSTS

Installation Cost (including electric power and accessory construction work)		$1,800,000
Fixed charges (at 10 per cent aggregate)		$180,000
Electric power, 1,670,000 KWH (per year)	$27,000	
Steam 35,000,000 lbs. (per year)	41,000	
Operating and Maintenance Labor (per year)	30,000	
Water, Maintenance Materials, etc. (per year)	3,000	
Annual Operating Cost including winter heating and ventilation		$ 101,000
Total Fixed and Operating Cost		$ 281,000
Increased Building Cost ($1,800,000/250,000)		$7.20/sq.ft.
Annual Unit Cost—Operating		40.4¢/sq.ft.
Annual Unit Cost—Fixed		72.0¢/sq.ft.
Total		$1.124/sq.ft.

It is evident that for the example given an increased average rental of $1.25 per sq. ft. would suffice to retire the investment, pay all interest, taxes, and operating costs. This figure applies closely only in climates analogous to the North Atlantic States.

By Bob H. Reed *
Texas Engineering Experiment Station

NATURAL VENTILATION

The effect of windows on natural ventilation is no new subject at the Texas Engineering Experiment Station. As early as November 1951, a report treating the subject was published by the Station (RL2).† Since this report had a very limited circulation and its conclusions are believed to be important, and since it is thought that improvement in window design has not and should not reach a stopping point, the subject chosen for this paper, largely from this particular report, is worthy of re-emphasis.

AIR FLOW A PRIME FUNCTION

Designing and building good windows is most assuredly a difficult task. Windows are expected to perform many functions and overcome many problems. In recent years great strides have been made in the improvement of windows. They have been made stronger, more economical, air-tight when closed, rain proof when open, and rust and rot resistant. They have been made easier to operate and simpler to clean.

Despite all that has been done, however, there seems to be an almost total lack of concern for summer ventilation in window design. This is undoubtedly not due to a lack of ingenuity on the part of the window designers, rather it is most likely due to a lack of information on summer problems in warmer climates. It may also be partly due to the fact that most of our windows are still manufactured in the east where winter problems are paramount.

Properly directed air flow is, nevertheless, essential to summer comfort in hot, humid climates, and should be considered a prime function of a window, if it is to be marketed in the south and southwest sections of the country. Manufacturers' advertising literature, however, indicates that more interest has been devoted to air infiltration than to air flow. That is, more thought has gone into the design and performance of the window when it is closed than when it is open. In nearly every case, such literature devotes a considerable amount of space to the results of infiltration tests with hardly a trace of information on air flow tests. Infiltration is, of course, very important, especially in cold and extremely windy weather, but so is air flow important in hot, humid and otherwise moderate weather.

WINTER VENTILATION vs. SUMMER VENTILATION

Joseph B. Kincer, senior meteorologist of the U. S. Weather Bureau, states: "Air movements have an important physiological aspect. They produce a cooling tendency in all conditions of temperature by accelerating the conduction of heat from the body and by increasing the opportunity for evaporation which is a cooling process. The physical effects of high temperatures are very much modified when accompanied by a brisk air movement. But a low temperature which may be even stimulating in a calm, becomes unpleasant in windy weather" (RL38).

Roughly speaking, then, the chief difference in winter ventilation and summer ventilation is that in the winter one usually does not want to be in a current of air, but in summer he often does. This conclusion is greatly simplified, of course, for the sake of clarity. The variables involved in producing human bodily comfort or discomfort are numerous and a change in

* Bob H. Reed is an Associate Research Architect with the Texas Engineering Experiment Station. He has a Bachelor of Architecture from Texas A & M and is a member of the National Conference on School House Construction, and of the Illuminating Engineering Society and its Daylighting Committee. He was formerly associated with the architectural and engineering firm of Caudill, Rowlett, Scott and Associates.

† *For Bibliography of Selected References see page 169.*

any one of them from one minute to the next can modify or reverse a person's need for air movement. These variables are listed in Henry Wright's excellent discussion, "What is a Draft?" (RL43) as follows:

"(1) Velocity of the air stream
(2) Temperature of the air stream
(3) Relative humidity of the air stream
(4) Surrounding thermal conditions
(5) Duration of exposure
(6) Degree of exposure (clothing)
(7) Physical and physiological state of the individual."

A great many of our buildings must still rely on natural air movement for summer cooling. In their lack of temperature and humidity control, air movement is the only factor left with which to work for summer comfort and it must be used to the utmost. Referring to the aforementioned list of variables effecting comfort, if we assume the physical and physiological state of the occupants of these buildings to be normal, and if we establish values for the temperature and relative humidity of the air on a typical southern summer day, substitute these values in the ASHVE comfort charts and effective temperature charts (RL17), and solve for variables 1, 5, and 6, the answer will usually be that these people should remove as much clothing as their social standing will allow, get in the fastest air stream available, and stay as long as possible. Rarely will a subjective test disagree with these calculations, and the proof is in the everlasting popularity of the short-sleeved sport shirt and the electric fan.

WHY STOP THE DRAFT?

There are times, of course, when air movement can cause discomfort even in summer such as when a person oversaturated with perspiration is subjected to a fast current of dry air, causing the "draft" sensation. This is aptly pointed out by Wright. Except for such special cases, however, it is still believed that air movement in summer is more often sought than avoided.

Mr. Wright has defined a draft as "an air movement within an enclosure of sufficient cooling power to cause local chilling of the more exposed portions of the body." This is a very good definition from a discomfort point of view, but it leaves us without a name for "an air movement within an enclosure of sufficient cooling power to cause cooling and comforting of the exposed portions of the body." For the purpose of this paper at least, it is preferred to use Webster's somewhat more concise definition that a draft is simply a current of air. On this basis, drafts would be generally undesirable in winter and generally desirable in summer. This should cause no more confusion than already exists in the window literature (Figs. 1.29 and 1.30).

Many standard windows would seem to be designed on the basis of winter ventilation only, since they are advertised as having operating vents which deflect "air currents" upward for "draft-free" ventilation. Some manufacturers are more specific in advertising their products by definitely stating that their windows are designed for winter ventilation. But most of the literature leads to the impression that the so-called "draft-free" principle of window design is just the thing, regardless of the season or the climate, using such phrases as: "fresh air ventilation in any weather . . . by deflecting drafts upward," "draftless ventilation in all seasons," "freedom from direct drafts," "indirect ventilation," "all weather ventilation" and "100 per cent controlled ventilation."

Windows which are to be used for summer ventilation should be designed to permit the greatest possible use of the natural wind forces when needed for cooling. This means that, in addition to deflecting drafts upward in winter, these windows should also be capable of directing the drafts or air currents downward through the living zone in summer. It doesn't seem

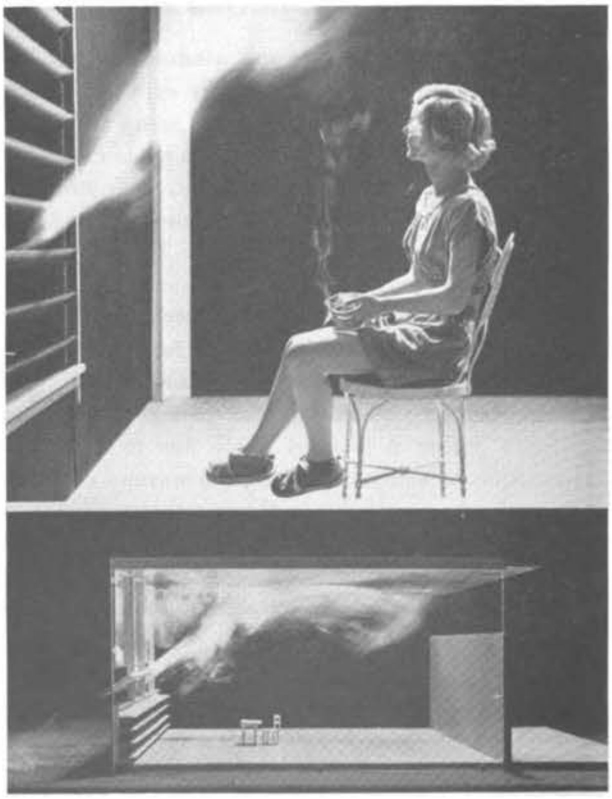


Fig. 1.29—Draft-free ventilation: a "must" in winter, a mistake in summer.

Fig. 1.30—Direct drafts are essential to summer comfort in hot, humid weather.

to make much sense to stop the natural draft with a window and then, for the sake of comfort, create another draft with an electric fan (Fig. 1.31).

Fig. 1.31—Creating a draft in a "draft-free" environment.

NOMENCLATURE IN THE INDUSTRY

There seems to exist a great need for eliminating the present confusion of terms and misleading statements regarding air flow performance in the window market. To most people, drafts mean undesirable air currents which have definite association with cold weather. But, defining a draft as a current of air, it is very desirable during hot summer weather, and the so-called "indirect" or "draft-free" summer ventilation becomes a bit ridiculous. Therefore, it seems advisable that the industry formulate a uniform nomenclature which either explains the difference in desirable and undesirable drafts of air currents, or adopt a precise definition for the term "draft" in the undesirable sense and another to represent the desirable aspects of air flow.

A better understanding of the air flow characteristics of common type windows would be a great help in eliminating the confusion that exists. Therefore, the remainder of this paper will be devoted to the classification of windows and a brief discussion of how the various types perform in terms of air flow.

It is not the purpose here to discredit any one window type simply because it is limited in its applications for summer cooling; there are other functions of the window, exclusive of summer cooling, which are just as important. The purpose is rather to point out the fact that some windows are limited in this respect and probably should not be used in applications where summer cooling is the major problem.

CLASSIFICATION OF WINDOWS

While manufacturers produce a great variety of windows, virtually every window in any kind of building can be classified as one or a combination of three basic types in regard to effect on air flow patterns. These three types will be referred to as: (1) simple opening, (2) vertical vane, and (3) horizontal vane (Fig. 1.32).

Simple opening windows are such windows as the single hung, double hung, and horizontal sliding—any window which does not pivot, but opens by sliding in a single plane.

Vertical vane windows are the side hinged casement, the folding casement, and the vertical pivoted or reversible window—any window which opens by pivoting on a vertical axis.

Horizontal vane windows are the projected sash, the awning, the basement, the horizontal pivoted, and the jalousie or louvered glass window—any window which opens by pivoting on a horizontal axis.

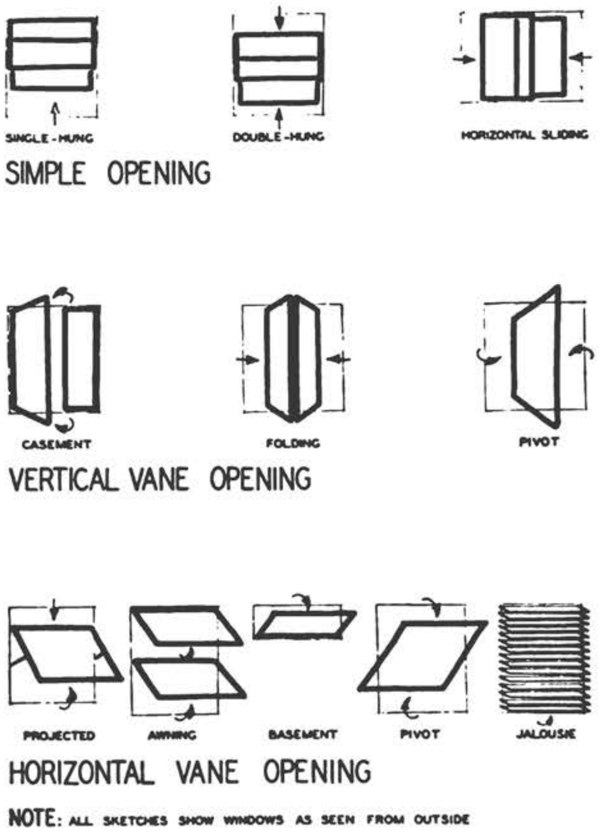


Fig. 1.32—Classification of windows.

AIR FLOW CHARACTERISTICS

Holleman gives a complete analysis of the air flow characteristics of each of the different windows in Research Report 33 (RL2) including various positions of adjustment and wind direction. Time does not permit the inclusion of this complete analysis here, but the characteristics of the three basic types of windows can be generalized, assuming average conditions.

Generally speaking, air is likely to flow in most any direction through a simple opening or through a vane opening in the plane of the operating sash, depending on the surrounding pressures at the various sides of the opening. Only when these pressures are symmetrical will the air flow straight into the opening (that is, perpendicular to the plane of the window wall). When these pressures are asymmetrical, which they usually are, the incoming air will flow through the opening at some angle other than perpendicular to the wall. On the other hand, in a plane perpendicular to the operating sash of vane type windows, the air generally flows parallel with the angle of adjustment of the operating sash (vane), just as the flow of air follows the rudder of the airplane's tail (Figs. 1.33, 1.34, 1.35).

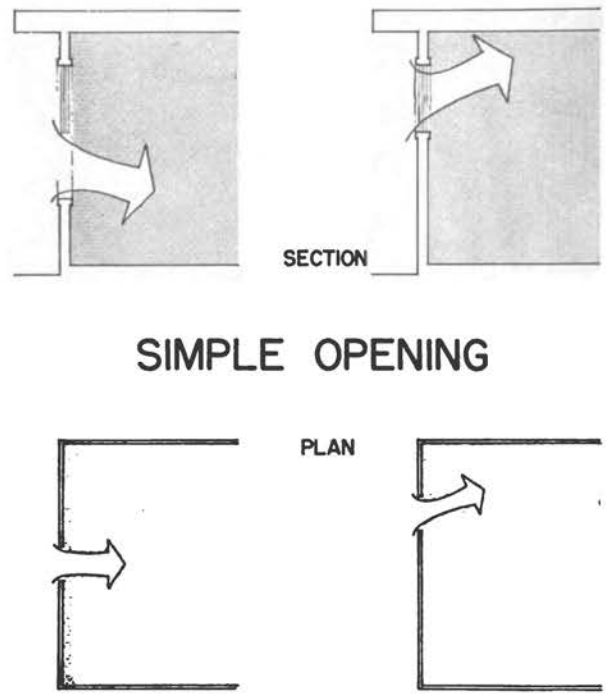


Fig. 1.33—Simple opening, section and plan.

In Figs. 1.33, 1.34, 1.35, typical air patterns are shown in section (above) and plan (below), assuming a wind perpendicular to the plane of the window wall.

Figure 1.33 shows a few ways in which air may flow through a simple opening. In the left section diagram, the pressure above the opening is greater than that

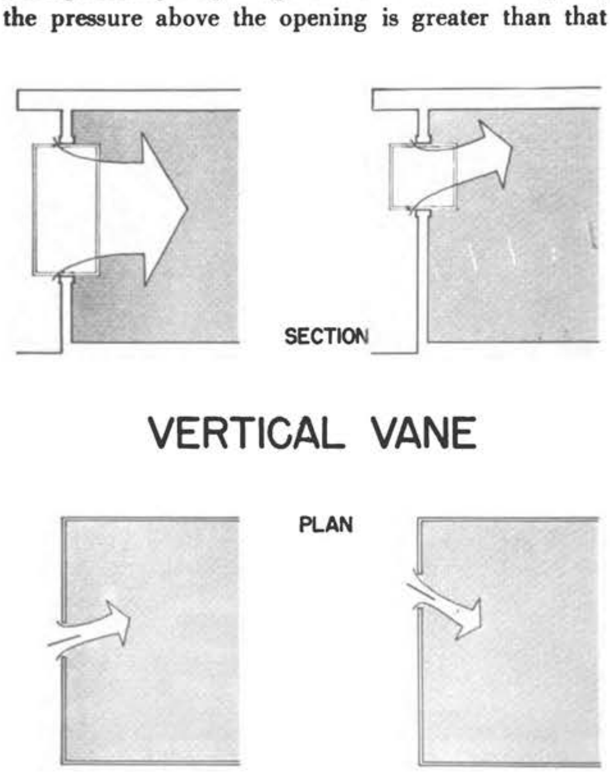


Fig. 1.34—Vertical vane, section and plan.

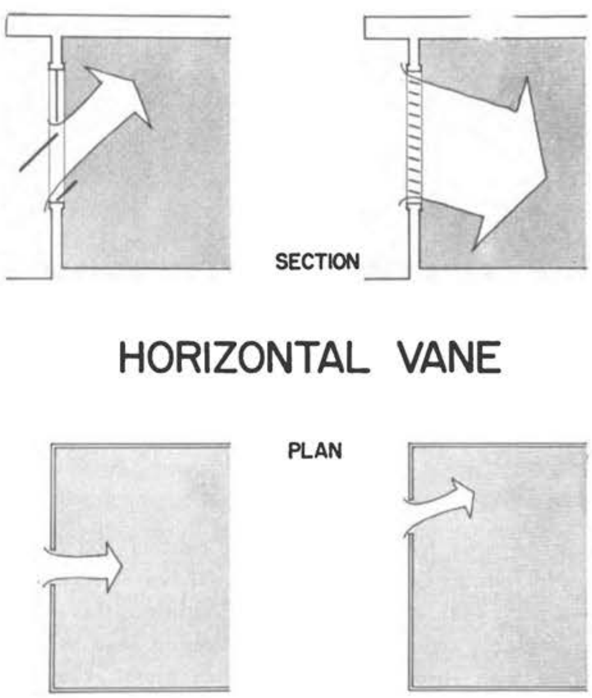


Fig. 1.35—Horizontal vane, section and plan.

below, causing the air to flow at a downward angle as it passes through the opening. In the right section diagram, the larger pressure below the opening forces the air to flow in an upward direction as it enters the building.

The two plan diagrams show how the air will flow straight into the simple opening when the pressures around the opening are symmetrical, as shown in the left diagram, and how it will flow in at an angle when the pressures around the opening are not symmetrical, as shown in the right diagram.

Figure 1.34 shows the general characteristics of the vertical vane type window. In section, as shown in the upper diagrams, the pressures above and below the windows determine the final direction in which the air will flow, as with the simple opening. In plan, however, the air stream usually follows very closely in the plane of the operating sash, as shown in the two lower diagrams, regardless of the pressures around the openings.

The horizontal vane opening shown in Fig. 1.35 is the direct opposite of the vertical vane opening, in that the air flow follows roughly the angle of adjustment of the operating sash in section, whereas it may flow in any of several directions in plan, as through a simple opening, depending on surrounding pressures.

CONCLUSION

While the importance of the various aspects of window design, such as weather proofing, durability, strength, ease of operation, etc., is recognized, it is suggested that more design consideration could be devoted to the air-control characteristics of the window—characteristics which will provide adequate performance when the window is open as well as when it is closed.

Discussion Period—HEATING, VENTILATING AND AIR CONDITIONING

MR. WENZLER: I would like to ask each of the three speakers if he has any questions or comments to make on papers given by the other speakers.

MR. VILD: Yes, I have some comments in regard to Mr. Jaros' paper.

In Appendix No. II of his paper Mr. Jaros compares the amount of air conditioning equipment required for various percentages of fenestration area. In essence his tabulations are within the accuracy of contemporary design procedures. Unfortunately the example is not typical from the standpoint of proper evaluation of the portion of the air conditioning load due to heat transfer through glass. In the majority of large commercial buildings, it is feasible to supply zones on opposite exposures of the building from a central air conditioning unit. Thus a high morning load on an east exposure is often balanced by a low load on the west exposure. In the latter part of the day, the loads proportionately may be reversed, although the total may be very nearly the same. In sizing equipment it is the maximum total instantaneous cooling load that is significant and not the load from one particular exposure. Take an example of an office building with large north and south exposure offices 16 ft. deep on each side. This is the way most architects would orient a building to best overcome climatic conditions, other factors being equal.

Calculations based on the procedure and values in the 1956 ASHAE Guide yield the following results. Using common window glass an increase in glass area from 25 to 50 per cent of the facade area requires an increase in air conditioning equipment of 0.9 tons per 1,000 sq. ft. of floor area. Increasing the glass area from 25 to 75 per cent increases the equipment size by 1.8 tons per 1,000 sq. ft. of floor. If, in place of common window glass, a double light of heat-absorbing glass and regular plate glass were used, an increase in glass area from 25 to 75 per cent of the facade would require less than 1 additional ton of refrigeration per 1,000 sq. ft. of floor. In addition, this would appreciably reduce the air conditioning load as compared with equal areas of window glass. Compare these increases with the 1.6 tons of refrigeration necessary to overcome the lighting load alone for the same floor area, or 2.0 tons needed to handle the ventilation and people load for 20 men in a conference room.

The increases in equipment size due to additional glass area are calculated assuming no shading of any type. Shading provided by adjacent buildings and building projections will reduce the amount of additional equipment required. In the extreme case, where all windows are shaded as indicated or oriented away from the sun, an increase in glass area from 25 to 75 per cent of the facade would necessitate an additional 0.8 tons of air conditioning capacity per 1,000 sq. ft. of floor. This is for common window glass. For the double light previously described, an increase in area from 25 to 75 per cent would require only an additional 0.4 tons of refrigeration for the same 1,000 sq. ft. of floor area.

Another factor to consider is that an increase in fenestration area may make it possible to decrease the lighting load. Assume a hypothetical case where an increase in area of a double light fenestration from 25 to 75 per cent would allow less frequent use of artificial lighting. With these circumstances, the net cooling load would be *reduced* by about 0.6 tons per 1,000 sq. ft. of floor area. Thus, increasing the glass area by 200 per cent has actually decreased the air conditioning load. As the natural illumination is decreased due to inclement weather conditions or other factors, the decrease in heat gain through the glass will partially offset the increase due to the necessity of turning on the lights.

J. M. SHULL (Reynolds Metals Co.): How significant is even a moderate amount of surface dirt in affecting the transfer of heat gain through glass?

MR. VILD: A moderate amount of dirt won't seriously affect the total heat gain. The transmitted solar energy will be reduced, but the absorption ratio of the glass will be increased with even a moderate amount of dirt.

T. S. ROGERS (Fiberglas Corporation): Most orientation data given in your talk deals with primary orientations—north, east, south, west. Are there any special control problems at intermediate orientations, such as southeast or southwest?

MR. JAROS: This is a problem that is ever present in New York, because what we call "north" in New York is not north; it's something like 28 degrees east of north. The result is that in mid-morning a southeast facade, and in mid-afternoon a southwest facade, is getting the sun's heat at an agle that is intermediate in altitude between those of a south facade early in the day and those of the east and west facade late in the day. As far as east and west goes, the figures differ but it is easy enough to apply them in designing the job.

When you come to shading devices, however, this has quite a bearing. The projecting balconies which I spoke of rather warmly for south exposures become less and less effective as you walk around to the east or west. A shadow machine, such as quite a few architects' offices have, in which any position of the sun can be simulated on a model, would tell just about at what angle the balcony of a given building ceases to be effective.

The vertical louver scheme and the horizontal louver scheme, particularly if they are movable and controllable, can be adapted just as easily to north or south exposures as they can to east or west. And this may be one reason why the newest buildings using such devices seem to show an increasing tendency to use more and more of the vertical louvers, particularly the adjustable ones, rather than the structurally heavier balconies.

JOHN EVERETTS, JR. (Charles S. Leopold, Engineer): Do you have any Btu transfer data with the lines between two plain pieces of glass or one plain and one heat-absorbing glass controlled between the pieces of glass?

MR. VILD: There has been no precise experimental work done on this. I think the ASHAE is presently working on this project. I think this is a very worthwhile project.

MR. JAROS: This brings to mind a scheme that I have seen suggested several times, although I have never actually tried it, which would relate to any method with two layers of glass as long as there were something in between that tended to absorb or obstruct the sun's rays. The suggestion has been made that we ventilate the space between the glass. The blinds or even the fact that the first layer of glass is heat-absorbing glass tends to convert radiant energy into sensible energy, and heat displaced between the two layers of glass to a higher temperature. I think Mr. Vild would agree with me that that would tend to increase the temperatures of the insulation. If you knew a way to absorb that heat, whether you did it with outside air or cooled air, you would increase the net temperature to the room by doing so. I think sooner or later something of this sort will be tried.

ALEX HAVLICSEK (E. K. Geyser Co.): In general, approximately how much opening in the spur of heat in natural ventilation is actually recommended related to square foot floor area in a room of normal ceiling height?

MR. REED: Without getting into the ridiculous, the more the better. The most ideal thing you can have in a tropical climate, I think, is a shed roof with no walls at all. I don't know of any figures that can be applied to the square foot area of windows, but the more the better; that's all I have to say.

H. B. QUICK (Glenmar Manufacturing Co.): Your general studies show lower light and heat transmission on a cloudy or overcast day. We were called in on a problem in Los Angeles where we recorded anomaly of higher heat transmission on overcast days. Does infra-red come through overcast?

MR. VILD: There is one instance where you may get a higher heat transmittance on overcast days, in that the distribution of the diffuse energy may be such that you are getting quite a bit in between your louvers, while on a clear day the diffuse radiation will be small and you will not get quite so much through the louvers. This is the only situation I can think of where you would get greater heat transmission.

R. T. HOLTZ (B. F. Goodrich Chemical Co): What is the effectiveness of double-glazed windows in reducing solar heat input, and can their higher initial cost be offset by savings in original and operating costs of air conditioning?

MR. JAROS: I think this question calls for an opinion and not simply for facts, especially the second part. The heat input due to conduction of heat from the warmer outdoor air to the cooler air inside of an air conditioned building is very definitely affected by using double, rather than single, glazing. Roughly speaking, without going into a lot of figures, you cut the conduction of heat in half. As far as solar radiation is concerned, each sheet of glass does reflect, absorb or otherwise dispose of some portion of the original radiant energy from the sun. Remember that we are talking now of radiant energy, not hot air as such.

However, the amount that each sheet of ordinary glass absorbs is only about 10 per cent of the radiant energy present before the beam of energy struck the glass. And the two layers of glass therefore might be expected to compare in radiant energy transmittance somewhat as 8 compares with 9.

I can give a much more definite opinion answer to the second part of the question. We have made studies over and over again regarding the merits of double-glazing of any type, whether it's two sheets of glass with single mounting or two separate windows, from the point of view of savings in air conditioning and heating costs. Usually under most conditions it does not pay. We have very seldom ever been able to establish to our own or the client's satisfaction that the increased cost of providing double glazing paid out in terms of savings in the cost of providing air conditioning and heating.

However, one of the difficulties in winter in cold climates, even though a room may be adequately heated in the sense of air temperature, is the negative radiation from the human body, exposed surfaces, particularly glass or metal surfaces exposed to the outdoors. You may have a condition where the air in the room is at 75°, but the sheet of glass is only at 30° or something of the sort. And if you sit near that glass, the side closest that glass is chilled because it radiates heat to the glass.

Double glazing eliminates most of this difficulty in cold weather by providing a much warmer inside glass surface. When it is zero, say, outdoors, instead of the inner surface of the glass being 30 or 35 or some such temperature, it may be at 50 or more if you have double glazing. And these local chilling effects of cold glass, while still theoretically present, are approaching the vanishing point as a practical matter of comfort.

This may make it possible to use a much simpler sort of heating system or air conditioning system, because you may get rid of the need for providing separate heat directly under the glass, which might otherwise be necessary. And in that sense, rather than actual Btu savings, you may get a large enough saving on installation and operating costs to pay or more than pay for the cost of the double glass.

I can cite one very specific example, the Alcoa building in Pittsburgh, which has double-glazed windows. The outer pane, if I remember correctly, is heat-absorbing glass, in addition. As far as the summer conditions are concerned, it made little difference in the air conditioning costs, but it did enable us to use a system in which no heat whatever is provided under the glass for winter heat, with a great simplification of duct systems, piping systems, and so forth. And in practice, after several years' occupancy nobody claims that it is chilly next to the glass.

PART II

PRODUCT ENGINEERING

Chairman
Robert W. McKinley
Technical Representative,
Pittsburgh Plate Glass Company

ENGINEERING PROPERTIES OF GLASS

By Leighton Orr *
Pittsburgh Plate Glass Company

The information presented here relates specifically to the use of glass in buildings. Since there are no particular problems with small plates, the discussion will refer to the trend to use larger size glass plates, often with special properties, where the stresses developed could possibly lead to failure of the plates.

We usually think of wind loads as the most common method of stressing large glass plates. Ordinary methods of calculating stresses and deflections are not valid because of the extremely large center deflections. For this reason we are in progress on an experimental program using equivalent static pressure loads on large size glass plates.

The other method of stressing large plates is by temperature difference, where the sun is the usual heat source. This is more common in heat-absorbing glasses, opaque structural glasses or enamel coated spandrel glasses, where the solar absorption is not uniform over the entire glass area.

In dealing with the strength of glass the rate of applying the load or the length of time the load is held is important in determining the stress causing failure. An impact type of loading will withstand three times more stress than that developed from a constantly applied load held for a long period of time. Also, a failure always originates at some form of imperfection on the surface or on the cut edge. The larger the plate, or the greater the area stressed, the greater the possibility of an imperfection being present and the lower the stress required to cause failure. With glass there are no indications of when or where a failure is starting. The severity of the break depends on the amount of energy available to continue the fracture. A high velocity, high energy break produces ragged fracture surfaces which fork and send out branches, while a low velocity, low energy break produces a smooth surface fracture which continues as far as the energy is available, but does not fork.

WIND LOAD TESTS PROGRAM

The test plan followed was actually a static load test using reduced air pressure on one side of a plate of glass mounted vertically. The frame used for the 82" x 120" plate shown in Figure 2.1 was made up using 6" x 6" H columns. A 2" wood liner was inserted all around the inside face of the frame. To the back edge of this liner was mounted 5/8" plywood stiffened with a double 2" x 2" angle at the joint of the two sheets. Near the front edge, 7/8" deep stops were used to mount the glass as shown at the bottom of Figure 2.2. The stops were lined with 1/8" x 1/2" rubber near the base and a 3/16" x 5/16" extruded glazing compound inserted near the edge of the stop. The glazing compound was compressed by pressure on the stops to 1/8" thickness which was limited by the rubber strip forming a definite seal. The glass edge was recessed 5/8" leaving a 1/4" clearance between glass and opening all around.

For smaller size plates additional 6" H beams were inserted in new horizontal and vertical positions, and the plywood and stops revised accordingly. The 2" diameter connection to the exhaust fan was located near the lower left corner with a valve for rough adjustment of pressure. A smaller line with control valve was used as bleeder for fine control of pressure. Another outlet to the enclosure was connected to a water column to measure pressure difference on the

* Leighton Orr is a member of the Research Laboratory staff of the Pittsburgh Plate Glass Company, and has done physical testing work for 20 years with this company. He has a Bachelor of Science in Mechanical Engineering from the University of Pittsburgh, and is a member of the American Society of Mechanical Engineers and the Society for Experimental Stress Analysis.

two sides of the panel, later converted to load in pounds per sq. ft. In converting to equivalent wind velocity mph we have used the form P—.0032V², but we realize there are differences of opinion regarding the constant used, ranging from .0025 to .0040, and also adjustments for air density at elevations above sea level.

During the test a constant center deflection in increments of .100″ was held by control of the bleeder valve while viewing the center mounted dial gauge with a small telescope at a distance. While holding the center deflection constant a series of observations were made, including deflections at stations 10 or 12″ apart along the principal axes using a machinist depth gauge inserted through the holes in the bars clamped to the cross arms shown in Figure 2.1.

Also measured was the change in strain from 20 bonded strain gauges located on both surfaces of the glass plates at critical locations along the principal axes boundaries of the lower left quadrant. On some plates a few of the gauges were located along a 45° diagonal from the lower left corner. We also measured bending by change in curvature using a 4″ span gauge at various locations along the full length of the

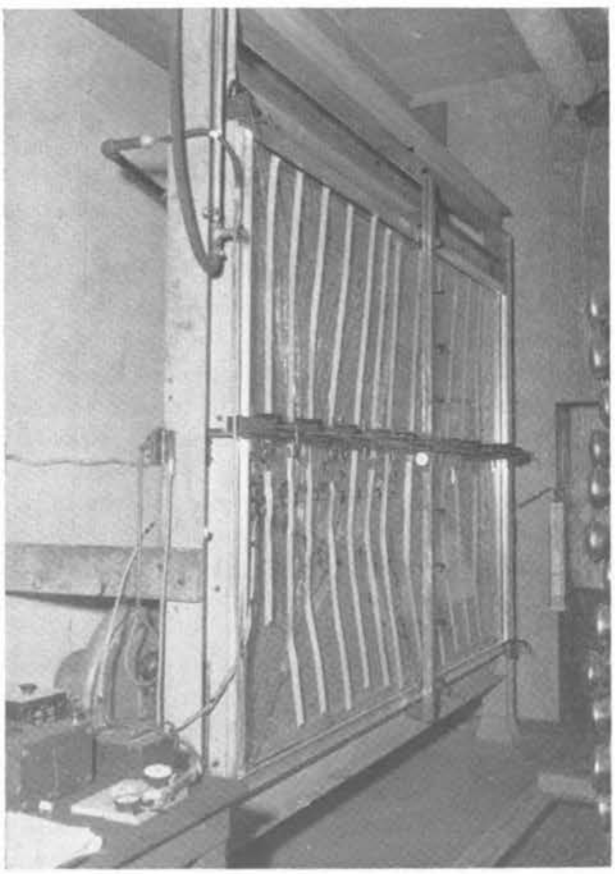


Fig. 2.1—Frame and other equipment used for wind load test of 6′10″ x 10′ plate.

principal axes and along one 45° diagonal. The pressure on the glass was observed at the start and end of the series of measurements for each center deflection, which required from 5 to 25 minutes depending on how many of the strain gauge, deflection and curvature measurements were taken.

Strips of masking tape were applied to the outside glass surface to hold the fragments in place in order to trace the origin of the break to a definite location. In each case the breaks were very severe, with the plate shattering into many pieces. In most cases the origins were located as shown graphically in Figure 2.2 for one group of tests. This also records the angle of the break and a sketch of the fracture face showing a scratch or crush on the surface, producing a weakness where the break started. From experience we have learned to estimate the stress causing failure from a measure of the smooth length between the break origin and the first roughened face of the fracture. These estimated stresses are recorded in Figure 2.2, and average about 3,000 psi for the group of plates.

WIND LOAD TEST RESULTS

Actually two separate series of tests were conducted involving 20 plates tested to destruction. The variables included plate glass and Solex glass, thickness range from .114″ to .383″, area from 47 to 80 sq. ft. and shape factor from square to 0.6 ratio of sides. Typical plots of center deflection versus load are shown in Figure 2.3 representing three different glass thicknesses and two different glass sizes.

The range in center deflection at failure for the 20 tests was between 1.0 and 1.6″. Naturally the larger sizes were in the upper range of deflections but what appeared unusual was that the glass thickness had very little effect on deflection at failure. The departure of calculated deflection from measured center deflection at failure was greater for thinner glasses, being in the order of 12 for 1/8″ glass, 5 for 1/4″ glass and 2 for 3/8″ glass. Lack of space prevents description of deflection measurements along the principal axes. In general, the trend is for the curvature to be greatest at the center and flat at the edges for low loads. As the load increased, the central area became flat relatively and the greatest curvature shifted to a region between center and edges. Even at high loads near failure there was negligible curvature at the edges, indicating that the glass is free to rotate as much as 3° but pulled out of the frame .02 to .04″.

We have not completed the analysis of the curvature measurements using the 4″ span gauge, but it appears that the greatest curvature would be at right angles to a diagonal a considerable distance from the corner.

Along the principal axes the greatest change in curvature was not at the center, but between the center and the edge. These measurements of change in curvature can be converted directly to bending stress in psi. However, because of membrane tension stresses, where the deflections are large in relation to the glass thickness, the bending stress is only part of the surface stress.

To obtain the combined stress from both bending and membrane we must depend on bonded strain gauges. It is very difficult to make a complete stress survey over a large area as there is a limit to how many gauges can be used with certain equipment. Twenty gauges were used on each test plate along the axis boundaries and diagonal of one quadrant. The gauges were divided between the two surfaces and, since there should be gauges in three directions at any one location, this does not allow a very complete stress survey. The greatest measured stresses were along a diagonal well in from the corner. The stress at the center is well below the maximum. It is interesting to observe that there were many locations where membrane stress predominates to such an extent that both surfaces were in tension.

The basic information regarding the 20 test plates and their performance at failure are summarized in Table 1. From an examination of the results expressed as total load at failure, we could not detect any significant effect of the size or shape within the range used in these tests. The thickness was the most important factor controlling total load. To show this more definitely, column ten of Figure 2.4 is a tabulation of the total load per .001″ thickness. This value is fairly close to ten. Thus for a quick estimate of total load in pounds to cause failure of a large plate simply multiply the glass thickness in thousandths of an inch by ten and divide by the loaded area to obtain the load in pounds per sq. ft. to cause failure.

A closer fit to the data is obtained using the empirically developed relation—$P = 7600\ (t + t^2)$ where P is total load in pounds and t is glass thickness in inches. To use this relationship for any area or glass thickness we have developed the chart shown in Figure 2.4. We would not attempt to use this formula beyond the limits of this chart. This is a practical representation of load carrying capacity of large glass plates subject to our test conditions, where the most important variable involved is the condition of the glass surface.

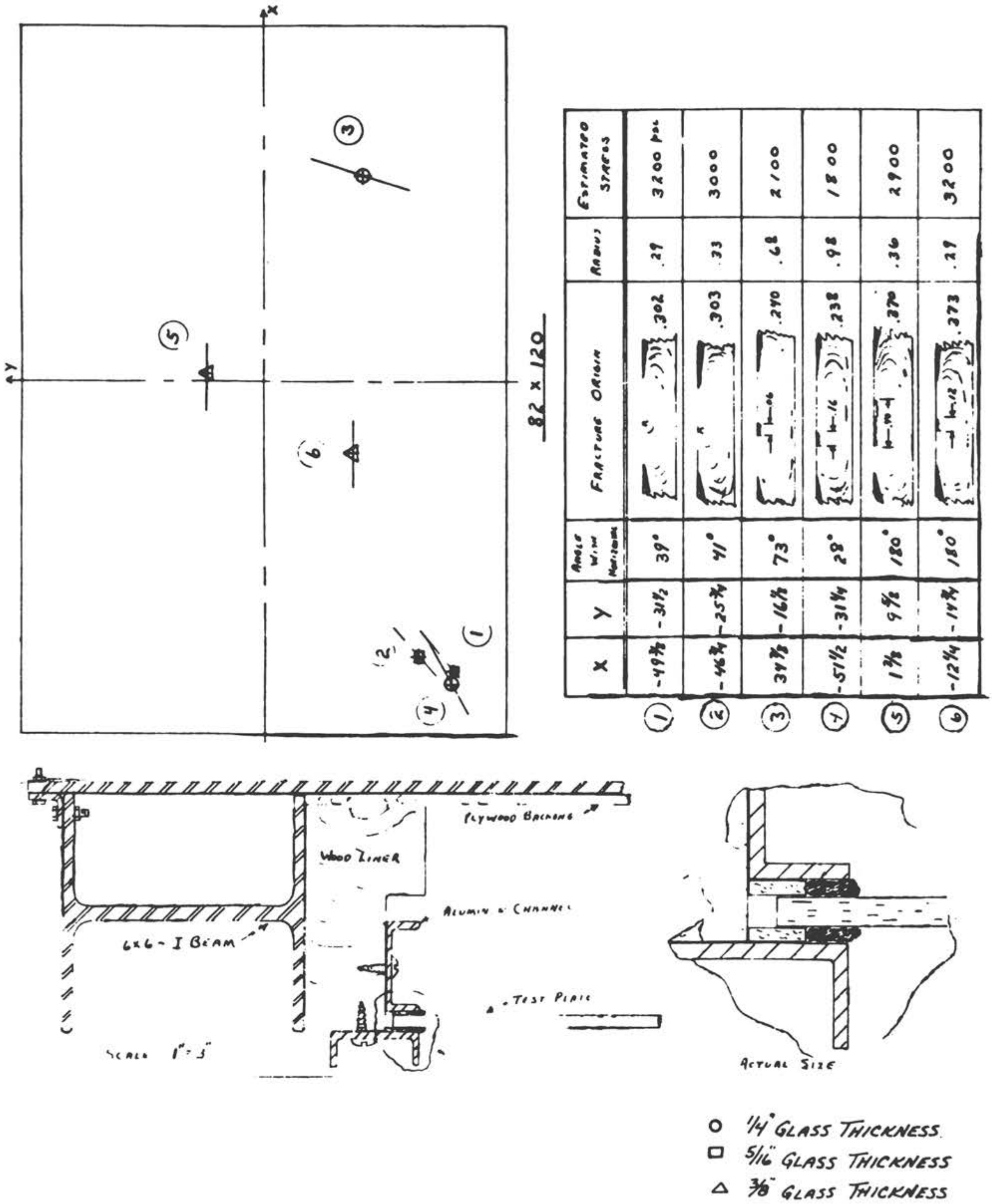
In comparing our test conditions with actual building installations, the principal difference would be the rigidity of the frame members to which the stops are fastened. We realize that edge frame members will never be 6″ H columns as used in our tests and we are already planning tests to show what effect the use of light-weight framing sections on one or more edges of the glass opening would have on the load carrying capacity of the glass. The other factor in which our tests differ from actual wind loads is the duration of the load. Each load increment was held constant for 5 to 25 minutes while making stress and deflection measurements. The extreme wind velocity loads on a building would be applied only occasionally and usually as a gust of short duration. We would estimate that the same plate would withstand almost twice the load applied as a gust, lasting only a few seconds compared with a constant load held for 25 minutes.

This was demonstrated in the tests of Twindow sealed, double glazed units, where when one plate failed under a constant load, the other plate withstood the load formerly held by both plates, while the blower was being stopped. Because of this difference in loading, the developed information, including the chart in Figure 2.4, would actually include some factor of safety. The architect is free to use any additional factor of safety depending on building conditions.

Wind load tests of large size Twindow sealed, double glass units have demonstrated definite advantages in comparison with single glass plates. This is explained by the deflection of one plate compressing the sealed air and transferring part of the load to the other plate. The actual pressure in the air space would be intermediate between the pressure on the two sides, and the pressure difference across each plate would be only a part of the total. In the tests of three different sizes, the increase in strength over what we would expect from a single plate amounted to 50 to 80%, being greater for the larger size where the strength is most needed. The plate on the low pressure side would be most likely to fail because the tension surface is exposed and subject to damage, where the plate on the high pressure side would have its tension surface inside the dry air space where it could not be damaged in use. The added strength of sealed, doubled glazed units was demonstrated during a wind storm in Winnipeg, Canada. A survey of the glass breakage for store front replacement orders revealed that not one Twindow unit was broken, while almost all of the larger single plates were broken along a certain section of the main street.

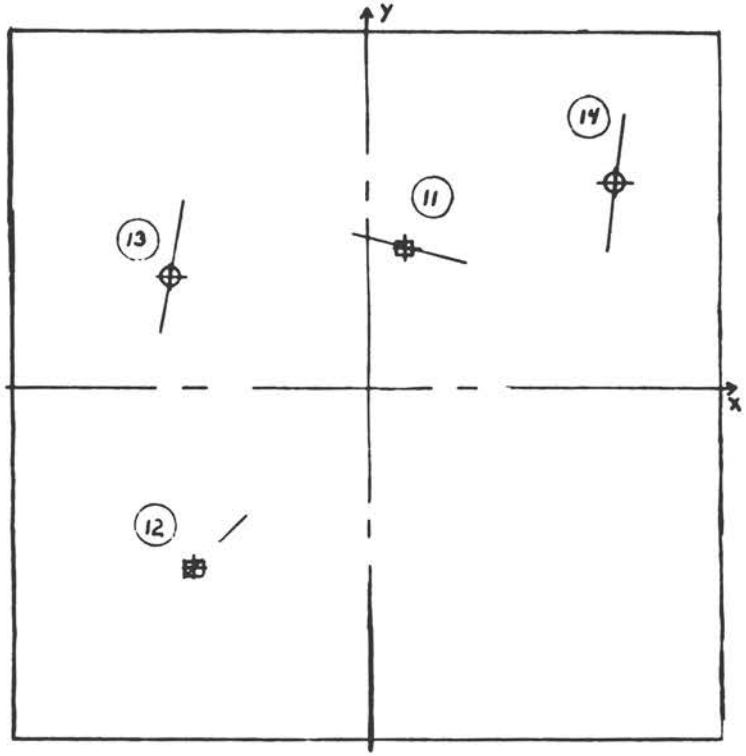
EFFECTS OF SOLAR ABSORPTION ON GLASS BREAKAGE

Before starting on a test program it would be advisable to review the fundamental data on solar energy available, and establish the behavior when intercepted by a plate of glass. The energy available from the sun,

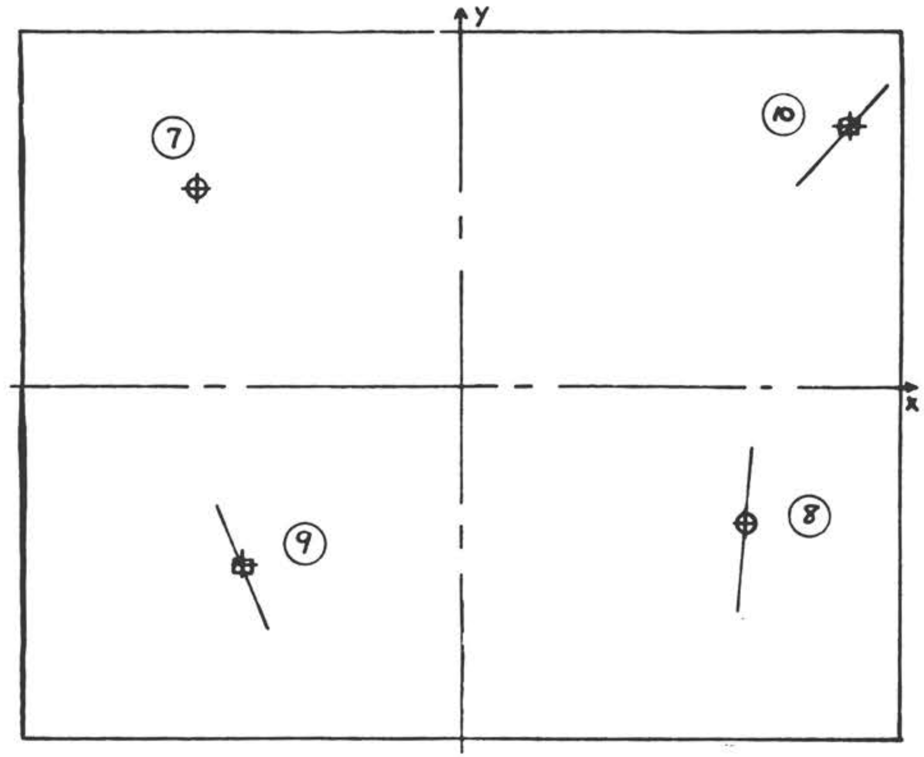


	X	Y	Angle with Horizontal	Fracture Origin	Radius	Estimated Stress
(1)	-49 7/8	-31 1/2	39°	.302	.29	3200 psi
(2)	-46 3/4	-25 3/4	41°	.303	.33	3000
(3)	34 7/8	-16 7/8	73°	.240	.68	2100
(4)	-51 1/2	-31 1/4	28°	.238	.98	1800
(5)	1 3/8	9 5/8	180°	.370	.36	2900
(6)	-12 3/4	-14 3/4	180°	.273	.29	3200

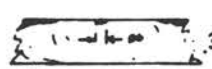
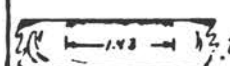
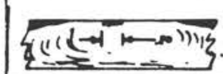
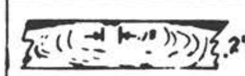
Fig. 2.2—Summary of fracture origins of large plates tested under simulated wind loads.

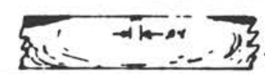
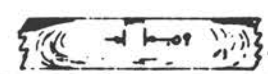
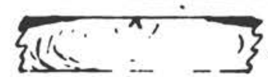


82 x 82



82 x 102

	X	Y	Angle with Horizontal	Fracture Origin	Radius	Estimated Stress
11	4 1/4	16 1/2	166°	 .302	24	3500
12	-20 1/4	-20 1/2	45°	 .298		
13	-23	12 5/8	80°	 .239	.24	3500
14	29 7/8	23 3/4	83°	 .244	.18	4000

	X	Y	Angle with Horizontal	Fracture Origin	Radius	Estimated Stress
7	-30 1/4	23	—		—	—
8	33	-15 1/2	85°	 .247	.48	2500
9	-25 1/4	-20 1/2	112°	 .302	.29	3200
10	45 3/8	30 3/8	47°	 .3[illegible]	.31	3100

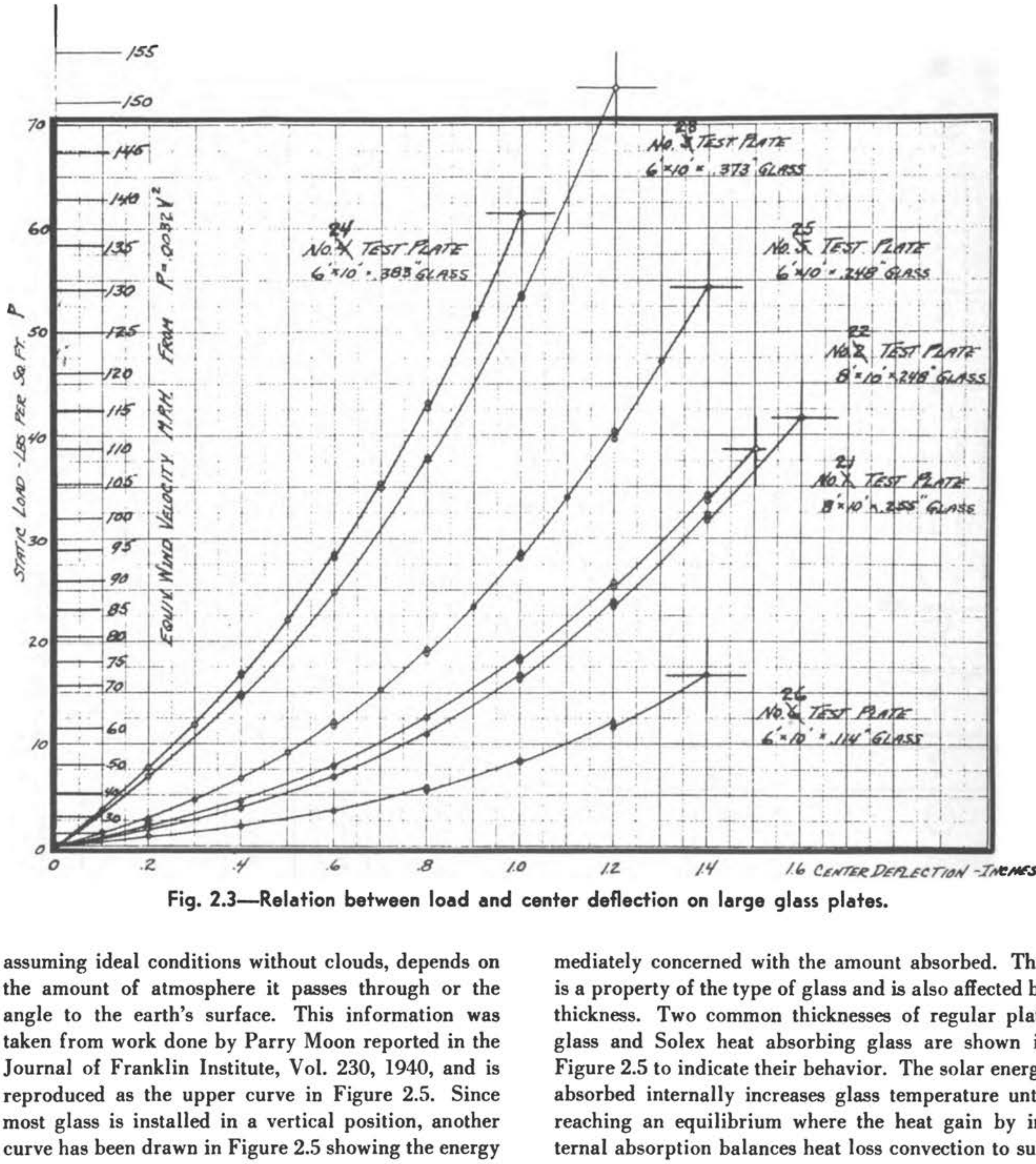


Fig. 2.3—Relation between load and center deflection on large glass plates.

assuming ideal conditions without clouds, depends on the amount of atmosphere it passes through or the angle to the earth's surface. This information was taken from work done by Parry Moon reported in the Journal of Franklin Institute, Vol. 230, 1940, and is reproduced as the upper curve in Figure 2.5. Since most glass is installed in a vertical position, another curve has been drawn in Figure 2.5 showing the energy available on a vertical surface, assuming the surface is constantly turned to face the sun. This would include the maximum possible condition for receiving solar energy on a wall of a building. This curve also shows that the greatest intensity of 204 Btu per hour per sq. ft. is obtained when the sun is 30° to 35° above the horizon.

When a plate of glass is installed on this vertical surface facing the sun, the available energy is either reflected, absorbed or transmitted. We are only immediately concerned with the amount absorbed. This is a property of the type of glass and is also affected by thickness. Two common thicknesses of regular plate glass and Solex heat absorbing glass are shown in Figure 2.5 to indicate their behavior. The solar energy absorbed internally increases glass temperature until reaching an equilibrium where the heat gain by internal absorption balances heat loss convection to surrounding air on both surfaces. The peak value for absorption of 3/8" Solex glass from Figure 2.5 was 126 Btu per sq. ft. per hour. If we assume half, or 63 Btu, lost on each surface and a film coefficient of 1.6 for still air at 70° F, the temperature rise would be 40° F. Air movement over either surface of the glass would increase film coefficient and reduce temperature rise. When using Solex in double glazing the insulating effect of the adjoining plate of glass would reduce the loss from one surface and increase the temperature

TABLE I

Summary of Wind Load Tests to Destruction, Various Glass Sizes and Thicknesses.

Glass Plate No.	Glass Size Inches	Average Thickness Inches	Loaded Area Sq. Ft.	Static Pressure at Failure In. Water	Static Pressure at Failure Lbs/Sq. Ft.	Total Load at Failure Pounds	Equiv. Wind Vel. M.P.H. P=.0032V²	Center Deflection Inches	Total Load Lbs. Per .001" Thick	Empirical Form P=7600(t+t²): (t+t²) Inches	7600(t+t²) Load-Pounds	% Diff. From Actual
13	82 × 82	.2373	45.3	10.06	52.24	2366	127.8	1.200	9.97	.2936	2232	-5.6 %
14		.240		9.99	51.87	2350	127.3	1.189	9.79	.2976	2262	-3.8 %
11	R=1.0	.303		15.54	80.65	3653	158.8	1.200	12.05	.3948	3000	-17.9 %
12		.301		10.83	56.17	2544	132.5	1.000	8.45	.3916	2977	+17.0 %
7	82 × 102	.2344	56.5	7.58	39.26	2218	110.7	1.300	9.46	.2893	2200	-.8 %
8		.2453		6.94	36.02	2035	106.1	1.200	8.30	.3055	2322	+14.0 %
9	R=.802	.3045		10.42	54.09	3056	130.0	1.200	10.04	.3972	3020	-1.2 %
10		.305		10.41	54.02	3052	130.0	1.200	10.00	.3980	3025	-.9 %
3	82 × 120	.242	66.6	6.27	32.52	2166	100.8	1.400	8.95	.3006	2285	+5.5 %
4		.239		4.55	23.58	1570	85.8	1.200	6.57	.2961	2251	+43.4 %
1	R=.680	.303		8.60	44.56	2968	118.0	1.311	9.80	.3948	3000	+1.0 %
2		.304		8.49	44.00	2930	117.3	1.300	9.64	.3964	3013	+2.8 %
5		.369		10.83	56.13	3738	132.5	1.200	10.13	.5052	3840	+2.7 %
6		.372		11.16	57.85	3853	134.5	1.200	10.35	.5104	3880	+.7 %
26	72 × 120	.114	58.13	3.22	16.72	972	72.3	1.400	8.52	.1270	965	-.8 %
25*		.248		10.45	54.22	3152	130.2	1.400	12.70	.3095	2353	-25.4 %
23*	R=.596	.373		14.11	73.20	4255	151.3	1.200	11.40	.5121	3892	-8.5 %
24*		.383		11.82	61.36	3567	138.5	1.000	9.31	.5297	4026	+12.8 %
21*	96 × 120	.255	78.12	7.43	38.56	3012	109.8	1.502	11.81	.3200	2432	-19.2 %
22*	R=.798	.248		8.00	41.52	3244	114.0	1.600	13.07	.3095	2353	-27.5 %
								Median Aver.	9.9			-.8 %

* Solex Heat Absorbing Glass

rise. Any obstruction to transmitted energy producing a heat block on one side of the glass, such as caused by tight fitting blinds or drapes, would return heat to the glass instead of allowing the glass to lose heat, resulting in an excessive temperature rise.

If the glass attained a uniform temperature rise over the entire area, no stress would result. However, where the edge of the glass is recessed in a frame and does not absorb energy, the edge temperature lags behind the normal temperature increase in the central area. This temperature difference produces tension stress all around the edge, where the plates are normally weakest. For an analysis of this effect, consider a large plate where the area absorbing solar radiation is large compared with the narrow, recessed margin. The expansion in the central area is 0.00000463" per inch per °F. For 40° F temperature differential the strain on the cold edge would be .000185" per inch. For a Modulus of Elasticity of 10,600,000 the edge stress would be 1,960 psi. This may appear low to cause a glass failure, but the stress occurs at the edge where imperfections are most likely to be located and there may be some unusual feature about the installation to cause excessive temperature difference, resulting in occasional breakage.

Painting solid designs on regular plate glass or applying decals would have the same effect as using heat-absorbing glass. Some of the darker colored opaque glasses or enamel coated glasses would be almost perfect absorbers, where the only safe solution would be to partially temper these plates to allow greater resistance to temperature difference.

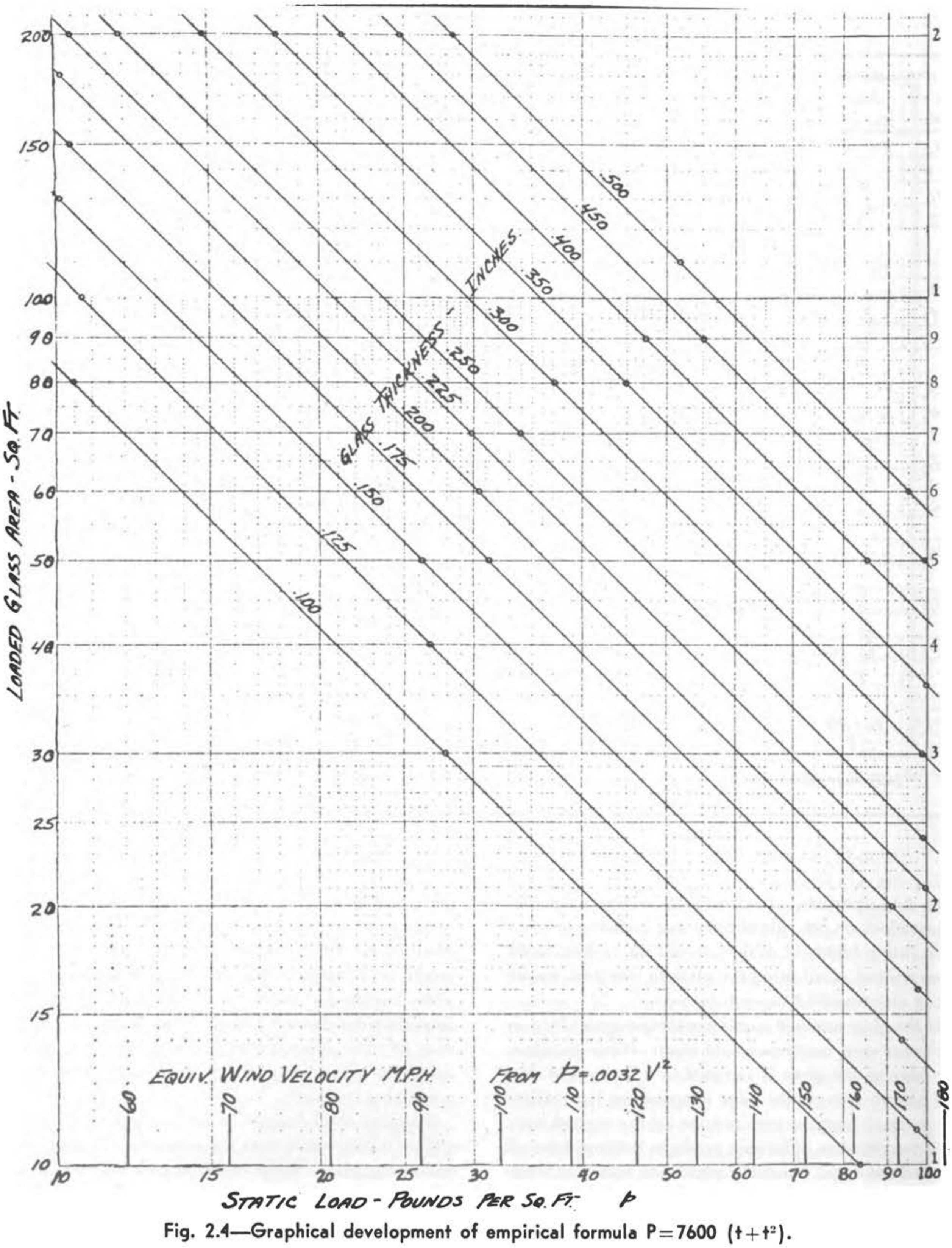


Fig. 2.4—Graphical development of empirical formula P=7600 (t+t²).

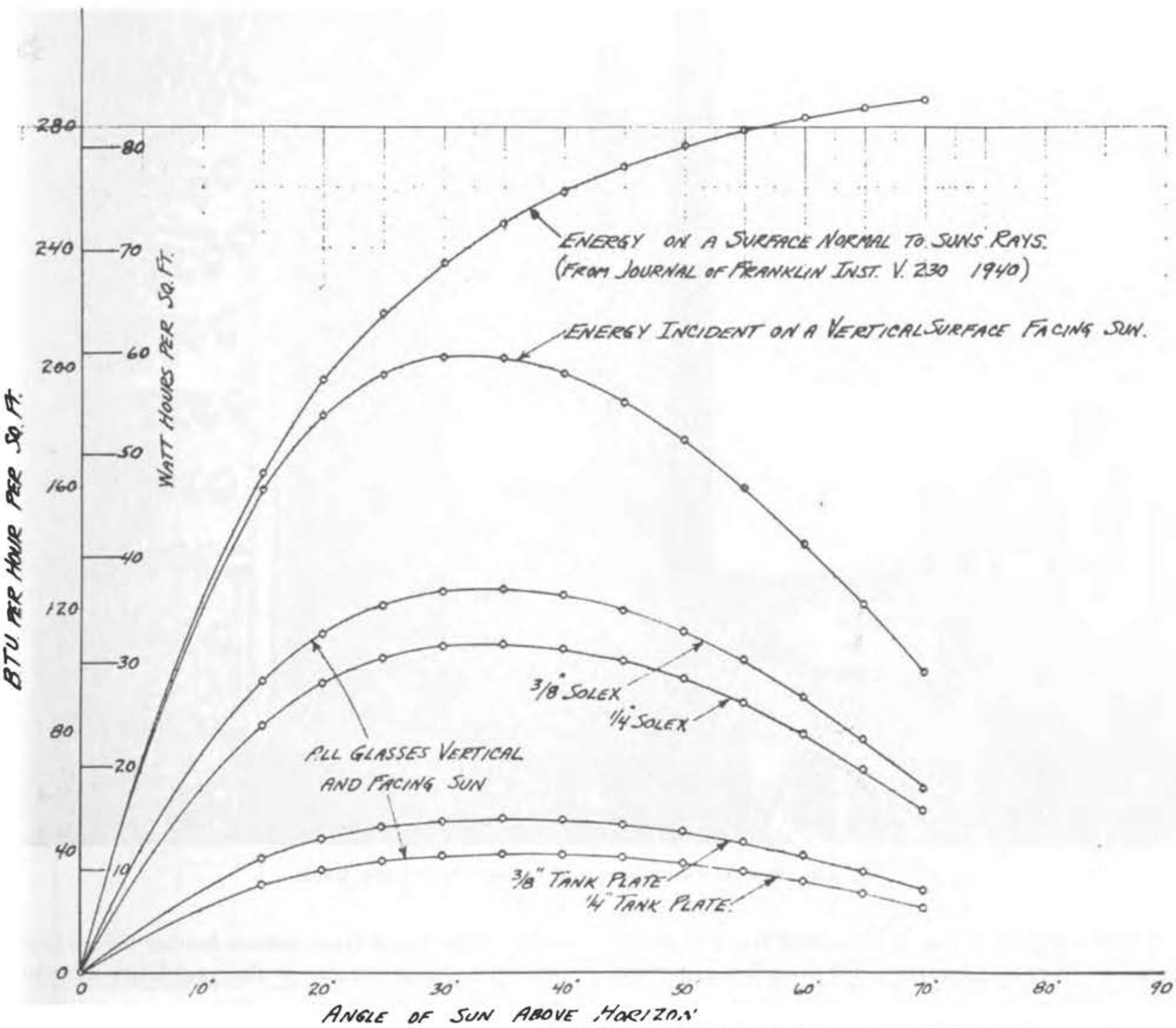


Fig. 2.5—Solar energy available and portion absorbed by various glasses.

HEAT ABSORPTION TEST PROCEDURE

Since uniform solar intensity is not dependable for test work, and solar overload tests impractical, we used a bank of 163 radiant heat 250-watt lamps as shown in Figure 2.6. The radiation intensity was regulated by a timer controlling the percentage of time the lamps were on during a 15-second period. The full intensity input to the lamps is 400 watts per sq. ft., but 18" away the energy received by the panel was 200 watts per sq. ft. or 3 to 3.5 times the maximum energy received by the sun on a vertical surface. The spectral distribution of the lamps is not the same as the sun, but it does produce temperature difference on plates which causes breakage.

For normal test procedure the lamps were turned on suddenly at any desired intensity causing the glass to heat up fast while the recessed edges lagged behind. The severity of this test can be measured by temperature difference as determined by thermocouples adhered to the glass along vertical centerline from top to bottom edges. A more direct method of rating this exposure is to measure optically the edge stress directly, using a quartz wedge viewing through a hole in the stop.

RADIANT HEAT TEST RESULTS

Early in this test program it became apparent that the occasional breakage in service and the breakage from overload radiation test in the laboratory were caused by the central area heating up fast while the recessed edges lag behind, producing temperature difference and tension stress on the edges. The curves at

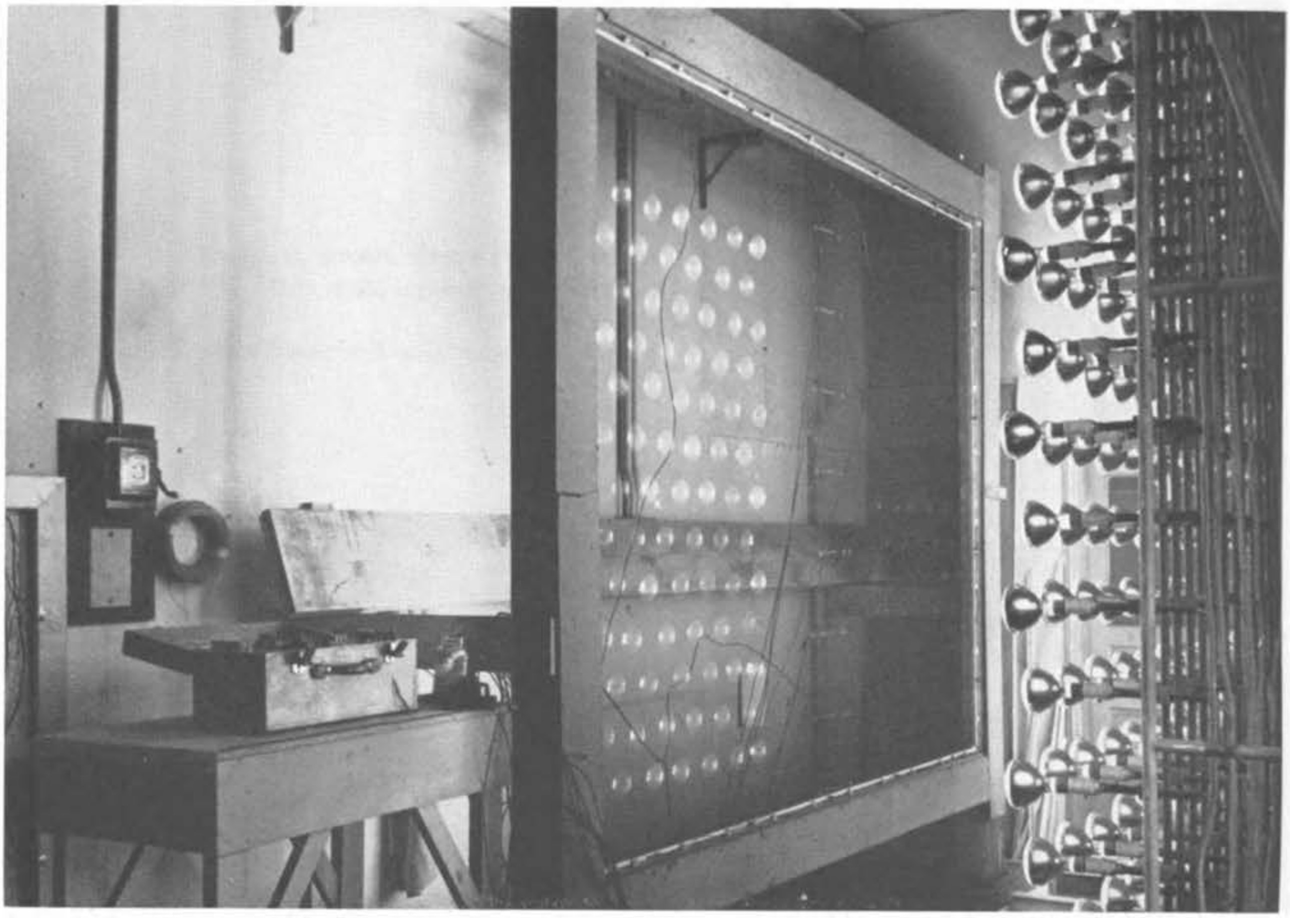


Fig. 2.6—8' x 10' test frame and radiant heat lamp bank.

the top of Figure 2.7 show this effect for a 6' x 10' panel of 3/8" Solex glass subjected to various radiation intensities. Directly below the temperature curves are measured edge stresses plotted against time with a curve drawn through the maximum stress. This shows that the stress reaches a maximum after 30 minutes, then decreases as heat soaks into the edges. These curves also show that the edges have an initial edge compression stress of about 500 psi. This is a definite advantage as the desirable compression stress must be relieved before the edge goes into tension. For our glass, the larger the plate the greater the initial edge compression on the edges, which is important because it is most needed in large plates.

The same plates shown in Figure 2.7 were used to investigate the possibility of breakage resulting from the solar heated plates suddenly being cooled by high winds or cold rain. The stress curves show that after suddenly stopping radiant heat after 55 minutes the edge tension stress was reduced fast when the central area was suddenly cooled. Tests on a smaller two ft. sq. panel showed that the surface had to be heated to 220° F before breaking with cold water spray. The glass would break from radiant heating before reaching such temperatures, so the possibility of plates breaking from heat shock in service is very remote.

Experiments on size effect using 1/4" Solex glass installed in the same store front section subjected to full 100% lamp bank intensity showed maximum edge stress as follows:

1 square foot........2,550 psi edge tension
9 square feet........3,150 psi edge tension
15 square feet........3,450 psi edge tension
24 square feet........3,950 psi edge tension
80 square feet........4,400 psi edge tension extrapolated because of failure

The possibility of breakage in the large sizes is even greater than indicated by the stress measurements because of the greater number of linear feet of edge with more chance of a defect being present to start a break.

From experimental work attempting to eliminate temperature difference we arrived at the following conclusions. The use of insulating materials applied to the edges of the plate was of little value in reducing

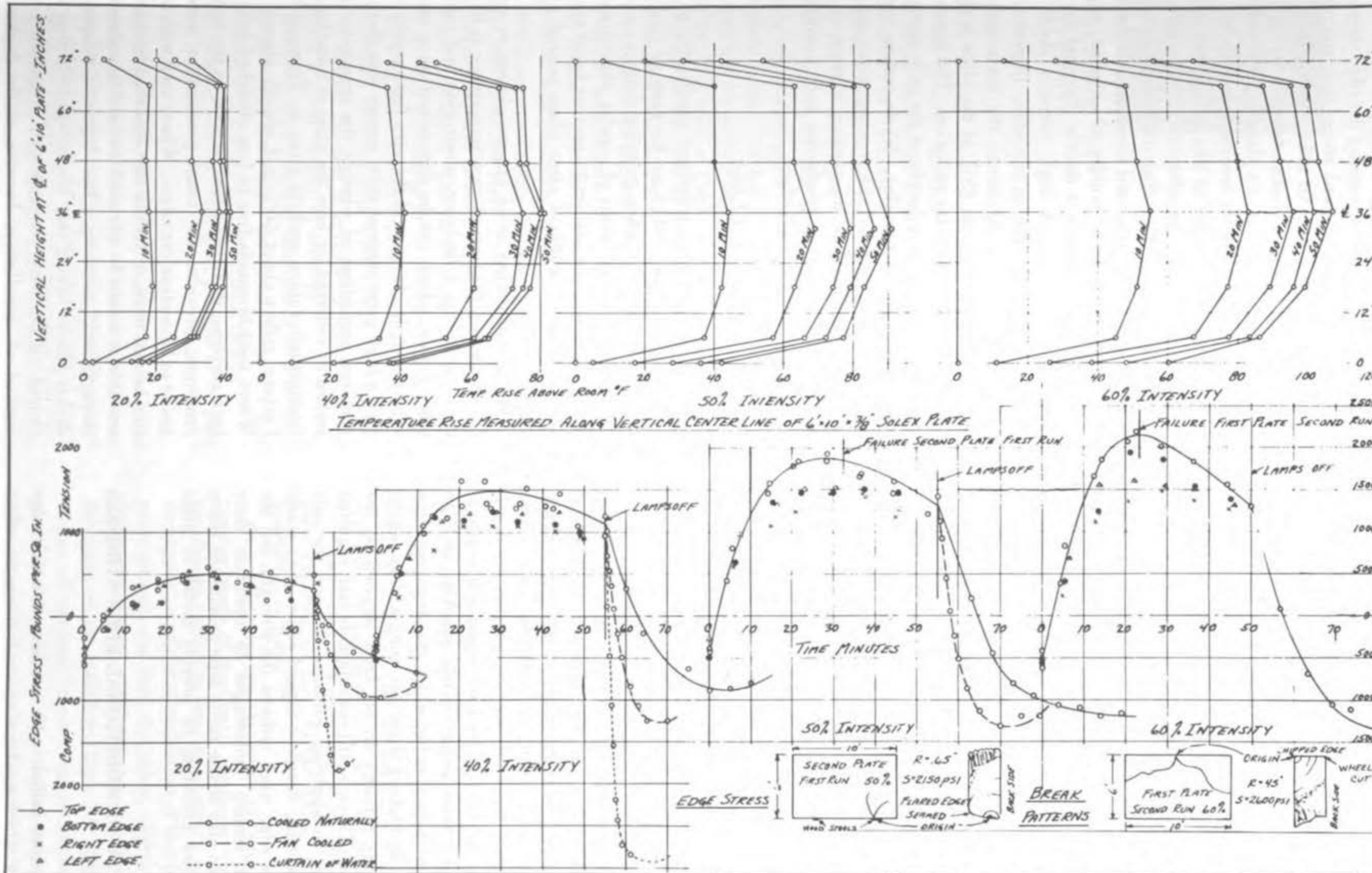


Fig. 2.7—Temperature rise and edge stress on 6' x 10' x 3/8" Solex plate mounted 24" in front of radiant lamp bank.

edge stresses. Where the outside stop or front face molding was removed, allowing the full area of the glass to be exposed, there would be no problem. If the face molding or stop is painted black to absorb solar radiation it would help to reduce the edge stress, but highly polished aluminum moldings would prevent heat from getting into the edges and produce tension stresses on the edges. Where the glass was installed in a massive masonry building, the edge temperatures would tend to lag behind more than when installed in a light-weight, curtain type wall building. This would be especially true where there are extreme changes in temperature between night and day.

Varying the width of the recessed edge over wide limits has shown that the edge stress is a maximum when the plate is recessed from 3/4 to 1" which is close to the value used in most installations. Increasing the depth of glass recessed provides a wider band to absorb the expansion of the central area, reducing the edge stress, and where the recessed depth becomes very large the maximum stress is on the glass surface in from the edge. It is much more practical to reduce edge stress by reducing the width of the recessed margin, but it is not safe to install glass with less than 3/8" edge recess. Supplying heat to the edge of the glass electrically with resistance ribbon using 2 to 3 watts per linear foot of edge would prevent the edge stress, but the necessary arrangements and equipment needed would not be practical.

Taking all these factors into consideration we have concluded that on a practical basis it is impossible to prevent tension stresses on the edges of heat-absorbing plates. We have concentrated our efforts on procedure for preparing plates with the best possible edges to withstand safely the moderate stresses that are developed. From mechanical tests of edges, and temperature difference tests using electric blankets and the lamp bank, we have concluded that the strongest edges are obtained by making clean cuts using a glass cutting wheel running through an oil layer applied on the glass surface. There is still considerable skill required of the cutter in applying pressure to open the cuts without producing flared or ragged edges. Any seaming or other edge work reduces the strength, but the edges must remain undamaged to maintain their strength. We also advise using tape around the edges in store front mounting to prevent metal to glass contact.

POSSIBILITY OF ADDITIONAL EDGE STRESSES IN SERVICE

Other factors which add to these normal edge stresses over which we have no control are the effect of using tightly closed venetian blinds or drapes close to the inside glass surface, which prevents loss of heat from the glass surface, increasing the edge stress. We have also observed localized stress increases due to certain types of shading. Of all the shading arrangements tried, those with a shaded strip of various widths through the center section of a plate were the only ones which did not increase the tension stress on the glass edge. Listed in the order of increasing edge stresses, the various shading arrangements were as follows—horizontal shading, 45° diagonal shading, vertical shading, double 45° diagonal shading with the shade lines intersecting at the middle of an edge, and the most severe shading was a double diagonal arrangement with 70° included angle between shade lines intersecting at the middle of one edge. In general, for all these shading arrangements, the maximum edge stresses occur when about 25% of the plate is shaded and 75% exposed to solar radiation. The greater the stress increase the more localized the high stress is at a specific section of the edge. While certain types of shading greatly increase the tension stress on some edges, they also reduce the tension stresses at other edges to the extent of producing safe compression stresses along the shaded edges.

SPECIAL TYPES OF GLASS

While we have been referring specifically to heat-absorbing glass we would have the same or possibly a more severe problem when painting designs or applying decals over large areas of regular plate glass windows. The recommendation to prevent breakage is to keep a 4" to 6" width of clear glass around all the edges.

When considering using opaque glasses or enamel coated glasses, the item of most importance is to know the solar energy reflectance, absorption and transmittance values, which can be determined on a two-inch square sample. In general the very light colors reflect such a high percentage of solar energy that there is no problem, regardless of whether the remainder is absorbed or reflected, or how the glass is installed. The intermediate colors, such as Gray or Tranquil Green Carrara, reflect about 50% and absorb almost 50%. Where used in panels free to lose absorbed heat from both surfaces, this glass could be used in the annealed condition, provided the usual precautions were followed to have clean-cut edges. Where used with insulation behind them, or free to lose absorbed heat only on one side, it would be advisable to have this glass "heat strengthened," meaning a low degree of temper. The darker glasses having very low energy reflection values should all be "heat strengthened," regardless of the method of installation, because of the higher edge stresses.

By Bruno Funaro, AIA *
Columbia University

WINDOWS IN MODERN ARCHITECTURE

Today we are faced with what appears to be a dilemma: modern building technology has, on one hand, made unlimited windows possible. With the outer surface of buildings freed from structural commitments, windows can be placed anywhere, everywhere. On the other hand, modern technology has replaced with more reliable artificial means many of the services which were performed by windows and which were their reason for being. Now that we can have them, we are not so sure that we really want them.

Let us first take a quick glance at our inherited tradition up to the time of the great upheaval caused by the discovery of electricity and of the steel frame.

1. Windows were limited in shape, size and position by structural considerations. To open wondows in a bearing masonry wall or in a balloon frame meant a compromise with structural stability.

2. Windows were doing a great number of tasks; let light and air in, let vision through while still satisfying requirements of weather protection, privacy, heat and sound insulation. The classical casement window (Fig. 2.8) still prevailing in the Mediterranean countries, with its outer slatted movable shutters, its inner solid shutters, curtains and drapes, was a wonderful piece of design because it performed effectively and graciously a great variety of services.

3. Windows were essential elements of architectural expression. They were often the focal points of a vast composition which embraced the whole facade.

Now, keeping this very schematic glimpse of the past in the background, let us jump into mid-20th century. It is a jump indeed; the Yankee at the Court of King Arthur was not as bewildered as we Victorians are in the 1950's. Let us take the high-rise office building—definitely an expression of our time—as our subject for observation. Its structural frame has given complete freedom to the outside walls. How has this freedom been used?

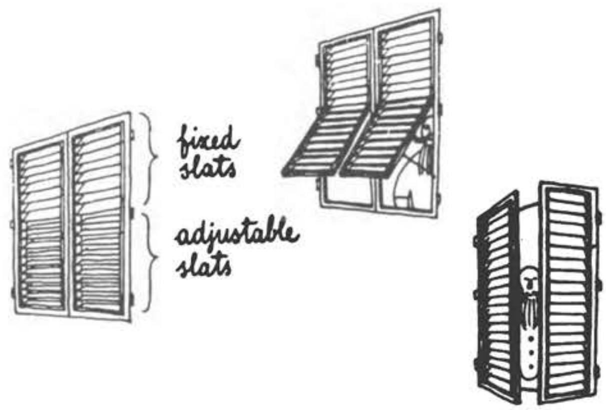


Fig. 2.8—Traditional shutters. Closed (left) they keep out rain and sun, let air circulate. For more air and some view, the lower half opens awning-wise (center). Swung half open (right) the two leaves act as vertical sun shades.

As a means for new architectural expressions, continuous bands of horizontal windows, which were impossible to realize in bearing masonry walls, become an expression of the stratification of independent office areas placed one over the other. Vertical bands of windows emphasize vertical communications and stress the unity of the building (Figs. 2.9 and 2.10). The climax of modern fenestration is reached when the whole building is entirely sheathed in glass. What is the real reason for it? Is it to make the fullest use of

---

* Prof. Bruno Funaro is Assistant Dean of the School of Architecture at Columbia University. He studied architecture in Rome, Italy, and at Columbia University where he secured his M.A. He is a member of the American Institute of Architects and of the National Institute for Architectural Education, and has co-authored with Geoffrey Baker the book, "Windows in Modern Architecture."

Fig. 2.9—The McGraw-Hill Building, New York, Hood & Fouilhoux, architects.

natural light? Is it to offer better natural ventilation? No. It is basically an aesthetic expression.

The architect had been longing for years to capture in the finished building the fascinating beauty which can often be seen in naked building skeletons before they are hidden by exterior walls. The glass wall has made this possible. Mies van der Rohe's design for a skyscraper back in the 1920's expresses this aspiration quite clearly. (Fig. 2.11) With the all-glass wall, the window as an individual element ceases to exist. It is the end of the line. From here, either we start moving back, or in an easy step we may move to the windowless wall.

We have so far considered windows in relation to architectural expression. Now let us move to the more tangible, practical reasons for their being. Still continuing with our observation of the office building, let us try to find out why we should want windows. For light? No, fluorescent lights are so much more dependable. For air? Indeed, not! That would throw our air conditioning system out of kilter. The scientists tell us that it is essential to focus the eye occasionally on a distant view, also that people psychologically need a visual contact with the outside.

Fig. 2.10—The Daily News Building, New York, Hood & Fouilhoux, architects.

Windows may take care of these requirements, but rather poorly, especially when the glass is heavily tinted to reduce glare or when the shades are pulled down.

I do not see why these functions could not be much better performed by electronic devices. Imagine each desk equipped with its own TV window through which the office worker may look down the street and "stretch" his eyes, no matter how distant his desk is from the outer wall. The climax of this horrible thought would be a closed TV office circuit which offers the opportunity to Washington office workers to feast their eyes occasionally on sunny Biscayne Boulevard.

Jokes aside, it is hard to find very valid reasons for having windows in most of today's office space. In fact, people draw their curtains, turn the lights on and settle into their daily routine, oblivious of the existence of any windows. When coffee-break time or lunch time comes, the office workers stream into the well

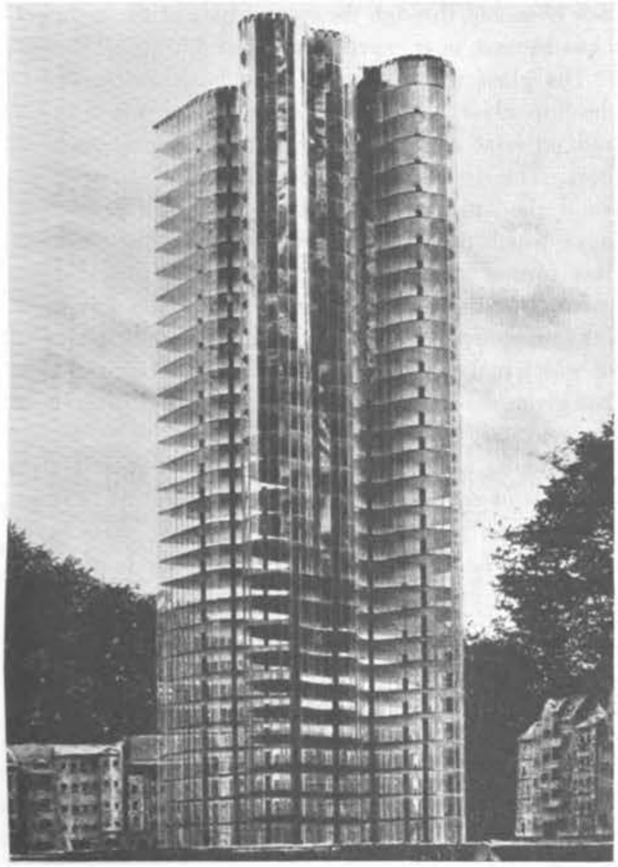


Fig. 2.11—Model of a skyscraper in glass and steel, Ludwig Mies van der Rohe, architect.

equipped cafeterias and rest lounges. Where are these rooms? In a great many buildings they are in the basement or in an inner, electrically illuminated space. Here, instead, is the real opportunity to open up. Here is where the glow of direct sunlight, the physical stimulation of fresh air have a place. Here is the place for windows. Why not place the communication areas, elevator lobbies, reception rooms and corridors on the outer face of the building so that people may walk from office to office out in the daylight?

A clear distinction between work areas with fully controlled artificial climate and communications, and relaxation areas opened to the outside, may eventually lead the way to forms of architectural expression much more articulated and humane than the abstract all-glass wall. The model of Italy House in San Paulo, Brazil, Gio Ponti, architect, is an example of this articulated fenestration. (Fig. 2.12).

There is another development of an entirely different nature which may also bring fresh meaning to the fenestration of the tall office building. In the next few years there will undoubtedly be great changes in the structural systems of tall buildings. The outside walls may assume again a structural function. Consequently, they will impose new restrictions on fenestration, and will give birth to new forms of architectural expression.

Fig. 2.12—Model of Italy House, San Paulo, Brazil, Gio Ponti, architect.

The Library at Rangoon, designed by Raglan Squirre & Partners, (Fig. 2.13) is indicative of the nervous, dynamic fenestration which may come out of this trend. It is a Gothic revival in a deeper sense than merely through imitation of form.

Let us now move our attention to an entirely different type of building, the single family house. In the last few years we have been exposed to many themes

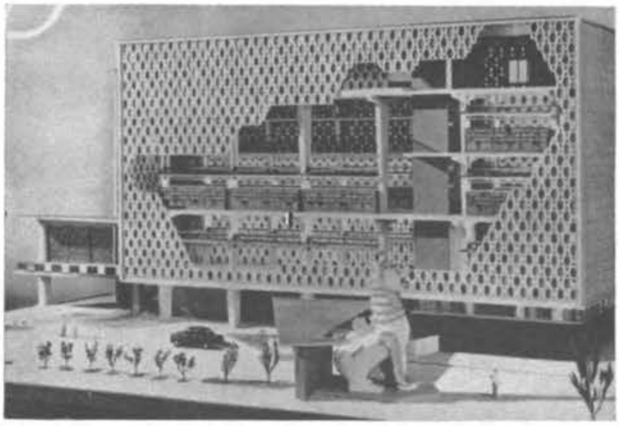


Fig. 2.13—Model of Library, Rangoon, Raglan Squirre & Partners, architects.

related to the house among which the "solar house" theme, and the "year-round air conditioned house" theme stand out. On the surface, these two present opposite trends in home design. The solar house advocates almost a cult of the use of the natural light and heat from the sun, at all costs. The air conditioned house suggests the urge to shut ourselves in, turn on the switch, and bask in our own ideal climate without mosquitoes and without any concern for what happens outside. With air conditioning established as a widely accepted service for the home and not as an imposed way of living, we can see no real conflict, but rather cooperation between the two.

It is the solar house movement that deserves our attention. Personally, I can not conceive anyone wishing to withdraw into an artificial climate except in extreme weather conditions. The solar house has had a good influence which is more noticeable now that the catch-name, solar house, has lost its glamour. First, it has called our attention to the fact that windows are not necessarily negative factors in the heating of a house, but on the contrary when properly applied, can become actual sun traps and cut down heating bills. The design of glass areas has been removed from a purely aesthetic placement of holes on a facade to a careful study and interpretation of conditions of geography, astronomy and climate. The architect has been challenged to devise new types of sunshades, blinds, shutters, fixed or stationary, to meet the new problem imposed by the large glass areas. These new elements, through the creativeness of the architect, have become new expressions of architectural design.

The glass manufacturers have been challenged to develop glass panes which, while transparent to the radiant heat of the sun, are insulators to convected heat. The designers' attention has been extended beyond the building itself to the grounds around it, upon which the large glass areas open. The meaningless formal planting of symmetrically placed evergreens, the useless front lawns, have given way to an integrated organization of open and enclosed spaces all of which make up the home. In fact, the large window has given new life to landscaping and has made it an integral part of the design of the home.

Windows in the house have become very articulate symbols of comfort, delight, and architectural expression. They range from large, movable glass walls which can be opened up when the climate is pleasant, closed and insulated when the outside temperature is too high or too low, to small glass panels which barely give a glimpse of the sky without sacrifice to privacy. Windows no longer have to be rectangular openings on vertical walls. They can be of many shapes, on slanted walls, or on roofs.

The great variety of windows demanded by the modern house makes life difficult for manufacturers and architects. The manufacturers have to expand the variety of stock items to meet as many different situations as possible. The architect, especially if tied down to a budget, has to use a great deal of ingenuity in making the best of what is on the market. They often have to use products for purposes for which they were not meant by the manufacturer. Fenestration has become so important that the design of the whole house revolves around it. The answer to this situation may be for industry to offer more independent parts which can be fitted together to suit specific cases, rather than completely packaged units of stock size. We might have to go back to more separate components, hardware, frame and track profiles by the foot, glass sheets, all of which would be assembled either by the dealer or at the job.

To sum it up, the future for designers and manufacturers is definitely not a static one. It is one of exciting search, of conflicting answers. The future of window design is closely tied to the kind of life we want to live in a rapidly changing world.

By James Arkin, AIA *

WOOD WINDOWS

The manufacture of wood window frames and sash is very properly a function of the millwork industry. Appropriately enough, this industry was initiated during the Industrial Revolution in England by Jeremy Bentham, an outstanding mechanical engineer and brother of the famous economist. The first patents ever granted for power operated woodworking machinery were awarded to Bentham in 1793. He was primarily interested in producing more and better decking for ships of the Royal Navy. This concern for mass production was apparently the motivating force behind a whole series of new woodworking machines which were invented in the two decades which followed 1793, including additional patents by Jeremy Bentham.

It should be remarked here that all of the new machines and the new processes were intended to produce an end product of lumber, namely interior and exterior finish. Power operated gang-saws for the production of lumber were used as early as the second quarter of the 17th century by American colonists who harnessed water wheels on the New England rivers.

The vogue for woodworking machinery spread from England to France and the low countries, to Germany, and to Russia, but the full impact of the revolutionary methods of production was reserved for America in the 1830's. Here there was no great tradition to shackle and inhibit the woodworkers. A new continent waited expectantly for settlement and development. Balloon frame construction helped to meet the demand for light, fast construction in wood. The demand for trim, windows and finish was met by the ingenuity of Yankee inventors who produced a new series of efficient woodworking machines.

The fact that large, but charming, Greek Revival buildings could be built of wood created an unprecedented demand for Doric columns, Ionic columns, entablatures, enframements, mouldings, and sash, all of wood. The mass production of woodwork went into high gear first in New England and the Atlantic seaboard, and then in neighboring states to the west. By the 1840's mass distribution began to develop. Thus was born the "stock" wood window industry, contemporary with many another mass production industry in America.

After the Civil War, the industry followed its markets and its source of raw material ever westward and large plants were gradually established in the middle west, a number on the banks of the Mississippi River. Here a continuing supply of logs could be floated down from the white pine forests of Minnesota, northern Wisconsin and northern Michigan.

However, the growing depletion of the forests of northern white pine, due to fires, waste and negligence as well as to normal consumption, forced the stock window industry again to seek sources of raw materials farther west, in the forests of the Rocky Mountains, the Pacific northwest and British Columbia. A large variety of softwood species were used and experience records were developed over many years. In the South, yellow pine and cypress were popular species for wood windows. Narrow gauge logging railroads were pushed into mountain fastnesses all over the continent to extract lumber. And by the 1890's, the continental networks of standard railroads made it possible for a builder in southeast United States to purchase and install a good, inexpensive window that was made in the Mississippi valley from a tree that grew in Oregon.

A single species of lumber—Ponderosa pine—is

* James Arkin is a consultant to the Architectural Woodwork Institute and to the National Woodwork Manufacturers Association. He has a Bachelor of Architecture degree from Carnegie Tech and did graduate work in art and architecture at the University of Chicago. He has also been on the faculties of the Departments of Architecture at Kansas State College and the University of Illinois, and has lectured on building construction at Purdue University. Mr. Arkin is a member of the American Institute of Architects and the Society of Architectural Historians, and is a Life Member of the Art Institute of Chicago.

now concentrated upon by many individual stock manufacturers because that species possesses most of the qualifications demanded for mass production of windows, and fewer of the disadvantages of other species. A plentiful supply of Ponderosa pine is assured for many years to come.

The form that stock windows must take today is no longer tied to what the glass industry can supply, simply because the glass industry itself has become far more flexible in its output. Nonetheless, the form, styles and sizes of stock wood windows at the present time are based entirely on the demands of the market for residential buildings in a price bracket of approximately $35,000 and under, and for light, utilitarian buildings.

Today's improved woodworking machines are on a par with any machines used in the metal working industries for speed of operation, accuracy and safety. New developments in the fields of adhesives have augmented the processes of production and have made finger jointing practicable. It is now recognized in several U. S. Commercial Standards. Automation lends itself to the manufacture of stock windows, and although full automation is several years away, semiautomation has been adopted in a few plants.

The National Woodwork Manufacturers Association, Inc. is the trade association of the stock woodwork industry in the United States. Mr. Ormie C. Lance is Secretary-Manager and general headquarters are maintained in Chicago with a branch office in Washington, D. C. The major activities of the N. W. M. A. are concerned more with the production than the marketing function of the industry.

Ever since it was organized in 1933 (under the name of the National Door Manufacturers Association), N. W. M. A. has carried on research programs in the interest of improving stock windows. These programs have related to such subjects as performance tests for use in developing standards for moisture content, materials, manufacturing processes, glazing and grading. The association has been active in the initiation of Commercial Standards relating to the windows produced by its member companies, by application to the Commodity Standards Division, U. S. Department of Commerce. The standards indicate marked progress in window design and construction. The trend toward a snug fit, without having windows stick and bind, has been accelerated. All of the Standards call for windows made from carefully selected and properly kiln-dried wood, defect free and chemically treated to operate easily under all weather conditions. A tolerance of $\frac{1}{32}$", plus or minus, is allowed in the width of all machined parts.

The following is a list of window and sash standards promulgated within the past few years, including standards issued this year:

CS 163-25—Standard Stock Ponderosa Pine Windows, Sash and Screens

Covers check rail windows, casement sash and cellar sash in $1\frac{3}{8}$" thickness; plain rail windows, storm sash, cellar sash and screens in $1\frac{1}{8}$" thickness; and screens in $\frac{3}{4}$" thickness. (The term "window" refers to two or more single sash required to fill a given opening, and not to a framed unit.)

CS 190-53—Standard Stock Double-Hung Wood Window Units

Covers window frames, balancing, and weatherstripping for $1\frac{3}{8}$" check rail type windows, including the assembly of these four components into a window unit. Also covers $1\frac{1}{8}$" storm sash, and window screens in $\frac{3}{4}$" and $1\frac{1}{8}$" thickness. Side jambs and head jambs are at least $\frac{3}{4}$" thick with a minus tolerance of $\frac{1}{32}$".

The window units may have spring, spiral or pulley balances that call for only the amount of energy to match the weight of the sash, plus a friction load of 1.2 lbs. per inch. The units may also have removable sash, which can be lifted out for washing and painting indoors.

CS 913-53—Standard Stock Ponderosa Pine Insulating-Glass Windows and Sash

Covers check rail windows and sash in $1\frac{3}{8}$" thickness to accommodate insulating glass of $\frac{1}{2}$" thickness; also stationary sash $2\frac{1}{4}$" thick to accommodate insulating glass of 1" thickness.

CS 204-56—Standard Stock Wood Awning Window Units, and Projected Awning and Stationary Sash Units

Covers frames, sash, operating mechanism, weather stripping, and assembly of component parts. Also covers storm sash of $\frac{3}{4}$" and $1\frac{1}{8}$" nominal thickness; and screen sash of $\frac{3}{4}$" and $1\frac{1}{8}$" nominal thickness.

An awning window unit is defined as a frame in which two or more operative weather-stripped sash are installed, with integral operating device. A projected awning and stationary sash unit consists of a single frame with either an operative sash or a fixed sash, or a stationary glass. Single units of this second type may be stacked vertically, joined horizontally in ribbons, or assembled in both directions to form a window wall. In lieu of single units adjoining one another, the complete frame may be manufactured with continuous vertical and/or horizontal members. Furthermore, projected awning and stationary sash units may be set vertically, when designed for such use by the manufacturer. In that position, awning sash or transom sash (hoppers) will function as casements. All awning sash are required to be not less than 1⅝" nominal thickness, and all projected awning and stationary sash are to be not less than 1⅜" nominal thickness, with a minus tolerance of 1/16" on each thickness.

Side jambs are required to be 1 1/16" at their thickest part for awning window units, and ¾" at their thickest part for projected awning and stationary sash units, with a minus tolerance of 1/32" in either case. Head jambs are required to be at least ¾" thick at their thickest part for both awning window units and projected awning and stationary sash units, with a minus tolerance of 1/32".

Weatherstripping requirements are the same as those for CS 190-53.

Hardware to control and securely close both types of units is required to meet very comprehensive performance tests including an operation cycle that must be repeated 10,000 times. All other hardware is in accordance with Federal Specification FF-H-111a. Two strengths of hardware are available for glazing with window glass and plate glass, respectively.

CS 205-56—Standard Stock Wood Casement Window Units

Casement units do not lend themselves to rigid standardization, because they vary widely in design, sizes, and methods of operation. Therefore sizes and thickness of sash are not mentioned in this Standard. However, construction requirements are given for sash, frames, hardware, weatherstripping, and assembly of component parts. Storm sash and screens are also described.

Side jambs and head jambs of the frame are required to be at least ¾" thick with a minus tolerance of 1/32".

Weatherstrip is required that shall prevent air infiltration or leakage in excess of 0.4 cubic feet of air per minute per linear foot of sash crack perimeter, at a wind pressure equivalent to 25 miles per hour.

There are, of course, other types of wood windows which are popular for residential use and which have not been standardized as yet. The horizontal sliding window has gone through a long period of development and highly perfected models are now available. This window embodies many of the advantages of the double-hung window, without the check rail which sometimes impairs a view. However, the double-hung window is still by far the most popular type for residential construction, according to figures recently published by the U. S. Bureau of Labor Statistics. These figures also indicate that wood windows constituted more than 55% of all windows installed in new non-farm dwelling units during the first quarter of 1955. Preliminary figures for 1956 indicate that this percentage will remain about the same.

This continued acceptance by owners, architects and builders is due to the inherent advantages of wood as a material for window frames and sash. However, these advantages in themselves would not suffice in a highly competitive economy, were it not for constant technological improvements in the production of window units. An example is the use of new materials and methods for weatherstripping, including vinyls and other synthetics, as well as metal. Wood windows lend themselves to weatherstripping and to constant experimentation in that field. Adjustments can easily be made in existing buildings as well as new structures. According to published studies carried on at the University of Minnesota, weatherstripping reduces 85% of air leakage and thereby cuts fuel cost by 24% for a typical one-family residence during a single heating season. Other advantages include the exclusion of dirt, sand, smoke and soot; and the deadening of street noises.

Another example of the improvement in window units is the application of modern chemistry to wood treatment. The treatment of wood against decay is not new, but the use of water repellent wood preservatives which permit the painting or finishing of woodwork only 48 hours after application is a relatively new method which dates back to only 1938. At that time the N.W.M.A. developed criteria for treatment. Through continual research, these have gradually become the world recognized standard for treating all forms of millwork, custom as well as stock. *In 19 years of continued application of these standards, there is not a single authenticated record of failure.*

The technology and chemistry of water repellent preservatives are fully described in the latest edition of the "Wood Handbook" of Forest Products Laboratory, inasmuch as that agency pioneered many of the early experiments. There are Federal specifications and ASTM specifications regarding formulation, but the only performance standards extant to cover preservatives, water-repellents and methods of treatment are the standards of N.W.M.A. At the present time, that association is in the midst of a two-year program in collaboration with the Forest Products Laboratory to verify its own methods of testing.

The N.W.M.A. standards are administered through the "Seal of Approval" program. This is a program of rigid inspection of fabricators and treatment plants throughout this country, their methods, and the chemicals used. Use of N.W.M.A. standards for treatment are implicit in the U.S. Commercial Standards governing stock sash and window units. Custom designed frames and sash should receive similar treatment, which is always available provided the architect specifies "water-repellent preservative treatment in accordance with the minimum standards of N.W.M.A."

LOW AIR INFILTRATION THROUGH WOOD WINDOWS

(Excerpted from Heating Ventilating Air Conditioning Guide, 1956, pages 227-231)

The air leakage which takes place through various apertures in buildings must be estimated in heating and cooling calculations. The rate of air flow depends on:

(a) The magnitude of the pressure difference between the inside and outside of structure.

(b) Resistances presented to pressure difference.

Pressure difference may be caused by:

(a) Wind; its effect depends on:

1. Interrelation of speed and direction.
2. Exposure of the building.

(b) Difference in density of air inside and outside building; its effect depends on:

1. Magnitude of inside-outside temperature difference.
2. Height of the rooms.
3. Shape of the openings.
4. Elevation of openings in room or building.

When pressure difference is the result of:

1. Wind pressure. . . .
   Air enters building through openings in windward walls.
2. Temperature difference. . . .
   Air takes path of least resistance from lower levels to higher levels.

Complicating factors:

1. Variations in quality of construction.
2. Variations in wind velocity and direction.
3. Exposure of the building.
4. Variations in outside temperature.
5. Relative area and resistance of openings.
6. Influence of a planned air supply.

TIGHT CONSTRUCTION IS ESSENTIAL FOR PREVENTING LARGE HEAT LOSS DUE TO INFILTRATION. The following comparative table is based on a series of tests conducted by the American Society of Heating and Air Conditioning Engineers. It is noteworthy that the original tests were conducted in cooperation with the American Institute of Architects. The double-hung wood windows used in the tests were 1⅜" thick, and varied in sizes from 2' 8" x 5' 2" to 3' 0" x 6' 0". Emphasis was placed on average windows, i. e., good windows, as distinguished from poor windows or from windows fabricated in accordance with the very best practice.

The fit of double-hung windows is determined by crack and clearance. Crack thickness is equivalent to one-half the difference between the inside window frame dimension and the outside sash width. The difference between the width of the window frame guide and the sash thickness is considered as the clearance. The length of the perimeter opening or crack for a double-hung window is equal to three times the width plus two times the height or, in other words, it is the outer sash perimeter length plus the meeting rail length. All of the window crack in any given room is not necessarily used in estimating the infiltration heat loss by the crack method. The length of crack to be selected in any given case depends on the number of exposed sides.

INFILTRATION THROUGH WOOD AND METAL WINDOWS

(Expressed in Cubic Feet per Foot of Crack per hour, Values corrected to allow for building up of pressure in rooms)

Type of Window	Remarks	Wind Velocity, Miles Per Hour 5	10	15	20	25	30
Double-Hung Wood Sash Windows (unlocked)	Total for average window, weather-stripped, 1/16" crack and 3/64" clearance. Includes leakage around frame in calked masonry wall.	4	13	24	36	49	63
Double-Hung Metal Windows (unlocked)	Weatherstripped	6	19	32	46	60	76
Rolled Section Steel Sash Windows	Intermediate Projected 1/32" crack (Average practice)	8	24	38	54	72	92
Rolled Section Steel Sash Windows	Residential Casement 1/32" crack (Average practice)	14	32	52	76	100	128
Rolled Section Steel Sash Windows	Architectural Projected 3/64" crack (Average practice)	20	52	88	116	152	182
Hollow Metal, vertically pivoted window		30	88	145	186	221	242

The figures shown in the table for double-hung wood windows are for the unlocked condition. Just how a window is closed, or fits when it is closed, has considerable influence on the leakage. The leakage will be high if the sash are short, if the meeting rail members are warped, or if the frame and sash are not fitted squarely to each other. It is possible to have a window with approximately the average crack and clearance that will have a leakage at least double that of the figures shown. Values for the average double-hung wood window in the table are considered to be easily obtainable figures, provided the workmanship on the window is good. Should it be known that the windows under consideration are poorly fitted, larger leakage values should be used. Locking a window generally decreases its leakage, but in some cases may push the meeting rail members apart and increase leakage. On windows with large clearances, locking will usually reduce the leakage.

Wood casement windows may be assumed to have the same unit leakage as for the average double-hung wood window when properly fitted. A normal operation in the closing of this type of window is the locking function, which maintains the crack at a low value.

When storm sash are applied to well fitted windows, some reduction in infiltration is secured; the application of the sash provides an air space which reduces heat transmission and helps prevent frosting of the windows. By applying storm sash to poorly fitted windows, a reduction in leakage of 50 percent may be obtained; the effect, so far as air leakage is concerned, being roughly equivalent to that obtained by the installation of weatherstrips. (From ASHAE Guide, 1956)

THE RELATIVE FREEDOM FROM CONDENSATION OF THE SURFACES OF WOOD FRAMES AND SASH

The factor of thermal conductivity, or the time rate of heat flow, is designated by the letter "k." The k factor for softwood is 0.8; for hardwood, 1.1. On the basis of the published k values for aluminum and for mild steel, all other factors, such as thickness and degree difference being equal, the relative heat flow through the following commonly used window materials is obtained:

Aluminum: 1770 times faster than softwood
" : 1280 times faster than hardwood
Mild Steel: 390 times faster than softwood
" : 284 times faster than hardwood

Hence, relatively high insulating qualities accrue to wood and these are of value in preventing condensation. In a room that is heated to 70°F, with a relative humidity of 40%, the ratio of actual vapor pressure to the saturation pressure will be approximately 40%. If the temperature on the inside of the frames and sash in this room should be 44.6 F°, due to low insulating qualities of the window material, the particular air-vapor mixture would tend to migrate to the window, and become saturated at the above mentioned temperature. A slight drop in temperature would result in condensation, and a below freezing temperature would result in frost. When this condition obtains, the vapor pressure at the condensing surface is also reduced, thereby establishing a gradient of vapor pressure from the room air to the window surface. This gradient will operate in conjunction with the convective action within the room to move water vapor continuously to the window surface to be condensed, so long as the concentration of water vapor in the room is maintained. This explains, in part, the greatly reduced relative humidities experienced in buildings in extreme cold weather, when cold outside air enters and is heated, with resulting discomfort for the occupants of the room, who are also subject to negative radiation. The solution to this problem is the use of window material with high insulation value plus adequate weatherstripping.

"Wood Handbook, #72" contains up to date chapters on the physical properties of various species of softwoods, and hardwoods which should prove of value to the designer and specification writer in selecting an appropriate and economical species. Reference should also be made to the chapter, "Control of Moisture Content and Shrinkage of Wood," for the purpose of specifying moisture content. The chapter, "Painting and Finishing Wood," is very valuable for the information it contains on priming, and on the paint-holding characteristics of various species.

In connection with the problem of reducing school maintenance costs to a minimum, some architects in Texas have in the past few years been specifying woods that do not require painting, or that will render good service with water-repellent treatment alone. It is noteworthy that the most recent standards of the Central Mortgage and Housing Corporation of Canada, which corresponds to our FHA, will accept treatment in lieu of priming for wood windows.

ADVANTAGES OF WOOD WINDOWS

The following tabulated advantages are excerpted from "Selection of Windows," a report by Task Group T-14 of the Federal Construction Council, prepared and edited by Homer J. Smith, staff architect and published by Building Research Institute, Washington, D.C., April 1956.

1. Surfaces of sash and frame not likely to collect condensation.

2. Durable when treated with preservatives.
3. Easily refitted if frame becomes distorted.
4. A convenient base for attachment of hardware.
5. Not readily affected by acid fumes found in air.
6. Easy to install.
7. Shock absorbing qualities reduce glass breakage.
8. Repairs can easily be made locally.
9. Resistant to corrosion by industrial air.

ARCHITECT—DESIGNED DOUBLE HUNG WINDOWS

Below are specification suggestions for utilizing 1¾" sash or 2¼" sash:

Tolerances: Use tolerances which appear in standards of N.W.M.A. for 1⅜" sash. (Reference may be made to latest U. S. Commercial Standards.)

Weatherstripping: Ribbed type with interlocking type at check rail.

Sash: Sash exceeding 3' 0" x 4' 10", utilizing glass size over 32" x 26", should be 1¾". Stiles 2", Head Rail 2", Bottom Rail 3¼". Add ¼" for sticking. Drip groove in bottom rail. Bottom rail should be increased, as width of sash increases. Check Rail, 1¾". Vertical dimension between glass, 1¼". Sash should contain ½" rabbet for plate glass. Plate-glazed sash over 42" wide should be reinforced with a zinc-coated steel angle, 1" x 1½", installed in a rabbet running the full length of bottom rail of upper sash. All sash should be blind tenoned.

Frames: Use box frames with counterweights and pulleys for plate glazed sash over 42" and for other heavy types of sash. Plank jambs may be used for smaller sash. Prevent or reduce infiltration through box frame by:

1. Adequate nailing of jointed pieces.
2. Calking bead back of brick mould.
3. Galvanized metal strip at back of brick mould.
4. Weatherbar in sill.
5. Weatherbar in head.

Pulley stiles: Up to 4' 10" in height: May be 25/32". Over 4' 10": 1 1/16" in Fir and Yellow Pine.

Blind stops are normally 25/32", but vary in width, depending on brick or frame construction. (See N.W.M.A. standards.) Gouge out bottoms of blind stops for water to run out.

Brick mould: 1⅛" min. thickness. 2" min. width, U.S.A. 1⅝" min. width, Canada. These sizes may require adjustment for modular brick openings.

Sills: Should be kerfed several places on bottom to prevent warping. Should be pitched at an optimum angle of 14 degrees, or slope of 3:12. Pitch provides better beam action and strength. Minimum of 1⅝" in fir, or 1¾" in pine. Weather-break recommended. For sills in masonry, use water bars 1" wide, 10 gage hot-dipped galvanized iron installed in groove cut in underside.

Sill, head, jamb and box to be properly framed at joints. Include spreaders for box.

Single units: Jambs to be dadoed to receive sill, particularly with plank frames.

Multiple units: Sills to receive mullions. For counter-weighted windows, mullions should provide standard width weight pockets, with space for 4 weights. Shoulder back-part of pulley stile to sill.

Stop beads at head and jambs should be removable, secured with stop bead adjusters. Stop beads should not be fastened, but should fit tightly.

Weight pockets should be removable with brass screws.

Treatment: All frames and sash should be treated with a water-repellent wood preservative in accordance with the minimum standards of N.W.M.A., and should bear the "Seal of Approval" of that association.

Custom designed wood windows as we know them today were ushered into Western architecture with the advent of the Italian Renaissance. Prior to that time the window was either an integral part of the structure or a convenient opening in a heavy masonry wall with limited facility. Except for the glorious tracery of the cathedrals, windows of humbler structures in Gothic times were small, with leaded "cames," set diamond-fashion to shed rain and snow. Operative windows moved in frames of lead, iron or wood.

The large, in-swinging casement was developed for the new palaces in Florence. Perhaps it was because of this very practical and functional solution that wood window design changed little for 250 years, particularly in monumental buildings. The shutters lingered on, long after the need for them had disappeared. In-swinging casement windows became standard equipment in the great Baroque buildings all over Europe. If left slightly ajar, these windows could admit plenty of air without interfering with the drapes and hangings on interior walls. This extremely successful and truly international window design, with single or double casements, continued to flourish in the revivals and neoclassical styles that were prevalent during the 19th century and the early decades of this century.

The double-hung sash window was apparently first used or developed in the Low Countries toward the end of the 16th Century. By the beginning of the 18th century, this window type was already being used for monumental buildings in Britain. The popularity of the window grew by leaps and bounds and many an owner replaced good casements with the new windows.

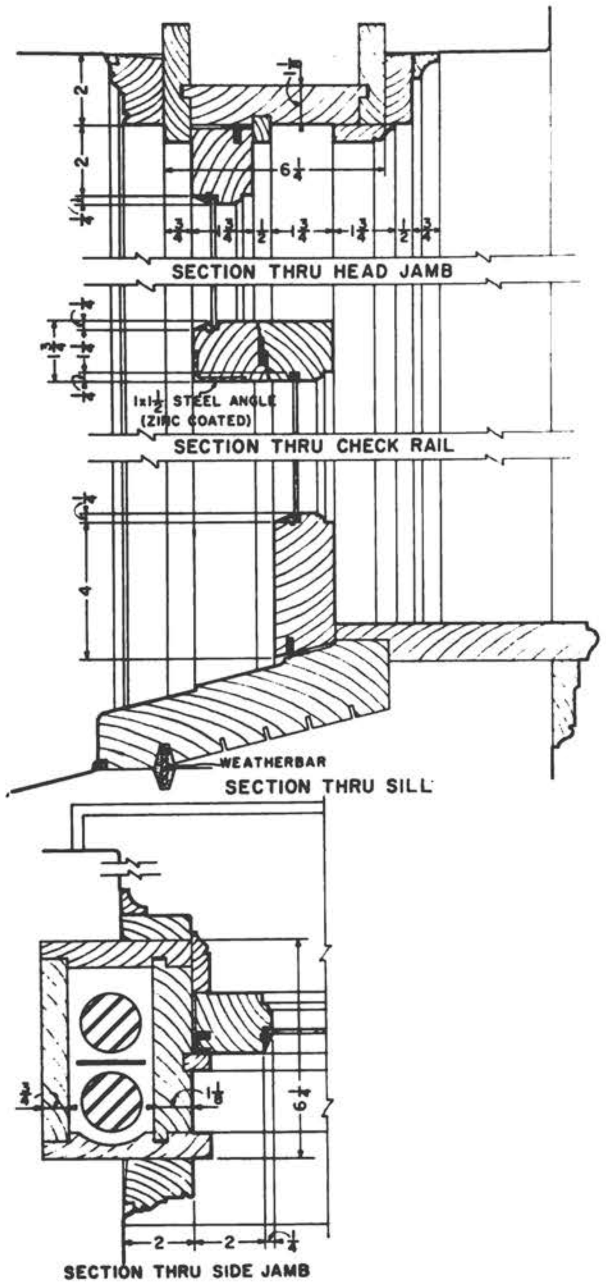


Fig. 2.14—Typical double-hung window and frame for institutional type building.

Georgian architects soon discovered that the double-hung sash window could be readily adapted to almost any kind of masonry opening, or to any proportion which they wished to conceive. As a result, the sash window was adopted almost universally in England and in her American colonies for all types of buildings. After the Revolution refinements in design, such as thinner muntins, were introduced. During the 19th century American architects integrated this window into all their designs, in every region of the country, and for every style of architecture.

Because of this extreme adaptability of the double hung window to every kind of wall condition that the architect might conceive, the wood D.H. window remained the standard window for construction well into the twentieth century. Indeed, the twentieth century saw an actual revival of interest in the double hung mullion window for high office buildings and for institutional work because of the ease with which interior partitions could be finished to the mullions, if and when necessary.

The great innovators of the Chicago School in the 1880's and 1890's realized that the potentialities of the wood window were by no means exhausted, and they strove mightily for new forms and new functions. The bay window in the high building was their first contribution; out of this developed the famous "Chicago" window. The Chicago window was adaptable to the plane surface, to a perfect expression of structure, and it functioned to admit a maximum of daylight with good ventilation. However, it was not adaptable to small, rentable floor areas in office buildings.

By the late 1890's the Chicago window was reserved for display space for large unpartitioned areas on the lower floors of office buildings, and for department stores. The Carson, Pirie, Scott & Co. store (Louis H. Sullivan, architect, 1899) brought the wood Chicago window to a high state of perfection. The windows in that building are in good condition today, and operable, except for the fact that they are not used to their fullest extent because of air conditioning and artificial illumination. During the same pioneering period of modern architectural history, Frank Lloyd Wright developed the corner window for residences, and introduced the out-swinging wood casement in his early Prairie houses.

Today architects all over the world may look backward for a period of 500 years and observe that only a few basic types of wood windows were developed during that period, and used over and over again with continued service. For the future, there remains an unlimited field of exploration in the design and use of wood windows. For example, it is doubtful that all of the potentials of the double-hung window have as yet been exhausted. Windows of that type designed in the 1880's are still in successful operation, in sizes that would dwarf many contemporary windows of the same type.

Of course there are other problems which cry aloud for solution. The wood window wall and curtain wall remain to be developed to the fullest extent. For the first time in American history, the special millwork industry is now organized to assist the architectural profession with its problems by providing technical information pertaining to detailing and specifications for custom frames and sash. The Architectural Woodwork Institute, 332 South Michigan Avenue, Chicago 4, Illinois, organized in 1953, is the trade association of that industry. The Institute has members throughout the United States and Canada, with the exception of California, and publishes a brochure series which is distributed to architects.

The direction that window design will take in the future is intimately related to the whole problem of architectural design. The two cannot be separated, for this is a unity that transcends materials. The philosophy of functionalism has held sway during the second and third quarters of the twentieth century. Current reaction to that not too well integrated philosophy is well expressed in the following quotations from "The Functional Neurosis" by Robin Boyd, Architectural Review, February 1956:

"Functionalism is being renounced because the first attempts to apply the principles of the functional ethic always tended in the same direction, and we are tiring of this direction. . . . One application suggested itself to men who were revolting against the aimless anarchy of nineteenth century eclectic exhibitionism. They saw a line of development which started with a white cube of concrete and appeared to lead ultimately to a cube of glass.

"If our present stage had been reached earlier while the functionalist principles were still fresh, more attention might have been concentrated on achieving equal purity of conception in terms not necessarily limited to rectangles and continuous glass, in terms which might give always increasing consideration to the demands of living and environment—a more subjective, constructive simplicity for every purpose; not merely the plainness that results from the avid practice of elimination. . . .

"The originating idea is the essence of character. If our buildings are monotonous, it is because our ideas are generally confined within a narrow range. Structure is approved as a stimulus by our unwritten architectural morality code rules; ideas based on shell-concrete or exposed steel cantilevers are always well accepted, but ideas based simply on the enjoyment of living, or springing from a sense of humour, or gaiety, or reverence, or mystery, or awe, are suspect, because we cannot bind them into a specification. . . . Only our own lack of ideas is responsible for the coldness, the monotony of atmosphere, the constancy of mood, the limited range of expression in modern architecture."

* * *

Mr. Arkin's paper, here condensed, contained a wealth of material on the historical progress of the millwork industry, and on the development down through the centuries of the various types of wood windows. Copies of the complete paper may be secured upon request direct from the author at 332 So. Michigan Avenue, Chicago 4, Illinois.

By William Gillett *
Fenestra, Incorporated

STEEL WINDOWS

Mr. Gillett's paper was presented to the conference by Clyde W. Kelly, Chief Engineer of Fenestra, Incorporated.

Like many of today's steel products, metal windows had their beginning as wrought iron, dating as far back as the time of the Roman Empire. Their modern version in steel is easily traced since 1880 in some of the old buildings in England where today they predominate the window market. The advent of steel windows in the United States began in 1906, when they were limited largely to use in industrial buildings. Through the years they have not only provided the basic industrial window but, with refined designs, have been popular in all other kinds of buildings.

Modern steel windows are manufactured from hot rolled solid sections as well as from cold roll formed strip steel. In general, solid rolled sections are used for virtually all industrial type windows and are suited principally to casement and projected type windows for the non-industrial fields. Cold roll formed strip is employed principally for double-hung steel windows in the non-industrial fields. A distinct advantage for the solid rolled section products appears in the correctional and penal institutional buildings where even tool-resistant steel is sometimes used to assure confinement of inmates.

Steel as a window material fulfills certain requirements not provided by any other material, such as fire resistance and detention. The relative strength of steel permits designs with a minimum of profile. Steel lends itself well to rigid assembly by welding or pivot end riveting. Its strength is well suited to the firm and permanent attachment of hardware and fittings. It is not subject to warping, has expansion and contraction characteristics comparable to adjacent building materials and, when properly protected, will last indefinitely.

As in the case of all materials, steel for windows has, along with its many assets, some limitations. It is relatively difficult to shape, form and cut. Although much work has been done in the extruding of steel, the process has not yet been sufficiently refined within economical limits to provide steel extrusions for windows. Both in the case of solid rolled sections and of cold formed strip sections, tolerances must be taken into account in steel window assembly designs. Also, designs have some limitation because of the inability to provide certain shapes. The insulation value of steel is often criticized even though it is comparable to other metals used in windows, and even though glass areas common to all types of windows represent the major window area. The corrosion of steel is considered a handicap but, when properly protected, this deterrent can be avoided.

There is a science to steel windows which, if followed, provides important economies. Virtually any form, type or size of steel window can be manufactured if the cost factor is disregarded. On the other hand, the basic equipment and rolls for forming either solid sections or cold roll formed sections is costly and, consequently, shapes must be so standardized as to provide substantial tonnage production if excessive cost is to be avoided. In relation, the tooling for cutting off and assembling steel sections which affects the types and sizes of steel windows is also relatively ex-

---

* William Gillett is Vice President of Engineering and Research for Fenestra, Incorporated. He is a graduate of Case Institute of Technology with Bachelor's and Professional Degrees in Civil Engineering, a Past President of the Producers Council, and past chairman of the Metal Roof Deck Technical Institute and the Industry Advisory Committee of the Building Officials Conference of America.

pensive. If economies are to be maintained, then it is necessary to have a substantial standardization of types and sizes. This latter problem also confronts window products manufactured in other materials.

Now let's look with more detail into the corrosion protection of steel windows. History indicates that early iron windows derived their protection from their own oxidized surface, but modern people are not satisfied with such oxidized surfaces in modern buildings. Old steel window catalogues show that in England in the early 1900's electro-copper plating was used as a protection for steel windows but, since this process died an early death, it apparently did not serve the purpose well. Paint has for years been the basic protection medium for steel windows and serves the purpose well in modern living where color is such an important part of our lives. Steel windows, which have universally been bonderized since the middle 30's, can be painted with any desired color to match changing interior decorations.

The most modern protection for steel windows is hot dipped galvanizing plus a surface treatment to make it not only more pleasing to the eye when further coating is avoided, but also to provide for the satisfactory adherence of paint when colors are desired. Several of the steel window companies in England have for a number of years maintained galvanizing lines solely for the treatment of steel windows, and at least one producer in the United States is currently operating such a galvanizing line. To be thoroughly effective and to provide a pleasing appearance in the finished surface, such a galvanizing line must be equipped with a conveyor system to support the steel windows throughout the trip in the various stages of galvanizing. First there is a degreasing unit to remove oil and grease accumulating on the surface during the manufacturing process, followed by a thorough pickling to remove all scale and rust, then the window surface receives a coating of flux before dipping into the galvanizing pot, which must be sufficiently large to receive the entire window unit at one time (Figs. 2.15 and 2.16).

Following the cooling of the window comes a dipped chemical treatment (Fig. 2.17) designed to passivate the surface and allow for the application of paint as well as to increase resistance to oxidization of the galvanized surface. Such a process must be applied to frames and ventilators separately with assembly of the two following. Such coating processes are normally applied only to solid section steel windows; windows of cold roll formed strip start with a coated strip when galvanizing is desired. Such surface treatments probably represent the latest improvement in steel windows, and although galvanized steel windows have been in use to a very limited extent for at least thirty years with highly satisfactory results under excessive conditions, nevertheless, it is only recently that galvanizing plants have been constructed specifically for window manufacture.

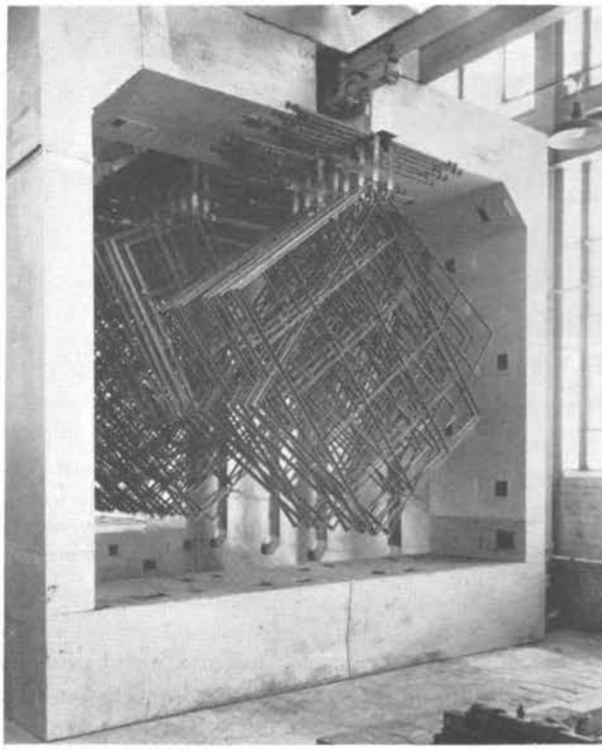


Fig. 2.15—Windows in drying oven after degreasing, pickling, rinsing and fluxing.

A problem which today confronts all window manufacturers has to do with the standardization of types and sizes. Varying the size and layout of windows is one of the architect's easiest tools for creating individualism in building facades, but at the same time it creates a situation in the window market which makes it virtually impossible for window manufacturers to introduce a high degree of automation in their plants. Consequently the cost of all windows can be considered relatively high in relation to other building materials where mechanism is employed. If we, as an industry, are to give our customers improved window products at the same or lower costs than now prevail, we must forthrightly solve the riddle of varying extreme designs, even though window types and sizes are limited in number. In the residential market there are literally hundreds of different types and sizes of windows. In the non-residential field a large percentage of windows have no standardization whatsoever. Some window manufacturers may feel that they have developed a high degree of mechanization in their producing facilities but, as compared to automation now employed in other industries, the surface has not been scratched.

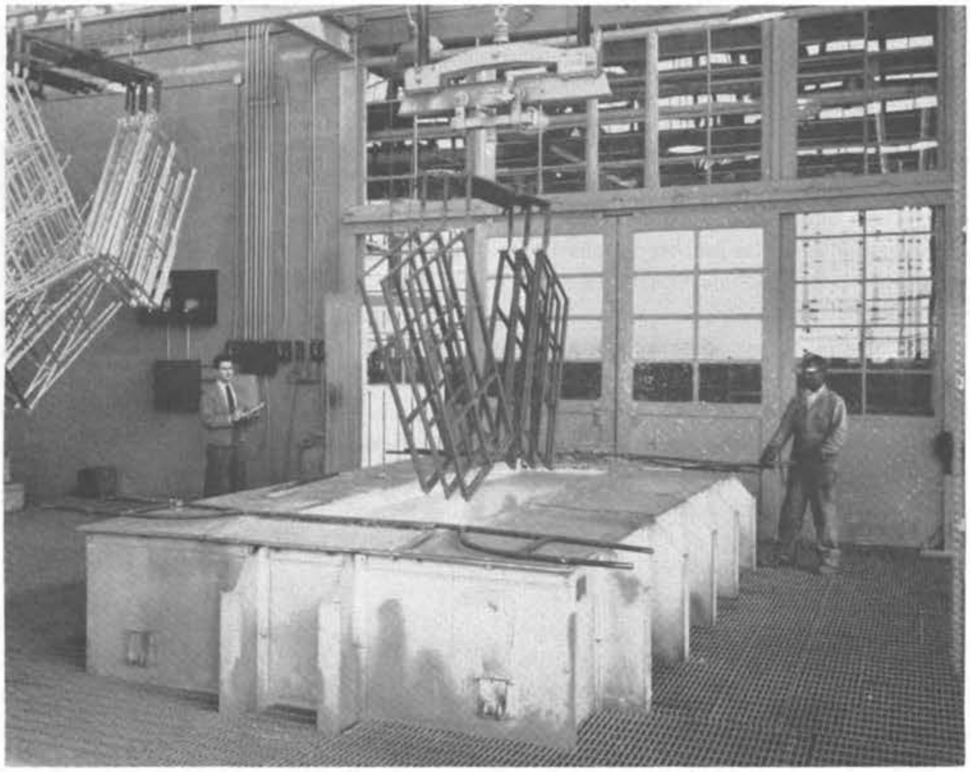


Fig. 2.16—Galvanizing bath, 110 tons of molten zinc.

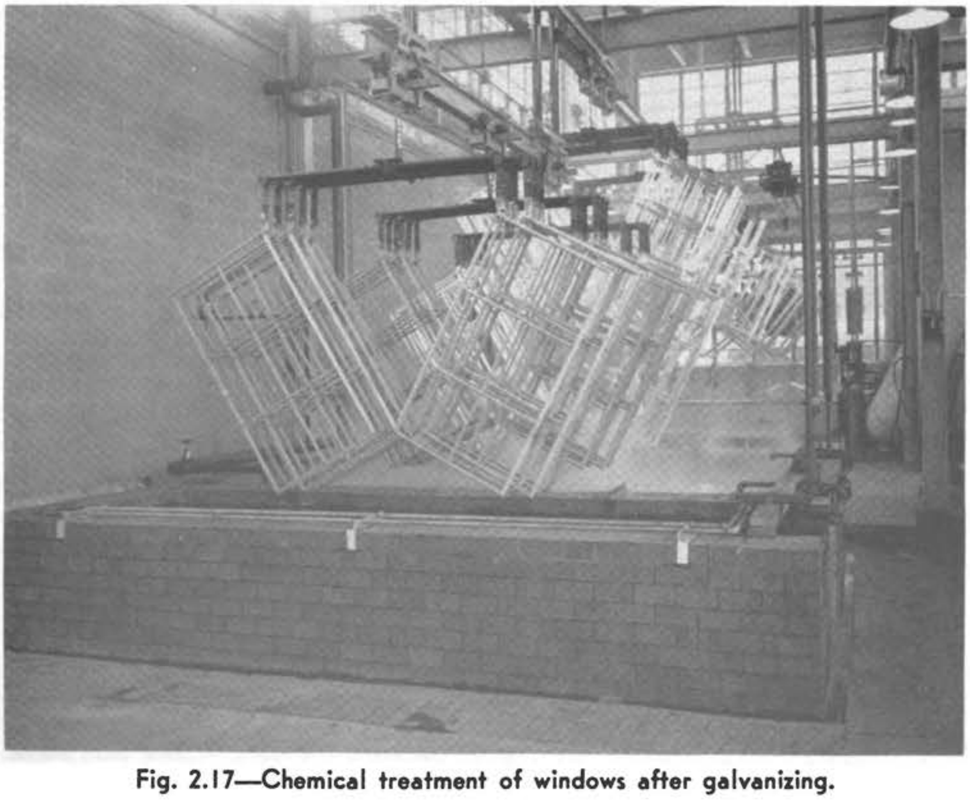


Fig. 2.17—Chemical treatment of windows after galvanizing.

Another problem for windows is common to virtually every building product where a poor field installation will harm or destroy the utility of the best made product. It should be recognized that any operating window is a mechanical part of the building and unless it is properly installed and properly maintained, the mechanical features will fail to serve well the building occupant. Here again is a problem needing the attention of all segments of the industry, namely; the designer, the builder, and the material manufacturer.

Although its ramifications may deserve separate treatment, any discussion on steel windows would not be complete without at least touching lightly on stainless steel. To date, a few buildings have been designed and erected with stainless steel windows but, to my knowledge, in all cases they have been manufactured by cold rolled or break forming processes, since it has been found impractical for the modest volume of production to date to produce hot rolled sections in stainless steel. This basic material is still in a cost range that has placed its use for windows beyond the reach of most building budgets, but with the amount of work being done to promote the use of stainless steel in buildings, it would be remiss not to predict its increased use in windows.

As in the past, new designs for steel windows will continue to be made and the intrinsic values of steel should continue to assure its need in the market place. Improvement in protective and decorative finishes will, I am sure, continue to be made. If a higher degree of standardization can be achieved, steel windows will offer many economies and advantages to future building buyers.

By John P. Jansson, AIA *
Aluminum Window Manufacturers Association

ALUMINUM WINDOWS

Mr. Jansson's paper was presented to the conference by Robert L. Klein, President of the Aluminum Window Manufacturers Association.

As near as we can determine the first aluminum window was produced in this country in the year 1926. About 1931 the first sizable installations were made in hospitals, schools, offices, monumental type buildings, apartment houses, railroad stations and in a few expensive residences.

The ever widening acceptance of aluminum windows is amply demonstrated by the fact that the aluminum industry after only 33 years of existence, now channels well over one hundred million pounds annually to prime building window manufacturers alone, for the production of double-hung, casement, awning, projected, vertical pivoted, sliding, jalousie, and other types of windows. This figure does not include a sizable tonnage of aluminum shipped to hundreds of manufacturers for combination storm and screen window units.

Major reasons for this outstanding growth lie in the characteristics of the metal itself. Its basic properties include lightness, corrosion resistance, durability, and attractive appearance. Alloying adds high strength without significantly impairing either the ease of working with it, or the comparative economies which result from its application.

PHYSICAL CHARACTERISTICS

Thickness of Sections: When determining the proper thickness or gauge for an aluminum window, consideration must be given to its type, function and size. It must also be decided whether it is to be fabricated from solid or tubular sections. Generally speaking, lighter gauges ranging from .062″ to .125″ are specified for windows in residences or low-cost housing projects. For industrial, commercial and monumental type buildings, such as factories, schools, office buildings, etc., gauges from .062″ to .188″ are more desirable.

A sill member should never be of lighter gauge than the jamb and head members of the frame since it is usually subjected to harder use. In commercial buildings, for example, window cleaners stand on the sills in order to clean the windows. Sill thickness should never be less than .062″ and, for non-residential buildings, .078″, .094″ or greater.

Strength Requirements: Gauge thickness is only one measure of strength for window members. Certainly size and shape, or to put it in more technical terms, section modulus, are important factors. However, to ask the building designer and/or specifier to check and request window members in terms of section modulus would result in a long and arduous task. The Technical Committee of AWMA has set up performance standards or specifications for practically all types of aluminum windows on the market today. These standards are to be found in the specifications for aluminum windows published annually by the Association, which consist, in part, of concentrated and uniform load requirements in proportion to the functions the various components of windows are expected to perform. In effect, the strength of the various window members can be specified in terms of per-

---

* John P. Jansson, Executive Vice President of the Aluminum Window Manufacturers Association, has a Bachelor of Architecture degree from the Pratt Institute School of Architecture. He is a member of the American Institute of Architects, the Construction Specifications Institute, the Producers Council and the Building Research Institute.

formance rather than on a section modulus basis for each type of window or window member.

Mechanical Joining and Welding: Either mechanical or welded joints are satisfactory for aluminum windows if properly engineered and fabricated. If two sections overlap, mechanical joining can be effectively accomplished. For abutting sections, welding or mechanical joining may be used. If gas welding is chosen, it is important that the flux be removed after completion of the welding process, otherwise the residue may subsequently act as a corrosive substance. Generally, inert arc-welding cannot be used for inaccessible locations, but this method as well as flash welding create no residue problems. Flash welding, incidentally, is being used almost universally by the casement and projected window manufacturers. In any event, it will be less expensive to use the method of joining preferred by the individual manufacturer for his standard window.

Finishes: Finishes tend to fall into four basic types. Although there are variations, the specifier will be able to keep his costs lower if he chooses one of the following:

1. Mill Finish—natural finish, the least expensive of all.
2. Satin Finish—produced by
   (a) etching in caustic,
   (b) belt polishing,
   (c) rubbing with emery cloth or steel wool.
3. Bright Finish—produced by buffing.
4. Anodized Finish—also known as "alumilite finish"—an electrolytic finish that provides a much thicker and more protective oxide coating than is naturally present on aluminum. It can be specified with any one of the three finishes mentioned above.

In view of the fact that AWMA has received a number of inquiries on this fourth type of finish, it may be well to compare the merits of electrolytic finishes with non-electrolytic. For outdoor architectural installations of aluminum, the finish is largely a matter of choice with the architects and owners, and is based on obtaining a specific architectural appearance. Where adequate maintenance has been provided, anodized finished windows have been used with excellent results. On the other hand, where the windows have not been maintained periodically, that is, where the grime and results of weathering have not been cleaned off, the use of the anodized finish has not been fully justified. Like any other exterior building material, if aluminum windows are not maintained the surfaces become stained and coated with dirt and products of weathering, regardless of whether or not an anodized finish was applied.

Aluminum windows do not require an anodized finish to protect their structural integrity or operating characteristics. This finish, however, does afford added protection against weathering and makes the problem of maintenance easier. An excellent example of the servicability of aluminum windows without any special finish is afforded by the Gulf Building, Pittsburgh, Pennsylvania. The windows on this building have been in service over 18 years and, although the surfaces have become roughened, the windows are structurally sound and operating satisfactorily. In comparison, the windows in the Mellon Industrial Research Building, also in Pittsburgh, Pennsylvania, have been in service for the same length of time. The casement windows on this building were given an anodized finish. They were also maintained periodically by wiping the outside of the frames and sash with a damp cloth. The finish on these windows is still excellent and they are more attractive in appearance than those of the Gulf Building. Mechanically and structurally, however, these windows are not functioning any better by reason of having an anodized finish.

It is our opinion that the anodized finish is not necessary for aluminum windows except where added protection against weathering and easy maintenance of the bright, metallic appearance are important factors.

Temporary Protective Coating: Regardless of the type of finish preferred, a temporary protective coating should be used to shield the finished aluminum surface from the many possible construction abuses. For this purpose the preferred coating is a clear, water-white, methacrylate-type lacquer, resistant to alkaline mortar and plaster, and applied to the windows at the factory before shipment. Such a coating must be able to withstand the action of lime mortar for a period of at least one week in an atmosphere of 100 per cent relative humidity at room temperature. The coating should also be the type to which glazing compound will adhere. Before application, the manufacturer must remove all fabrication compounds, dirt accumulations, and steel-wool fibres deposited by abrasion cleaning.

To insure good temporary protective coating, the Protective Coating Committee has recently developed a performance specification for clear coatings. Copies of this specification can be obtained by writing to the AWMA office.

Hardware: Hardware used to control and lock ventilating units should be designed to have long life under repeated operation and be resilient to twisting, shock, and abusive treatment. The basic hardware material should not cause the aluminum to corrode. If it does, it must be treated so as to render it passive. Non-magnetic stainless steel and "white bronze" are strong, durable materials which have demonstrated their suitability for use in hardware components. A few other bronzes may be used after being heavily chrome plated and insulated from direct contact with aluminum window surfaces. Zinc is widely accepted for die-cast hardware, and plastics are now beginning to come into wider use.

Aluminum alloys are enjoying a rapid acceptance for use in window hardware because of their strength, durability, economy and attractive appearance. When they are specified, caution should be exercised to avoid possible galling or seizing which could result from direct aluminum-to-aluminum contact. This can be prevented by the use of inserts, bushings, and similar components of non-magnetic stainless steel, plastics, oilite bronze, or other suitable material.

PERFORMANCE FACTORS

Performance specifications based upon performance requirements rather than designated physical characteristics have been developed by the AWMA Technical Committee for use as a guide for the aluminum window industry. To establish the tests now used by the independent Pittsburgh Testing Laboratory, consideration was given to weather-tight conditions and strength requirements to suit wind and other operational loading factors.

Air Infiltration: Air infiltration resistance of an aluminum window varies by window type, and whether the window is mass-produced or custom made. The standard measurement of air infiltration is in terms of cubic feet per minute per lineal foot of crack length when a window is adjusted for normal operation and subjected to a static air pressure equal to the pressure exerted by wind at a velocity of 25 mph. This will result in a force of 1.560 lbs./sq. ft. The conversion of wind velocity to lbs./sq. ft. is based on the Ensewiler formula ($P=.002496V^2$). There are other wind velocity-to-pressure conversion formulas but the Ensewiler formula is the one that is most widely recognized by the leading laboratories and window manufacturers. The Technical Committee of AWMA has agreed that a performance test is far superior to feeler-gauge tests used to measure the size of a crack between the sash and frame, since performance is the prime consideration.

Test Data: Specific knowledge regarding air infiltration, strength and other performance characteristics of a particular window, should be obtained from manufacturers in the form of accredited copies of the results of the tests made on a window identical in construction with the window to be furnished. Test reports should state that the window unit under consideration has met or exceeded the requirements set forth in the specifications. If mass-produced windows are being considered, the tested model should be a production line window.

Weather Stripping: Sliding aluminum windows, either vertical (double-hung) or horizontal, will render better service if all contact points between the sliding sash and frame are weather stripped. Not only does weather stripping give excellent air infiltration control, it also permits the sash to slide more freely in the frame. The recommended specification reads, "There shall be no aluminum-to-aluminum contact between window members that are required to move relative to one another and at the same time remain in contact."

The nature of the window design will usually determine the location of the weather stripping. For double-hung windows, weather stripping on the sill must be properly protected to prevent damage by window washers. Satisfactory weather stripping should:

1. Control air infiltration.
2. Withstand external atmospheric conditions.
3. Hold up mechanically under use.
4. Resist corrosion.
5. Resist galvanic action.
6. Be easily replaceable.
7. Keep dirt accumulation to a minimum.
8. Be very durable in relation to the sash material.

Fabric pile, stainless steel, Monel metal, felt, neoprene and other types of plastic weather stripping are often used to accomplish these objectives.

Where no sliding action exists, as in the case of projected, casement and awning windows, and where the hardware normally forces a tight closure, metal-to-metal contact can be satisfactory without weather stripping.

Life of Aluminum Windows: With nominal maintenance, the life of aluminum windows can be expected to equal that of the buildings in which they are installed. No painting is required. Such a period of service may not generally be considered possible, but if the windows are properly designed, fabricated and installed, the building owner can be assured he is obtaining a lasting building product. The purpose of the "Quality Approved" Seal of the AWMA is to assure the buyer of a lasting building product through the medium of the specifications and testing program.

Aluminum windows can serve in any climate in which normal atmosphere exists. This would include coastal and inland areas that encompass rural, city or industrial sections in wet, dry, hot or cold climates. The 6063 alloy, generally employed for the extruded sections of windows, contains sufficient magnesium and silicon to impart the strength required and at the same time it can be extruded at high speed for economic advantages. The 6063 alloy has a silvery appearance, an excellent basis for protective or decorative coating, and a high inherent resistance to atmospheric weathering.

Aluminum alloy windows have been used for the past thirty years in all types of natural atmospheres, including a wide variety of industrial and seacoast atmospheres. Based on this experience aluminum windows may be expected to have adequate life in most industrial environments. As a rule of thumb, if a human being can work comfortably in an industrial atmosphere, aluminum windows will perform satisfactorily. If you are specifying products for plants with unique atmospheric conditions, it is advisable to consult a prime-metal producer (Alcoa, Kaiser, Reynolds) concerning the expected performance of aluminum windows for the specific project.

Corrosion by Dissimilar Materials: Galvanic action in terms of the corrosion resistance of a material cannot be expressed quantitatively; it is only a relative term. No known construction material is entirely resistant to all conditions to which it might be exposed. To judge it fairly, it should only be compared with other materials under similar conditions. Unlike many other metals, aluminum has the ability to form a thin, adherent film of hard oxide instantaneously on freshly exposed surfaces.

Except for the possible over-all corrosion caused by highly contaminated atmospheres, the only corrosive actions of any concern to aluminum windows are:

1. Galvanic attack excited by non-aluminum metals.
2. Drainage of salts from non-aluminum metals over aluminum windows.
3. Poultice attack, which aluminum and other metals suffer when held for extended periods in intimate contact with absorptive materials.

Galvanic corrosion involved in window installation can easily be controlled by the choice of the dissimilar metal and the design and use of protective measures. The most compatible non-aluminum metal possessing the physical characteristics needed should be selected. Metals that will in general perform well with aluminum are: non-magnetic stainless steel, heavily galvanized steel, and zinc. Components of copper or nickel alloys can be used under specific conditions, although it is best to avoid their use if at all possible.

Galvanic attack can be prevented by providing weather-tight joints between dissimilar metals by mechanical tightness plus the use of a protective coating such as lacquer, zinc chromate, bituminous paint, non-conductive and non-absorptive gaskets, or mastic seam compounds. It is also essential to locate the joints in order to provide free drainage of moisture away from the dissimilar couplings.

The use of water-absorptive building materials (such as wood or insulation board) between aluminum and the dissimilar metal (such as steel) can result in direct galvanic corrosion, if the absorptive materials remain wet or damp. An electrical contact between dissimilar metals could easily be effected by a metal fastener; however, no galvanic attack will occur if the metal parts are fully insulated from one another. Where this cannot be effected, the use of a uniform layer of water resistant mastic between the aluminum and non-metallic members will generally prevent galvanic attack.

Wash from Dissimilar Metals: Corrosion of aluminum windows can also be caused by wash from dissimilar metals, notably copper and nickel. Such drainage contains salts of copper or nickel particles; iron salts are considerably less harmful. It is important, therefore, to prevent drainage or drip from flashing, gutters, valleys, or ornaments of copper and nickel alloys from coming in contact with aluminum. This can best be prevented by maintaining a paint coating over the dissimilar metal parts.

Poultice Attack: Poultice attack, as the name implies, may result from extended contact of aluminum or any other metal with a water-absorptive material. These materials hold moisture against the metal surface for longer periods of time than the freely exposed surfaces and, in so doing, screen oxygen away from local spots on the metal. This creates small galvanic cells between spots containing different amounts of oxygen or moisture.

The absorptive material itself need not be corrosive. Certain types of products create greater poultice attack than others. This type of attack might be caused by wood, insulation board, or poorly impregnated building paper. It is best prevented by *not* allowing construction materials to become wet. One successful precautionary measure is to make non-metallic construction materials water-resistant by painting with two coats of a good grade aluminum house paint and sealing the joints with a good quality mastic calking compound.

Masonry Joints: Where aluminum windows come in contact with masonry, the prime consideration is to be sure that a close fit exists between the frame and masonry. It should be determined whether the frame is going to sit behind masonry or butt against the masonry reveal. When cement block is used, special attention should be given to specification and application details. If possible, it is advantageous to use cement blocks that are made especially to receive windows.

Manufacturers' recommendations for installation and anchorage should be carefully checked to insure that adequate calking is provided. Every effort should be exercised to eliminate any crevice which might allow water to collect around the frame. In addition it is advisable to paint the aluminum surfaces in contact with lime mortar, concrete or other masonry materials with alkali-resistant coatings such as water-white methacrylate lacquer, or a bituminous paint.

INSTALLATION FACTORS

Aluminum alloys used in windows have a coefficient of thermal expansion of .000013 per inch per degree F. This means an 8′ length of aluminum will change by ⅛″ per 100°F. change of temperature. Aluminum windows must be designed and anchored so that they will not be distorted, nor the fasteners overstressed from the expansion and contraction of the metal.

To insure proper anchorage:

1. Anchorage must hold the window rigid.
2. There should be sufficient strength in anchorage of jambs of commercial windows to satisfy the requirements of the window cleaner.
3. Windows must be supported properly at the sill to withstand normal use by window cleaners.
4. Anchors should be fabricated and installed to eliminate any staining of aluminum surfaces.
5. All anchoring devices used in the erection of aluminum windows must be of aluminum, nonmagnetic stainless steel or other corrosion-resistant materials compatible with aluminum.
6. It is important to specify and clearly indicate who shall supply the anchors, the window manufacturer or erection contractor.

Each aluminum window manufacturer will normally show in his literature the best method of anchoring windows to surrounding construction; the manufacturer's representative should be consulted in the event that a special design is used.

Because of aluminum's lightness, relatively large individual windows can be installed with ease. Four to six small windows can be handled as one unit and two men can speedily lift this window assembly. It should be remembered that large assemblies made up of individual units in the factory are feasible only up to a certain point, because of the controlling factor of transportation. In such cases, assembly at the site provides a simple solution.

Glazing and Calking Compounds: Mastic-type calking compounds should be provided and installed by others, except in the case of metal-to-metal contact points in the window assembly. In this case they should be provided and installed by the window erection contractor.

A mastic-type glazing compound that does *not* require painting should be specified. As aluminum colored mastic alone is an insufficient precaution, a compound should be labelled, without qualification, that it does *not* require painting. A glazing compound should remain elastic enough to perform properly when subjected to the rigors of atmospheric environments. Mastic-type compounds are advantageous as they permit a broken light to be replaced easily, as opposed to those glazing compounds which become hard and brittle with age.

Performance specifications for Elastic Glazing Compound for Metal Sash Face and Channel Glazing, dated July 15, 1955, are available by writing the AWMA office. Glazing compounds should be supplied and installed by the glazing contractor, as should all standard glazing clips. A special type of glazing clip is usually provided by the window manufacturer. Glazing clips for double insulated glass are provided by the glass manufacturer. Aluminum windows can be prepared for either inside or outside glazing. It is best to consult the individual window manufacturer to determine their respective glazing details.

Some of the manufacturers of aluminum windows are no longer using glazing compounds for their windows. Many of them use neoprene or vinyl glazing beads. Generally speaking, these manufacturers preglaze in their factories, previous to shipment, although site glazing is also prevalent. All of the manufacturers who use these techniques consider them equal to and, in some cases, superior to glazing compounds.

Care During Construction: The window erection contractor will install the aluminum windows in a good condition and will assume full responsibility for their condition. However, once the installation has been approved by the architect and/or the general contractor, the contractor must assume responsibility for their protection as other trades continue their work. Many times the question of protection and cleaning is completely ignored in the specifications, but more commonly it is placed in the hands of the window erector. This is the worst thing that the specifier can do to preserve the quality of the finished appearance of aluminum windows. The responsibility should be placed *completely* in the hands of the general contractor who is running the job. The general contractor is the only one who has control over all of the many trades on the job. He is the only one in a position to demand satisfaction from the various subcontractors, police them and give instructions, and withhold their payments if they do not cooperate. Care of aluminum during construction is not a difficult thing to achieve. The recent AWMA publication entitled, "The Care and Cleaning of Aluminum Windows During and After Construction," gives rather complete coverage of this important subject.

Maintenance: Aluminum windows require little maintenance to preserve their appearance and efficient operation throughout the life of the building. The care consists of merely washing the sash and frame along with the glass; the frequency of the washing depends upon the location of the building. Caustic or acid cleaners should not be used. Many solutions marketed today are satisfactory for washing both glass and aluminum.

DESIGN FACTORS AND ECONOMICAL SELECTION OF WINDOWS

Last June the Federal Construction Council, which is made up of some 36 Federal agencies active in construction, asked AWMA to help outline methods for the economical selection of windows. A full report covering all types of windows is now available from the Council through the Building Research Institute. In our work on this project we found that there are many factors to be considered in the choice of windows for a building. In making a selection of window type and material, consider whether the window will:

1. Suit the overall design of the building.
2. Provide daylight in adequate amounts.
3. Offer minimum obstruction to view.
4. Provide the desired ventilation.
5. Provide weather-tightness when the window is closed.
6. Be fitted with hardware which makes for easy operation.
7. Be economically adapted to the construction technique to be used.
8. Not interfere with passage (interior and exterior) near the windows, nor interfere with draperies, blinds, or furniture, when open.
9. Be easy to fit with screens and storm sash, if required.
10. Be easily washed.
11. Be inexpensively maintained.
12. Be adapted to the climatic conditions of the building location.

In most cases the type of window selected will be determined by the desired architectural design of the building. It is advisable to consult with the window manufacturers at an early stage of the building design. Usually they can make suggestions for proper application, anchoring trim, glazing, etc., which can reduce fabrication costs and can result in substantial savings for the owner. Some of the general factors which assist in maintaining minimum costs are: stock designs; maximum use of one type and size throughout the building; uniform design of windows; only minor adjustments at most on a standard design recommended by a manufacturer.

Initial and Maintenance Costs: The initial cost of a window unit will depend on the material (wood, steel or aluminum) and the type of window selected. Generally speaking the initial cost of aluminum windows is slightly more than steel or wood. However, when the first painting cost for the steel and wood windows is added to their basic cost, the price difference will disappear. It must be remembered that aluminum windows arrive on the job in the finished state and additional finishing is not required.

Maintenance costs over the life of the building have been and will continue to be one of the best selling points of aluminum windows. It is axiomatic that buildings become successful from a cost standpoint only when income is substantially in excess of maintenance. Certainly, the painting of windows must be taken into consideration in a study of building maintenance costs. One of the major advantages of aluminum windows is that they do not require painting throughout the life of the building.

The savings that are possible are worthy of the owner's and architect's consideration, since aluminum windows do not rust, rot, or warp. For instance, a group of building windows with 15,000 window openings, leased at present day prices would save almost $400,000 over a 20 year period, or $1,000,000 over a 50 year period.

AWMA SPECIFICATIONS

The AWMA Specifications covering minimum structural standards, quality materials, construction, strength of sections and minimum air infiltration requirements were first established by the Association in 1946 for the protection of all who specify, buy or use aluminum windows. There can be no doubt that the specifications have proven beneficial to the building industry. We know that the architectural profession has been effectively utilizing these specifications in both private and public construction. In surveys conducted by the Association of the architectural profession it has been indicated that 80 per cent of the architects who use these specifications believe them to be effective documents. Various Federal agencies such as the FHA, U. S. Army Corps of Engineers, U. S. Navy Bureau of Yards and Docks and others use these specifications as minimum standards for aluminum windows in their respective projects.

In spite of overwhelming acceptance by the building industry of these specifications, the AWMA membership feels that improvements can be made. With this in mind the Association has recently retained the firm of Arthur D. Little, Inc., to make a study and evaluation of aluminum windows. The basic objective of this study will be to provide an impartial and authoritative analysis of the fundamental requirements of prime aluminum windows and sliding aluminum frame glass doors and, based on this analysis, to establish standards and testing procedures which will be the basis for the preparation of sound and reasonable performance specifications for the building industry.

The first part of this research project will comprise a survey by Arthur D. Little, Inc., to determine what architects and builders expect in the way of performance standards from aluminum windows.

"QUALITY APPROVED" SEAL

In our specifications, advertising, and other literature published by the Association you have all noted reference to the "Quality Approved" Seal. What exactly does the "Quality Approved" Seal mean to the building industry? The seal is an indication that the windows on which the seal appears (double-hung, casement, projected, awning, sliding and jalousie) meet or exceed the specifications of the AWMA. To ascertain that these requirements have been met it is necessary for the window manufacturer to submit his window to the independent Pittsburgh Testing Laboratory for tests outlined in the specifications. In addition to this, the manufacturer must abide by the rules and regulations governing the test program of the AWMA and the Pittsburgh Testing Laboratory, and by the rules, regulations and procedures for obtaining the "Quality Approved" Seal of the AWMA. This means that the window manufacturer must sign a license agreement for the use of the seal and that the seal can only appear on the window units that have complied with the aforementioned documents.

Use of the "Quality Approved" Seal is *not* limited to members of the Association. Any manufacturer whose windows, when tested by the independent Pittsburgh Testing Laboratory, meet these minimum standards can qualify for use of the seal.

In addition to the specifications AWMA also publishes other useful literature as follows:

1. Simplified Instructions for the Proper Handling and Installation of Aluminum Windows in Commercial and Monumental Buildings, No. 53 CM.
2. Simplified Instructions for the Proper Handling and Installation of Residential Double-Hung Aluminum Windows, No. 54 RDH.
3. Simplified Instructions for the Proper Handling and Installation of Residential Casement Aluminum Windows, No. 54 RC.
4. Ever See a Window Talk about . . . Condensation!
5. Tips on Selecting Windows for your New Home.
6. Aluminum Windows—Selection and Detailing, reprinted from Progressive Architecture, April 1952.
7. The Care and Cleaning of Aluminum Windows During and After Construction.
8. Weather Tests Determine Rigid Window Specifications, reprinted from Progressive Architecture, March 1956.

Copies of these publications may be obtained from the AWMA, 75 West St., New York 6, N.Y.

By H. F. Kingsbury *
Pittsburgh-Corning Corporation

GLASS BLOCK

To give some context to the development and usage of glass blocks, it seems in order to review briefly their history.

They were introduced in the mid-1930's by the two manufacturers presently engaged in the production of these items. The early designs were mainly decorative in nature and concept, and did not make use of the possibilities for light control inherent in the basic design. As the need for better daylight controls was recognized by architects and lighting experts, the design possibilities of glass block began to be investigated, with the end result that there are available today a variety of types of blocks in both the so-called decorative and functional patterns. Individual patterns, particularly of the functional series, are designed for certain types of usage.

Because design progress in blocks for particular functional needs has been so rapid, and because glass blocks are actually quite a new product in the history of fenestration, it is not felt that the full range of design concepts has yet been explored, either in manufacturing or end usage.

Since the use of any product in a building is at least partly determined by the properties of the material, it seems worthwhile to consider the properties that are typical of all glass block, as well as some that are specific for certain patterns.

In the first place, glass blocks are hollow, all-glass, evacuated units, made and sealed at high temperatures. Being glass and hollow, they are non-load bearing, although they do have a compressive strength on the order of 500 pounds per square inch, when uniformly loaded, such as in normal panels. Point loading, quite naturally, will break them.

Since they are both hollow and evacuated, panels of glass block have low heat transmission, both conducted and radiant. Conducted heat loss or gain, depending on pattern and size of the blocks, ranges from approximately one-half to one-third that of single glazing. Instantaneous radiant heat gain, again depending on pattern, is approximately one-third that for common single glazing. For reference purposes, the values for both conducted and radiant heat transfer may be found in the current ASH&AE Guide.

Glass block panels, because they are masonry construction of some mass, also have a relatively high sound reduction factor. The average over the various commonly accepted frequencies is a 40 decibel reduction, and is comparable to a 4" thick concrete block wall. Also, because of the masonry construction, glass block panels are essentially low maintenance installations. They are highly resistant to weathering, and a whole range of industrial atmospheres and fumes. While they are glass and therefore can be broken, such breakage is difficult, usually only on one face and, if it occurs, can normally be taken care of on a planned basis at a convenient time. Since panels of glass block are translucent, for most patterns, they seldom need washing other than by normal rainfall.

Since glass blocks have four pressed surfaces, two of them protected from the weather, it is in the field of light control, using prisms and lenses pressed in any or all of the four surfaces, that broad design possibilities exist. A variety of patterns is available for the control of light by the principles of either light direction or light diffusion. Light directing patterns have

* Howard F. Kingsbury is the Director of the Daylighting Research Center of the Pittsburgh-Corning Corporation, at Port Allegany, Pennsylvania. He has a Bachelor of Science degree in Glass Technology from Alfred University, and a degree in Ceramic Technology from Pennsylvania State University. He is a member of the Illuminating Engineering Society and the Society of Glass Technology.

been used in many installations where control of entering daylight is required or desired, without the use of auxiliary brightness control devices. The principle upon which these blocks work is simply that, by the use of carefully designed prisms on the inside surfaces of the blocks, the entering daylight is redirected upward to the ceiling, and reflected down from there to the task level, with two immediate results. In the first place, by redirecting a major portion of the light upward, this light is projected deeper into the room to obtain better lighting of the rear of the room. Secondly, and perhaps of equal importance, this redirection lowers the fenestration brightness, to obtain better ratios of fenestration brightness to task brightness.

Blocks of light-directing design are available wtih varying degrees of brightness control to suit various circumstances. For example, there is one type specifically designed for use on north exposures which not only offers the high light transmission required for this exposure, but also sufficient brightness control for comfortable lighting.

For excellent control of both brightness and heat flow, there is another style of light-directing block available, which incorporates a fibrous glass screen or cavity divider, sealed into the block during manufacturing. And finally, for the control of extreme brightness, or for use in areas where heat gain is a specific problem, both manufacturers have special block available. One such unit operates on the principle of rejecting a portion of the unwanted heat and light at certain sun positions, for the better control of this energy. Another pattern includes a blue-green tinted fibrous glass cavity divider, which aids in the control of radiant heat and, at the same time, gives a psychological feeling of coolness by reason of its color.

For those areas where the extreme qualities of the light directional patterns are not required, but where brightness control is still important, various patterns of light diffusing block are available.

Since these technical descriptions of the lighting properties are, necessarily, a bit involved for easy understanding, reference to Figs. 2.18 and 2.19 shows the difference in light patterns created through directing and diffusing. In Fig. 2.18 the light source from the upper left is noticeable redirected, finally emerging above the horizontal. Fig. 2.19 is a similar picture, but for a diffusing pattern, and shows the scattering caused by the prism action.

All of these descriptions of the technical properties of glass block lead to the end-point of usage in buildings. Perhaps the biggest single present-day usage of glass block is in schools. Here the fundamental properties of blocks with regard to light con-

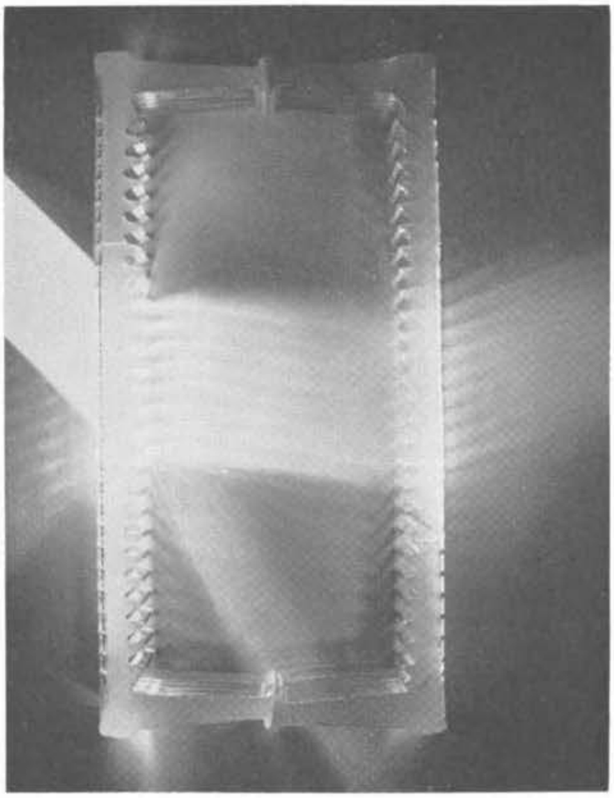


Fig. 2.18—Light path through light-directing block section.

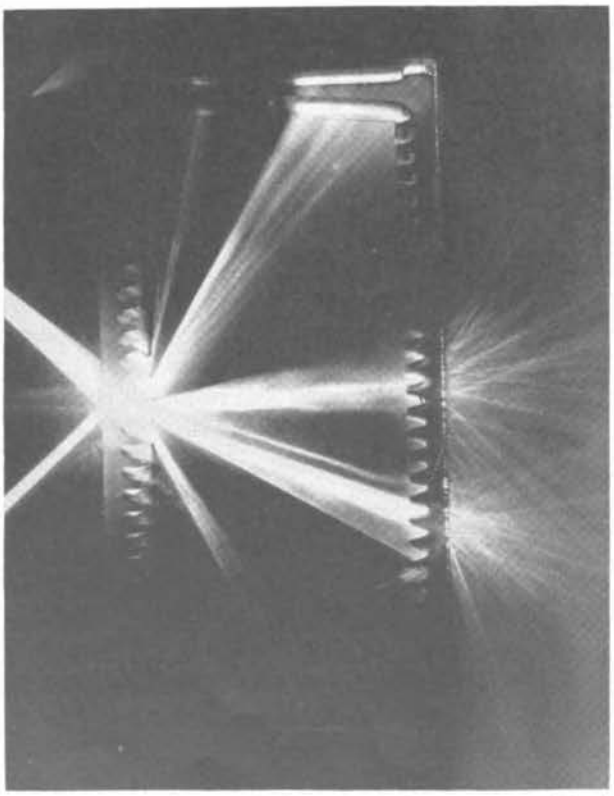


Fig. 2.19—Light path through light-diffusing block section.

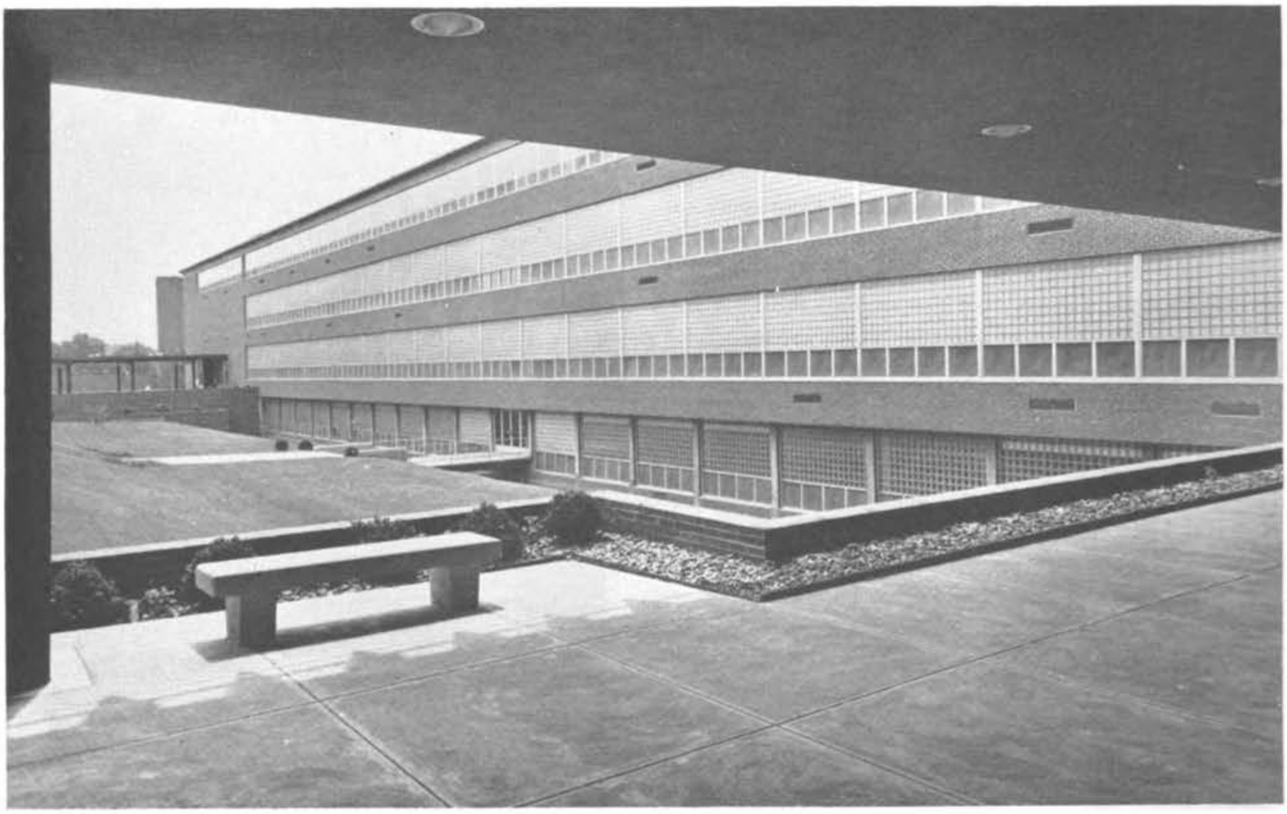


Fig. 2.20—Bishop Dubourg High School, St. Louis, Mo.

trol and maintenance make them a widely accepted fenestration material for classrooms, gyms, and other portions of school structures. As an example of typical usage in schools, Figure 2.20 is included. While there have been many strides in school design incorporating glass block, and in the design of glass block for such usage the performance advantages of glass block have been well described elsewhere and will not be dealt with here.

Among the newer developments in glass block usage has been that of skylights. For a variety of technical reasons, glass block skylights have always appeared to be a logical usage, and two types have been developed and marketed. In one style, the blocks are prefabricated in an aluminum grid and are available in a selected number of panel sizes. The blocks themselves are designed to reject a portion of the heat and light at certain critical angles, when properly oriented.

The other style of skylight uses glass block cast directly in concrete, and may either be cast in place or prefabricated and hoisted into place. Diffusing type block, specifically designed for skylights, are used in this system. One feature of this system is the flexibility of sizes and shapes that can be obtained. Examples are sections of barrel roofs, fan or pie shaped skylights or other forms, depending on the end usage and imagination of the designer.

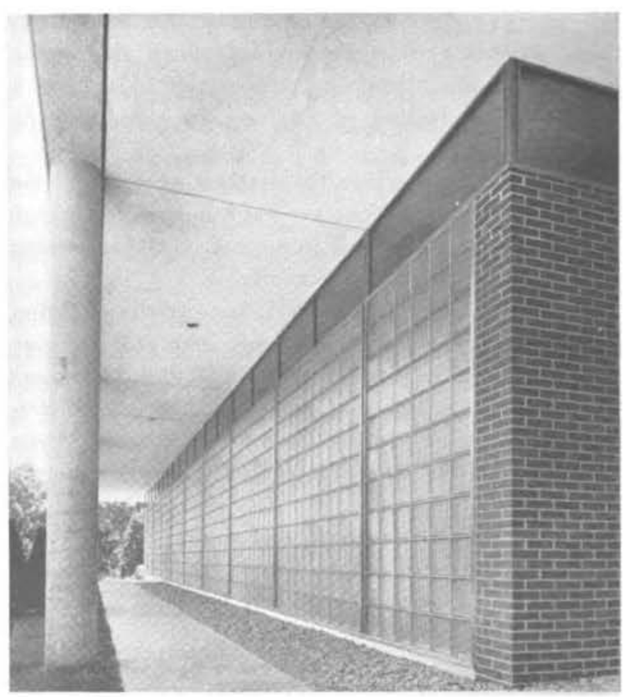
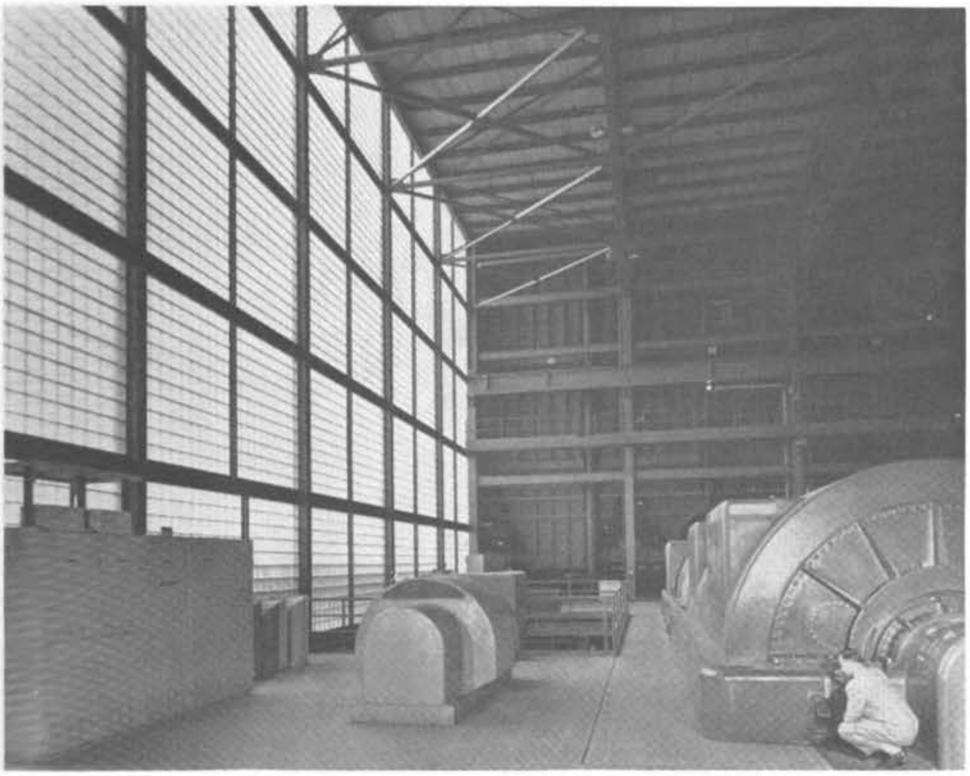


Fig. 2.21—Glass block curtain wall in Y.M.C.A., Port Chester, N. Y.



. Fig. 2.22—Philadelphia Electric—Cromby Station, Philadelphia, Pa.

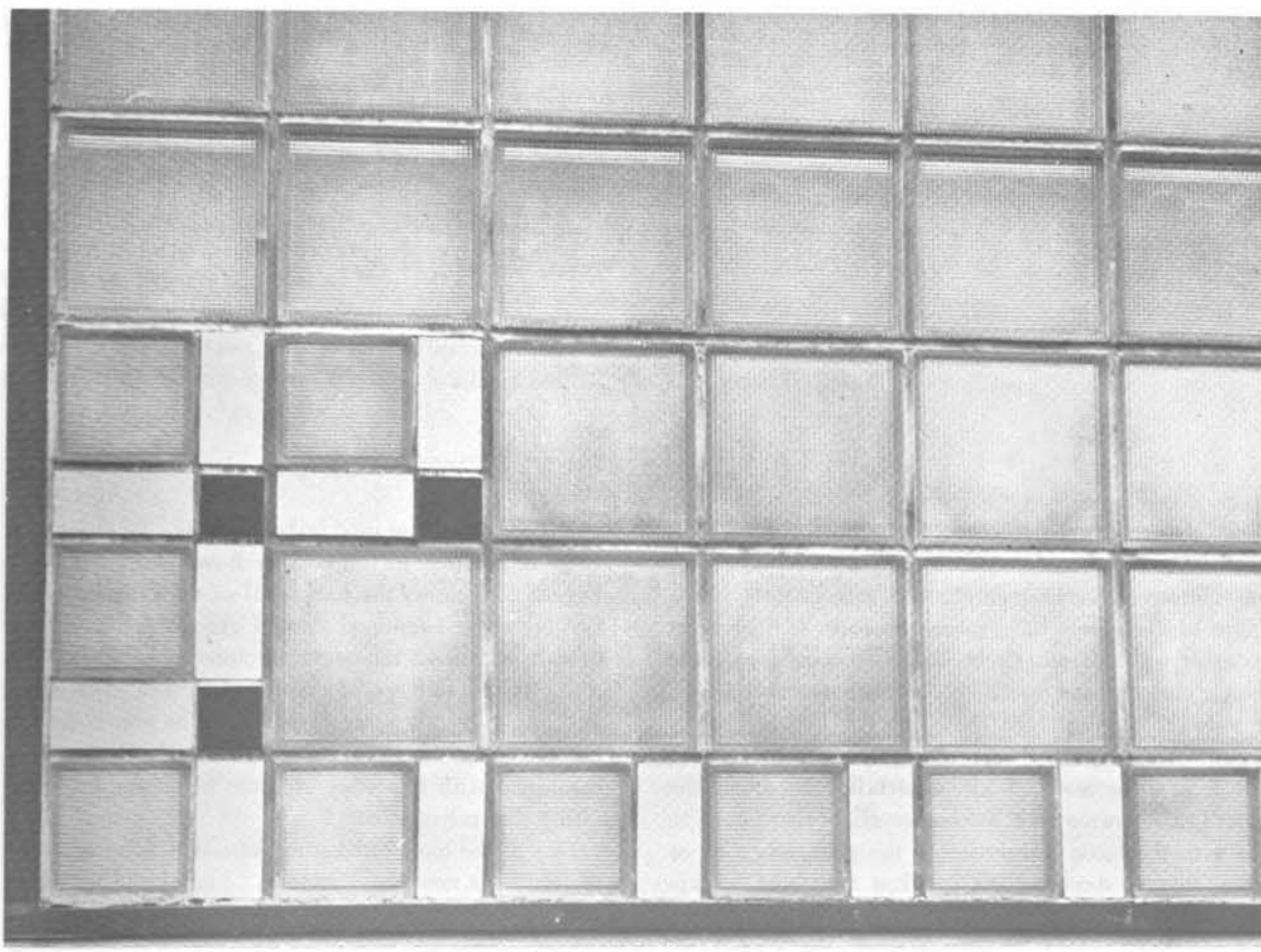


Fig. 2.24—Tile combined with two sizes of glass block for decorative effect.

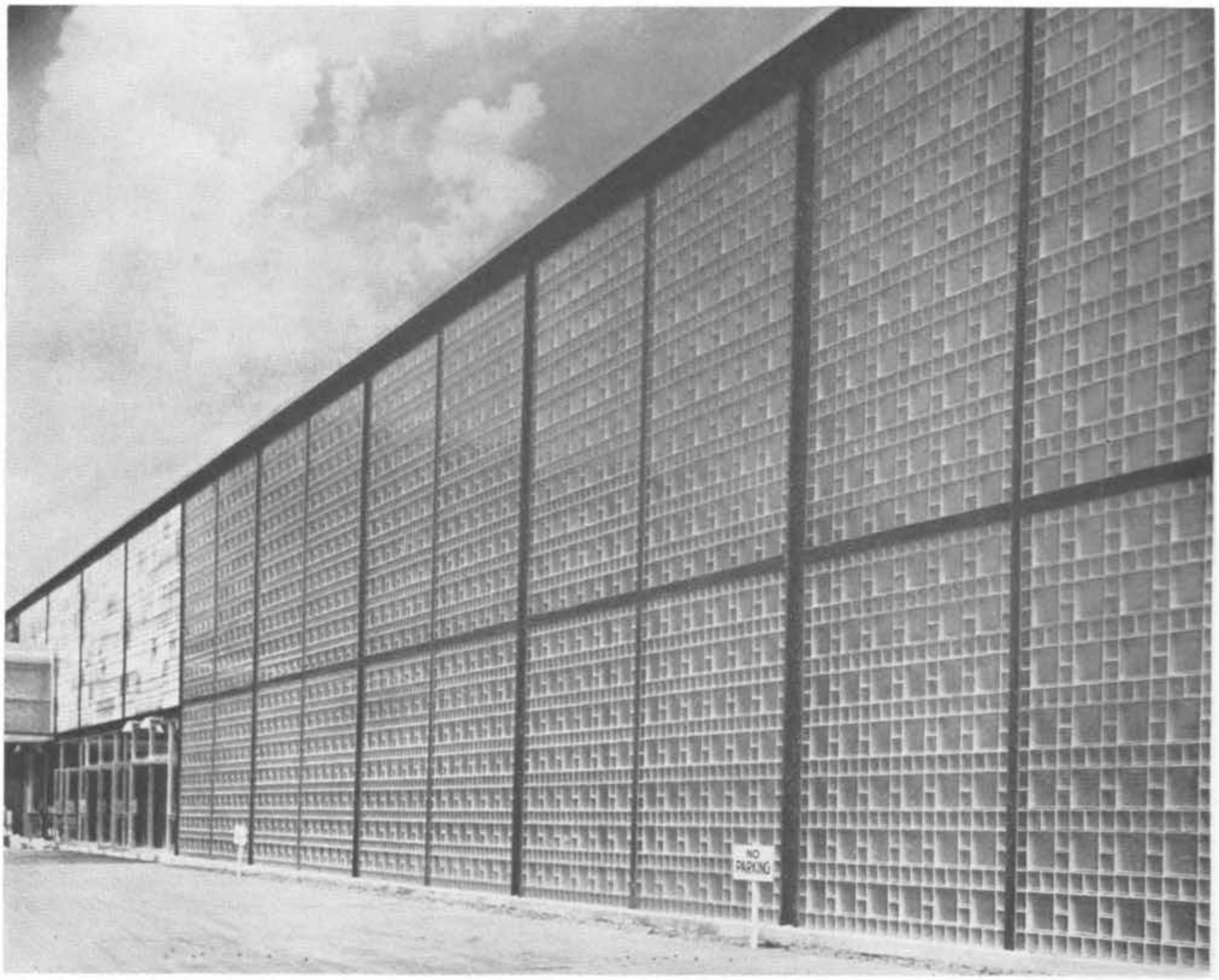


Fig. 2.23—Corning Glass Works, Corning, N. Y.

By nature and by designs, glass block panels constitute a curtain wall type of construction. This feature, however, has been emphasized infrequently. Most glass block panels have taken the form of inserts in exterior walls of other materials. To show how glass block can be used to make complete exterior walls, Figures 2.21 and 2.22 show installations in newer buildings. There are various reasons for the use of block in these installations, as detailed by either the architect or owner, but in essence all of them have to do with the basic properties of the material, such as maintenance, daylight control, low heat loss, or appearance. Some say that glass block panels have a monotonous appearance in large areas. To show how such difficulties or objections have been overcome Figure 2.23 shows the back wall of the Corning Glass Center, where combined sizes of glass block have been used to obtain an interesting architectural effect. It is also possible to use both combined sizes of glass block and inserts of other materials within the panels to give additional visual stimuli. In Figure 2.24, tile has been combined with two sizes of glass block for an interesting decorative effect.

One of the most interesting jobs of which the writer is aware is a new installation in a bank building where vision, brightness control, color and appearance have

Fig. 2.25—Richfield State Bank, Richfield, Minn.

been combined in one structure and yet entire walls, with the exception of the tile inserts, are glass block. Figures 2.25 and 2.26 are exterior and interior views of this building and show how, by combining sizes and types of glass block with other materials, monotony may be avoided, the functional characteristics of glass block retained, and a finished wall, inside and out, obtained with but one material.

Inherently, glass block has a number of advantages for the building designer, and future, broadened uses of this material will be determined to a certain extent, by his imagination and curiosity.

Fig. 2.26—Interior view of wall treatment in Richfield State Bank.

By C. R. Sigler *
The Kawneer Company

FIXED GLASS INSTALLATIONS

Mr. Sigler's paper was presented to the conference by D. C. Muessel, Manager of Architectural Products Development, The Kawneer Company.

Fixed glass installations in commercial, public, and residential buildings can be found back through the centuries. Over these many years we are able to point to only a few basic design advances. However, in more recent years there have been several almost revolutionary steps taken in the design, installation, and application of fixed lights of glass. We at Kawneer believe that the modern era in fixed light design began fifty years ago with the birth of the idea of using lightweight, all metal, glass-holding members which provide a resilient setting, easy to install and to handle during glass replacement.

We see fixed lights playing an important part in today's buildings. Among the many specific uses, these installations form the major part of storefronts and entrances. The modern design is built around large, single or multiple fixed lights. This design gives a feature effect to the elevation or to the specific entrance. Psychologically this design provides an open and welcome atmosphere to the building, thus minimizing the barrier between the potential customer and the merchant. Flexible and expanded display areas are provided in this design; the entire shop is opened and may serve as a display in itself. The universal acceptance of this design approach to store fronts and entrances by the architects and owners has made this one of the major applications of fixed lights.

In commercial buildings of all types—including office buildings, schools, hospitals—we see an increasing use of fixed glass. The trend today is to have in the physical plant of the building equipment which will control the heating and cooling of the building along with providing the proper humidity and ventilation. This not only eliminates the need for operating sash, but actually makes it undesirable on many jobs. The fixed light in a wall system is the simplest and most flexible from a design standpoint. It is also more economical and forms a more positive weather barrier.

Although this conference deals with windows and glass in the exterior of buildings, I think that it is important to note that fixed lights of glass also play an important part in the interior of the building, especially the glass used in partitions for borrowed light. These partitions may be office or corridor walls or separators for the control of traffic. Of course, there are also interior display areas and shops which are treated similarly to a storefront.

The various uses and applications of fixed lights having been noted, it is probably well that we consider the light itself. There are as many variations in the light as there are uses for it. The glass itself may be simply plate or sheet, which is most common of course, and is used almost exclusively in storefronts and entrances. Or it may be a double glazed unit, which is finding more and more usage in commercial buildings as a part of metal walls. Patterned and ornamental glass, in addition to its many uses on the interior of the building, is also used on exterior openings and may require special consideration.

We see each of the glass types just mentioned set in several ways. They include everything from the simplest putty system to minutely designed metal members incorporating a weathering gasket. Therefore there could be literally hundreds of designs for fixed light openings if all combinations of the variables

---

* Charles R. Sigler is Manager of Engineering for The Kawneer Company. He has been with this firm for nine years, principally in product development and engineering. He has a degree in Mechanical Engineering from Purdue University.

were explored. Rather than pursue that frightening thought any further, let's examine some of the functional requirements of fixed light openings and see how generally these can be best met.

1. Prevention of air infiltration is certainly a consideration. The degree to which this is a factor varies widely with application. On storefronts and entrances it is of relatively small importance; on residential and certain commercial applications it is of major importance. The fixed light is generally easier to make airtight than operating sash. Several materials of both putty type and gasket type, applied continuously around the light and properly retained by the stops, solve this problem nicely.

2. Water leakage must be prevented in all applications. In light of how casually I discussed air infiltration one might assume that water leakage is no larger problem, since if you have no air penetration, certainly no water will come in. In part this may be true. However, in a sense, air is abstract and relative, while the water is as positive as each stained wall, drape, or rug. Theoretically, as was mentioned under air infiltration, the light can be perfectly sealed with a continuous bead of quality glazing material properly retained by the stop. However, consider the actual conditions. Here we have to introduce the fact that the stops are not continuous around the window and joints do exist. Errors or poor workmanship can occur in installation. Metal expands and contracts; wood warps, swells, and rots. Glazing compounds age and deteriorate. Consider the glass as a member moving under changing wind load and traffic vibration.

Realistically, then, the designer faces a real task indeed, if he proposes to stop all water at the exterior glass line under these conditions. Water weathering does not stop with sealing the area between the stops and the glass. A weathered unit must include sealing the glass to stops, the stops to frame, and the joints in frames. This, then, being the size and shape of the problem, it would be foolhardy to plan on allowing no water to go beyond the outside glass line. Rather, it is better to assume that some water will enter, and then provide in the stops or frames a system of collecting the water and returning it to the outside. This would essentially be a system of gutters and downspouts which would contain any leaks within the frame members and not allow the water inside the building.

While this may seem a further complication to the problem, we have used this approach in storefront sash and division bars, as well as wall type framing systems (Fig. 2.27). This provides a solution not subject to the same errors and failures noted above. The solution has required only minor modification of

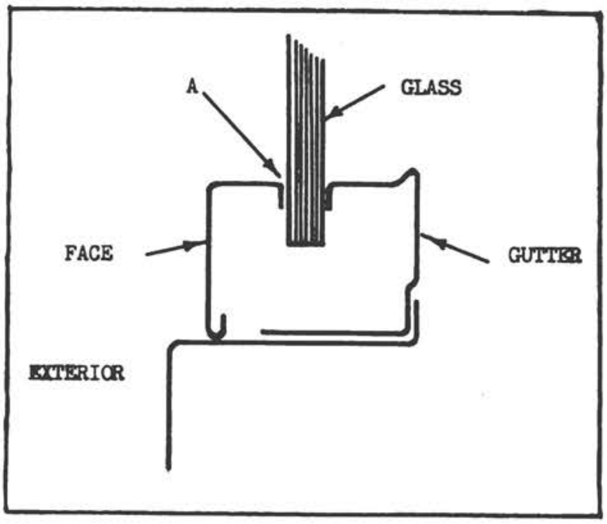


Fig. 2.27—Sash section at sill.

the glazing or framing members and has resulted in a very effective and economical solution.

3. Designing for wind load is another task that the designer must perform in accurate detail on certain types of installations. Specifically, this is true on those openings using the large plates of glass, where intermediate vertical or horizontal mullions are introduced. Here, in addition to all other considerations, a structural system must be developed. Economics demand the maximum structural use of the materials used. On the other hand, it should be recognized that failure of the system would seriously endanger life and limb. Engineering values for the strength of glass have not been defined to the degree that, in this case, we could consider glass as a structural material. Further, the formulas for stress developed in plates under this type load are not as yet precise, nor does the designer know in exactly what manner the load is transmitted from the plate to the framing system he is attempting to develop.

In spite of this apparent dilemma, the situation is not hopeless. From the extensive tests and studies that have been made, a practical approach and set of values have emerged. Starting with allowable deflection in glass, the glazing members must be designed to contain the deflection within this value. Allowable deflection defined for this purpose would be that developed in a 1″ strip of glass loaded as a simple beam. We assume no strength in the glass itself, in resisting windload. Actually, in our designs we allow the glazing member to deflect only ⅓ the allowable deflection in the glass.

To establish the windload that is transmitted to each of the glazing members, we divide each light of glass by 45° lines from each corner (Fig. 2.28). The wind-

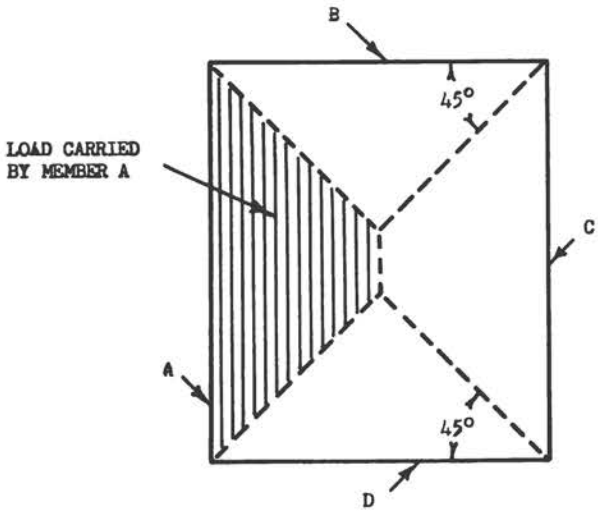


Fig. 2.28—Wind load transmitted to glazing members.

load carried by each of the four frame sides is that carried by the area of the triangle or trapezoid formed on it. Member A is loaded by the shaded area. The unit load is established from the wind velocity for which we are designing.

It is interesting to note that in a relatively high and narrow opening the vertical members which would support a single light of glass might have to be beefed up if a horizontal were to be introduced, say, at the midpoint. (Fig. 2.29). Note that not only is the load area supported by A^1 in case #2 larger than that supported by A in case #1, but the area in dark shading is transmitted by H to A^1 as a concentrated load. A^1 must be a stronger member than A. The framing member, having limited the deflection as required, must now be examined to determine if, under the load, the allowable stress has been exceeded. If not, in effect the design has been achieved.

On high, large lights where the design is sound from an engineering standpoint, with a rather lightweight vertical division bar holding the glass, the allowable

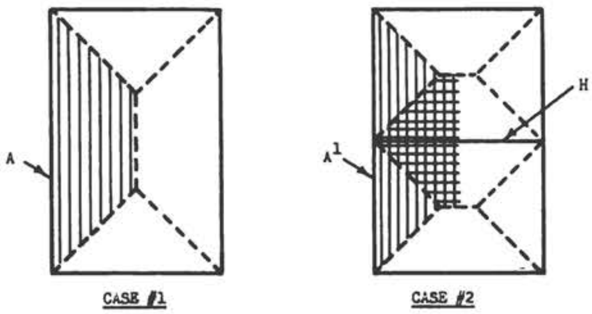


Fig. 2.29—Effect of introduction of a horizontal member.

deflection could be several inches. Here, for psychological reasons, we would arbitrarily limit the deflection, since the public would react unfavorably to glass movement as great as that actually allowable. Limiting the deflection also puts less of a burden on the glazing members, since there would be less movement of the glass in this member.

This is generally the design approach to be used on large lights. However, on specific jobs, other considerations may be required. These could include determination of twist in the member due to off-center placement of the glass. Or they may be concerned with the location of the light where, due to surrounding buildings, air velocity on the light may be a multiple of the open area velocity. Suffice it to say that the designer, when properly aware of the job conditions, can resolve the problem with a sound, economical design.

A brief summary on fixed lights of glass in the exterior of buildings reveals that they do play a large part in today's buildings, and will continue to play even a larger part in the future. The applications are extremely varied, but proven designs of many types are available for use in practically every case. The functional and structural design of the individual unit, while it may be a challenge to the designer, can be created in confidence based on engineering data using a variety of proven materials.

By William Demarest *
National Association of Home Builders

STANDARDIZATION OF WINDOWS

There are probably as many opportunities for standardization of windows as there are characteristics of windows. It should be possible to standardize degrees of light transmittance, as well as thermal conductance characteristics; window hardware and accessories can also lend themselves to standardization. I have been asked to talk to you about dimensional standardization of windows. The importance of this is self-evident and, furthermore, it has been a particular interest of mine—one upon which I have something to report to you. Isolated standardization of window sizes is quite prevalent today, but I am sure that many of the architects here can recall the day when they actually designed windows. Sash and frame were made up for them by the mill because there simply was no other procedure to follow. A range of catalog window sizes and combinations in many types and grades has only been with us for a relatively short time.

Such standardization as we have has been accomplished by the window manufacturers themselves, and by their trade associations, in a serious (and largely successful) effort to hold down the delivered price of their product. "Simplification" is the term for a leading principle in window manufacture in post-war years—a combination of standardization with the reduction of the choice of variations of the particular product kept in stock. The resultant economies are obvious: simplification of the jigs, etc., needed for efficient fabrication, easier warehousing, simpler record keeping, catalogs, and so on. This effort has contributed materially to keeping costs down.

Meantime, there has been developing what BRI Executive Director William Scheick likes to refer to as "the science of building." As more effort goes into research on construction technology, we have come to study the building as a whole. It is, after all, the product which we sell in competition with other industries. We must assure, by whatever means are necessary, that its price and its quality are truly competitive. Realization of this gives rise to several basic concepts.

One, for instance, is an appreciation of the fact that a building can have an optimum useful lifespan in relation to other variables, such as costs of construction and maintenance, permanence of the function of the building, etc. Another such concept is that, rather than being a mere physical object, a building is essentially the enclosure of space for a particular purpose.

Also springing from recognition of the whole structure as the end product, another concept regards construction as a production process—the site-assembly of parts. This is frequently labeled the "component concept" and is yet to be fully explored in building research. It may have revolutionary significance, particularly for what is termed the construction side of the building industry.

This component concept quickly points up the necessity for bringing building dimensions under control. There was a day, not really so far back in history, when dimensions were wholly the province of the craftsman. The man, or crew of men, who built a house fashioned every part of that house, thus controlling and relating the sizes of the units, as well as the dimensions of the whole. Industrialization of our industry has already begun with building materials and—fortunately for the country's standard of living—is here to stay. But, before long, this will not be enough. Industrialized production of building materials means standardized unit sizes and soon raises the

* William Demarest is Assistant Director of the Construction Department and Research Institute of the National Association of Home Builders. He is widely known for his previous work as Modular Coordinator for the American Institute of Architects, is a graduate of Princeton, and a member of the Building Research Institute.

question of coordination of these sizes with each other.

Taking the window as an example—if it is considered to be an end product, it can be judged on a basis of maximum quality at minimum delivered price. However, if the *building* is the end product of which the window is a *component*, there are additional criteria which must be given weight. These have to do with how well the window is adapted to the structure, and how well it is coordinated with other related components.

The need for dimensional order in building was recognized sometime back and led to the development of "modular measure" as the basis for coordinating unit sizes and building dimensions. Acceptance of modular dimensioning, based upon a 4-inch unit, has been gaining in recent years, although slowly. Some builders and a great many more architects now dimension their drawings by modular measure. For them, it is simply a better way of dimensioning, both in the drafting room and on the job.

But the new method is still far short of realizing its full potentialities. This is because of the persistent lack of modular-coordinated material sizes available as stock items and priced accordingly. Materials producers, for the most part, acknowledge the potentialities of modular measure for bringing sizes and dimensions under control. However, because of the enormous amount of study necessary for the development of a modular range of sizes for any one product, their conversion to the new system has been slow. By and large, modular measure has thus far been applied only to masonry and a few related products and to a limited range of basic materials used in homebuilding. Future progress in converting our entire building industry to orderly modular dimensioning hinges, in my belief, on our success in developing a wide range of modular-coordinated materials. Coordinated standard window sizes are among the most urgently needed of such products.

BASIS FOR STANDARDIZATION

In homebuilding, there are several factors influencing the development of standard window sizes: One of these naturally concerns the aesthetic preferences of the owner, a factor upon which traditional window proportions bear heavily. Another major factor encompasses the requirements of use. At the University of Illinois, a Small Homes Council team under Professor Lendrum has, for example, studied anthropometric requirements—the preferred heights of sills based upon the eye-level of a seated man or woman. The latter will also establish the heights at which meeting-rails should not be permitted to occur, since they will obstruct the view through the window.

Other requirements include ventilation, insect screening, even the addition of venetian blinds and window-sill air-chilling machines. Indeed, there are many considerations which will be discussed by others at this conference which may influence standard sizes. These arise from the problems of manufacturing, shipping, and stocking the window unit. They have, of course, been given close study by the window manufacturers themselves. We of the homebuilding industry probably can contribute little new thinking on this score.

There remains, however, one factor upon which we are qualified to comment—the factor of installation of the window in the house. This factor can affect standard sizes greatly. In line with my earlier comments, window installation has already been fairly well thought through for that minority of houses which have all-masonry walls. There is now available a limited variety of stock residential window sizes that are adequately coordinated with the dimensions of modular masonry openings. For wood frame houses, including those with masonry veneers, coordinated window sizes are still needed. Studies to this end are new being pursued by several groups, including the NAHB Research Institute.

Although urgently needed, no specific sizes have yet been accepted in view of lack of agreement at this moment as to a reasonable basis from which the standard coordinated sizes will be developed. The NAHB has long been a sponsor of modular measure, which has been officially promulgated under the American Standards Association in a series of American Standards defining the 4-inch module and its uses in building. Our thinking, then, on all projects having to do with dimensional standardization has been predicated upon modular measure. This is a natural state of affairs in the homebuilding industry in view of the many important materials we use which come in stock sizes that are multiples of the 4-inch module.

The general acceptance of 16 and 24-inch spacing of studs again supports our adherence to modular dimensioning. It is fundamental in the thinking of the NAHB Research Institute that the house be given prime consideration at all times as our end product. Any work we may do on the pieces, parts or components of the house must be within this frame of reference.

In June 1956 the NAHB Research Institute proposed that stock residential window sizes for conventional wood frame construction be based upon either 30⅜″ or 46⅜″ as the actual rough-framed opening width. Actual rough-framed heights of 23″, 34″, 41″, 53″ and 74″ were also proposed with tolerances of ¼″ more or less to allow for variations in rough carpentry.

Among the factors bearing upon the selection of these particular sizes were: suitability with regard to vision from within, modular framing of walls coupled with modular veneer, and visual alignment of window heads with exterior door heads. Also, the selection of the 41" height was influenced by the critical placement of a window over a kitchen sink backsplash. The 74" height was intended to leave adequate space for a hot air or hot water register below it. The 34" height was intended to enable a 4' wide interior-skin material to be used beneath it without cutting.

May I emphasize that the widths named above are for *conventional* construction; they are not necessarily correct for panelized construction any more than they are for masonry. Special uses of these standard windows, such as placement side by side to create a "ribbon" window entail special problems. Such problems are, however, fewer and simpler than those which would be present without window standardization; it is unrealistic to assume that one group of standard sizes will meet all the many installation possibilities.

Our purpose is to foster development of a very few stock sizes for windows in home building which will be best coordinated with the other pieces with which they must fit, so as to accomplish two things: (1) ease and economy of installation; and (2) a reduction in the number of stock residential sizes called for by home builders. It is logical to expect that this will reduce manufacturers' costs in producing and stocking windows and—it is hoped—ultimately result in a lower delivered unit price, as well as a lower in-place cost.

We are confident that this mode of achieving window standardization will pay off in terms of our overall objective—a better house at a lower price. We have been greatly impressed by the enthusiasm of the window manufacturers for this fresh approach to the question—an approach which is bolder and larger in concept than heretofore. They realize that it is bound to be more difficult to accomplish than mere standardization within the window industry, without much regard to the many other related components of the house.

Some manufacturers report they have already begun to produce stock sizes based upon the NAHB Research Institute's "installation" approach to window sizes. The major associations of window producers are right now engaged in studies of their own toward the same end. It is more than likely that the basic stock sizes as finally worked out between the builders and the manufacturers will not be quite the same as our Research Institute's present proposed sizes. Our proposals were put forth primarily as a means of initiating cooperative studies by the two groups. A joint effort of this kind cannot be completed overnight, but the problem has now been stated. It should be possible to move forward cooperatively to a practical solution. It is not unreasonable to expect that, before much more time has elapsed, the small volume builder will have available to him at competitive prices a choice of sizes, materials, and styles of window which will be best suited to his operation. Windows, we expect, will come first. But it is our hope that they will be followed by a host of other residential components, sized to fit and designed for simple installation procedures.

FUTURE WINDOW STANDARDIZATION

There is one important point that needs to be made in any discussion of coordinating materials sizes. It is inherent in my earlier observation that modular windows to fit masonry houses are not necessarily the right size for most houses today, since most of our houses are wood frame. The governing factor is always the system of construction. This controls the installation of the window, thus affecting its standard sizes. In the residential field, we are still using conventional construction methods. As they evolved, the window was not conceived of as a component part of the system. It had to fit as best it could and not until very recently have there been serious attempts to develop it into an integral component of the house structure.

The way has been shown in other building types. Some houses these days feature the so-called "window wall"—a floor-to-ceiling combination of sash in such a manner that the frame assembly is structural. This is a reflection of many present-day schools, commercial and other buildings which explore the component concept thoroughly. With the most advanced of them, the window unit has no more significance by itself than does the spandrel unit. Each is a component and integral part of the whole, and the size and shape of each is fixed accordingly.

This is why it is probably fortunate for the home building industry that change is in the air. It will be only a first step when we have developed a few stock window sizes which are coordinated with conventional methods of wall construction. I am confident that radically new and better ways of building a house will be coming into use before very long. Now—under the component concept—windows can never be afterthoughts in the development of such new systems of construction. Their redesign will have to be worked out continuously as the design of the system progresses. Here lies our greatest opportunity, with windows as with other components, to restudy the unit in relation to the complete end product. Here is the way that window manufacturers will best serve the public—by working with builders, designers and other segments of the industry toward the production of a better building at a lower price.

Discussion Period—PRODUCT ENGINEERING

V. W. WIEDMAN (E. I. du Pont de Nemours & Co.): What precautions are taken to prevent galvanic corrosion between aluminum windows and hardware of copper base alloys?

MR. KLEIN: The problem of galvanic corrosion involves the presence of moisture in order to have a galvanic current flow. Frequently, the hardware used is a plated material. It could also be zinc plates or a bronze material. Our experience has been to date that usually we do not get enough moisture present where the hardware attaches to the aluminum on the inside, and I assume you are talking about operating hardware, such as handles and locks, to cause us any problem. Where we use anchors or attach the aluminum to dissimilar metals, it is essential that they be separated from the aluminum by bituminous paint, plating or by some similar means so there will not be any direct contact between aluminum and dissimilar metals where moisture is present.

E. C. TAYLOR (Carbide & Carbon Chemicals Co.): In a multi-story building having large fixed units should the panels be inside or outside glazed?

MR. MUESSEL: There are advantages to glazing it from the inside in that the replacement which will conceivably have to be done at some time in event of glass breakage can be done without scaffolding or other means. If the building were arranged with a mechanism such as, I believe, the Lever House has, in effect an elevator where you could reglaze from the outside conveniently, it would be no problem. We have attempted to work out systems where the glazing can be handled from the inside and still maintain the water trap or baffle system that is necessary.

E. R. BALLANTYNE (Div. of Bldg. Research, Australia): Has untempered colored or flashed glass been used successfully in curtain wall construction? Have breakages occurred in heat-absorbing glass due to shadow patterns or other reasons?

MR. ORR: Where the enamel-coated or flashed glass has a very high absorption, it is essential that it have some degree of heat strengthening or tempering. With this procedure, breakages from partial shading, I think, are completely eliminated. There may be other reasons for occasional shattering, but I don't think it would be from any unusual shading, although shading conditions will break it definitely if it isn't heat strengthened to some degree.

MR. McKINLEY: You have put this in the category of the darker glasses, rather than the very light, reflective glasses?

MR. ORR: Very light glasses reflect so much solar energy that there is not much of a problem.

R. H. BLISS (Bliss Steel Products Corp.): Has any attempt been made to standardize packing and crating methods for commercial aluminum sash?

MR. KLEIN: This is one of the subjects of a committee study in the Aluminum Window Manufacturers Association. We have a Traffic and Packaging Committee that is collecting data from the various manufacturers and working with the freight and trucking companies in order to come up with the ideal method of packing to prevent damage and to keep the cost of that packing to a minimum. I expect it will probably be a number of months before anything is revealed as far as these studies are concerned, but it is the subject of study, and it is one of the problems we hope to solve very soon.

MR. KELLY: We in the steel window business don't have quite that problem of damage to our product. That is possibly why we steer away from a prefinished or finished article which would have to be protected and which wouldn't have to be painted or processed on the job. In connection with galvanized windows, there is a problem of protecting them against abrasion during shipment, as they rub together in the carriers. But it is possible to put work corners on window frames, as well as other types of protection, to protect them to a big degree against damage in shipment.

MR. ARKIN: One reason why the manufacturers of wood windows don't have to crate their products is because they treat them with the water-repellent wood preservative before they leave the factory, and this treatment is sufficient to protect the product from rainfall and various other things that might happen between the time the window leaves the factory and the time it arrives on the job. This is no substitute, however, for covering the windows with a tarpaulin or keeping them indoors when they do arrive on the job. Incidentally, the commercial standards for wood windows do cover treatment also, that is, for the so-called stock window for residences. For a custom designed window which the architect designs, it is up to him to specify water-repellent treatment.

GEORGE SANER (E. I. du Pont de Nemours & Co.): What are the physical requirements of the material used as a cavity divider in glass block? Specifically, what are: its construction, color and other requirements?

MR. KINGSBURY: The requirements for the cavity divider can be summarized rather briefly. In the first place, it must resist high temperatures, since it is inserted in the block at the time of sealing when the glass is at the temperature of approximately 1,200 to 1,400 degrees Fahrenheit. It must also withstand temperatures of about 1,000 degrees Fahrenheit because the glass must be annealed. When the block is in a 75 to 80 per cent vacuum there is some oxygen.

Furthermore, it must have great physical stability, since it must withstand shipment within the block. For instance, we have tried to seal a variety of items in the glass block. We presently use fibrous glass treated in a variety of ways because it offers the greatest possible freedom. There are a number of things you can do with it.

GUSTAVE KEANE (Eggers & Higgins): We have all seen pits develop in unprotected aluminum, especially so in industrial areas. Would these pits continue and eventually destroy the aluminum section if left unprotected?

MR .KLEIN: ALCOA has completed a series of 20 years of study on aluminum in various types of atmospheres—industrial, seacoast and ordinary atmospheres. They have studied the depths of pitting and find that these surface pits go to a maximum depth of something like .005 to .007" and then they stop. So that while the pitting which appears on the surface is detrimental to appearance, it is not something that materially affects the strength or the lasting qualities of the aluminum.

If I remember correctly, over a 20-year period the tensile strength of aluminum, in all atmospheres, did not decrease more than 7 or 8 per cent.

MR. FUNARO: Is there any prospect now, with the revival of reinforced concrete, of going into more integral application of glass products? I think there is a great horizon open for that.

MR. KINGSBURY: In our export business we do a fairly large volume in the Sweden branch and in Germany with that specific type of construction where glass block, made in America, are incorporated directly into concrete. There is also available from one of our companies a skylighting system incorporating the same features, which has the obvious advantage of great flexibility as far as the design is concerned and as far as the amount of light the architect wishes to have transmitted.

GUSTAVE KEANE: The testing data prepared showed the effect of medium and long-time wind loads on glass panes. Some recent failures of large glass panes in all-glass buildings indicate that failures occurred not during the original wind load, but rather on its cessation and were caused by the sudden rebound of the glass. Similar behavior was observed during bomb explosions during the war. Are there any data available on strength on rebound?

MR. ORR: That's a little beyond my knowledge, and I really don't have any specific information that would help you out. When you have enough energy, glass will break at the rate of 5,000 feet per second. Whether this rebound comes immediately afterward or whether there is a delay, the energy would have to come from somewhere to start the break very soon after the energy is available.

MR. McKINLEY: Are we in a position to suggest that if someone knows the forces involved in the rebound, then we can say whether or not there is likely to be breakage?

MR. ORR: Well, if the rebound is more severe than the original load, I think it would be logical for the break to occur at that point.

MR. McKINLEY: This seems to be one of those unexplored areas to a degree. I wonder, Mr. Muessel, if you want to comment on this subject? You have indicated you have been doing a certain amount of structural studying.

MR. MUESSEL: Actually, we don't have very much information on the subject either. One of the interesting things I think most of the gentlemen are familiar with, at least in store front construction, is that most plates of glass break out or blow out from the building, rather than blow in. The glass will generally be found on the sidewalk rather than on the showcase area. Very often it's due to a slight pressure inside the building with someone opening another door in the building and allowing a gust in and forcing the glass to pop out, or it could also be this rebound property where the glass is forced in and, with a release of pressure, it will pop out.

MR. KINGSBURY: If I recall correctly, there was an excellent publication put out by the English during the war on that precise problem of the breakage of glass due, not to the forces of explosion, as such, but to the vacuum cycle that immediately followed the pressure cycle. I think it does relate those factors quite well as to cause, types of stress and durations.

W. S. SWANN (Pilkington Glass Co.): Have you any recommendations with respect to the amount of glass which should be contained between the stock, both plate glass and heat-absorbing glass to be covered in the answer?

MR. ORR: Our tests, based on temperature difference in optically measured stresses at the edges, show that the worst condition that you can have is a recess of two or three-quarters to an inch in depth. If you go beyond that, the stress on the edge increases, and if you go far enough, the maximum stress is no longer on the edge, but on the surface, which is generally much better able to take care of the load than when the maximum is on the edge. But it is not very practical to recess to a depth of, say, two or three inches.

The simplest arrangement would be to make the recess as small as possible. I am not familiar with how far that can go, but I would think it shouldn't go much below three-eighths of an inch. That will keep the temperature difference between the edge and the center at a much better balance than where the recess is, say, three-quarters of an inch or as much as one inch.

PART III

CONTROLS

Chairman

John F. Hennessy

President,
Syska and Hennessy, Inc.

PROBLEMS REQUIRING CONTROLS: VIEWPOINT OF THE OWNER

By Harold S. Miner *
Manufacturers Trust Company

The question most often asked of those of us who live in our particular glass house (Manufacturers Trust Co.) is: "How was it that a bank put up a building like this?" That's a good question, and behind it lies an interesting story.

During the darkest days of the depression of the 30's, our president, Horace C. Flanigan, was visiting in Detroit. Many enterprises were being forced out of business, among them banks. Mr. Flanigan observed that when a bank vacated its building it was difficult, if not impossible, to get other tenants. The structures themselves were just not suitable for other purposes. As he puts it: "The only people that would take over vacated bank buildings were bookies, bars and dry-cleaning establishments—nobody else wanted or could use them."

So he determined that if he ever had a chance to erect a bank building he was going to make it so appealing, so unusual, so inviting that it would compare on the most favorable terms with the best of modern plants and commercial buildings. That's what he set out to do with our office at one of the busiest intersections in the world, the corner of Fifth Avenue and 43rd Street in New York City. He commissioned the architectural firm of Skidmore, Owings & Merrill to conceive and design the structure, the George A. Fuller Company to build it, and Miss Eleanor Le Maire to decorate it.

In the banking business we talk a lot about offering our customers convenience, efficient service and friendliness. Through the medium of this building our bank set out to project these perquisites by means of the inviting appearance of the structure itself. We saw no reason why banks should not be as attractive, as comfortable and as pleasant as any other place of business. And in the world's most competitive banking community, New York City, we saw many reasons why our bank should extend itself to take leadership in this phase of customer relations. Because, as you have seen, the exterior of the building is entirely of glass set in polished aluminum frames, we offer, in effect, a giant showcase for banking.

My architectural friends tell me what we have is a glass box structure in which the glass walls—some 13,000 square feet of glass in all—hang like curtains and support no weight. Paradoxically, ours is a windowless building. The plate glass panes are sealed in place. This reduces street noises, minimizes dust infiltration and, with our air conditioning, controls the purity, humidity and temperature of air.

I am told that not everybody in every situation could build a building like ours. Nestled as we are among some of New York's tall skyscrapers, direct sunlight hits our building for only about an hour each day. Were this not so I am sure there would be problems of screening and drapery and temperature control that do not exist in our location. But these are matters about which you, as professionals, are far better informed than I.

I understand that you want me to talk about what it's like to live and work in a glass house. I'll try to give you a firsthand point of view. Most important of all, it's restful. This may sound odd, and may convey a wrong impression about the banking business which rates high in the production of ulcers! However, banking under glass as we have experienced it, is very definitely easier on the nerves. You can feel the difference at the end of a busy day. Part of this is caused, I am sure, by the sense of spaciousness imparted by the glass walls. No claustrophobia here! You feel, in a sense, as if you are working out of doors, but without

---

* Harold S. Miner is Vice President of the Manufacturers Trust Company of New York City.

the inconveniences of weather. As one member of our staff put it: "It gives you a certain sense of freedom."

Perhaps I can make you understand what I mean by quoting one of the characters in David Grayson's colloquy on "Contentment." When asked whether his neighboring farmer is friendly, he replies: "Yes, we are good friends in matters of whiffletrees, hog-killings and haying, but we have never looked up to the sky together." In our bank we've always been good friends in matters of loans, bookkeeping and credit reports, but now we can also look up to the sky together. It's harder to breed misunderstandings or to stay peeved or pessimistic when the sky is right above you. As I mentioned earlier, we are located at one of the busiest —therefore one of the noisiest—street intersections in the world. But, while we can see, we cannot hear. I guess you might say we have a sealed-in serenity. This shows itself in improved efficiency by our staff of 220 employees, a matter of very considerable importance to any business. It also reflects itself in better satisfied customers and, in our instance, many *more* customers. Since moving from an old building right across the street, the rate of opening of new accounts has increased nearly three-fold.

Sealing-in has its more homely virtues as well. One of our vice presidents—the man you see every Tuesday night handing out checks on the $64,000 Question television program—confided to me that since we have moved into our glass building he hasn't been troubled by his formerly persistent hay fever!

One of the most interesting aspects of working in a glass building is the effect it has on personal morale. Anyone in the public eye takes pains to look his best. The personal appearance and dress of all members of our organization have improved. Hand in hand with this greater pride in appearance goes improvement in morale, a heightened sense of personal well-being and the resulting improvement in efficiency that I mentioned earlier. As one of our staff put it in a survey conducted to get employee reactions to the building: "I want to bring a graciousness to all of my contacts with visitors, customers and colleagues in keeping with the cordial surroundings."

Or, as another said: "In such a bright, uncluttered place you just can't help feeling bright and alert yourself."

Customers react favorably to the environment too. They seem more relaxed and in less of a hurry to be served.

Visibility also affects deportment, as witness this comment from one of our staff who works in plain view of eight million New Yorkers passing up and down Fifth Avenue: "You must be more alert. Customers, visitors, even fellow associates approach you from all sides. You are observed from all angles. You must be careful not to yawn or scratch. If you do, you will be seen, even from across the street!"

This survey of employee sentiment regarding our glass bank is more eloquent in its testimony than I can possibly be. Asked whether they preferred the new bank as compared with the more traditional type of structure in which they previously worked, all but one favored the new look. In answer to whether the new surroundings had given any more of a feeling of well-being or had had a favorable effect on general health, 99 per cent said they feel healthier. Some attributed this to air conditioning, others to the glass building and the dust and draft-free atmosphere. Still others to the "lift" of virtually working in the great outdoors. As to whether there were any unique problems in working in a glass house, 96 per cent said there were none. The other 4 per cent said it took time to get used to being observed and certain consequent distractions.

This business of being on display under glass has its humorous side, too. As you noted in the slides, our vault has been moved up to the street level floor from its traditional place in the basement. It faces Fifth Avenue, set ten feet back, but with its door opening directly toward the Avenue. It is separated from the public by only one-half inch of plate glass. All of this caused one of our friends to comment that, "in case of an atomic bombing, Manufacturers Trust Company's vault will become the most accessible vault in the country!"

But all this visibility almost lost the bank some customers at the time of the building's opening. These customers did not fancy having the general public observe every time they went to their safe deposit boxes. This was easily solved by pointing out to publicity-shy customers that there is also a back door to the vault and this is the only entrance for customer use.

It would be out of place to build a building of glass and then fill it with partitioned office cubicles. Therefore, our interior is as open as our exterior. Officers' desks are located adjacent to huge plate glass windows, and others are on the open floor, or as we call it in banking "the platform." We had some reservations on this, but we have none now.

In common with my fellow officers, I found that the "boss" is faced with a real problem in organizing his time. People step off the escalator, for example, see me, and promptly walk over with the invariable comment, "I saw you weren't busy so I thought I'd come over and chin a while." These interruptions are time-consuming, but they do serve a most useful purpose. Our business, banking, has become a personal contact business. The fact that our officers are more available

Fig. 3.1—Over-all view of Manufacturers Trust Co. building including the four main floors and the set-back fifth floor.

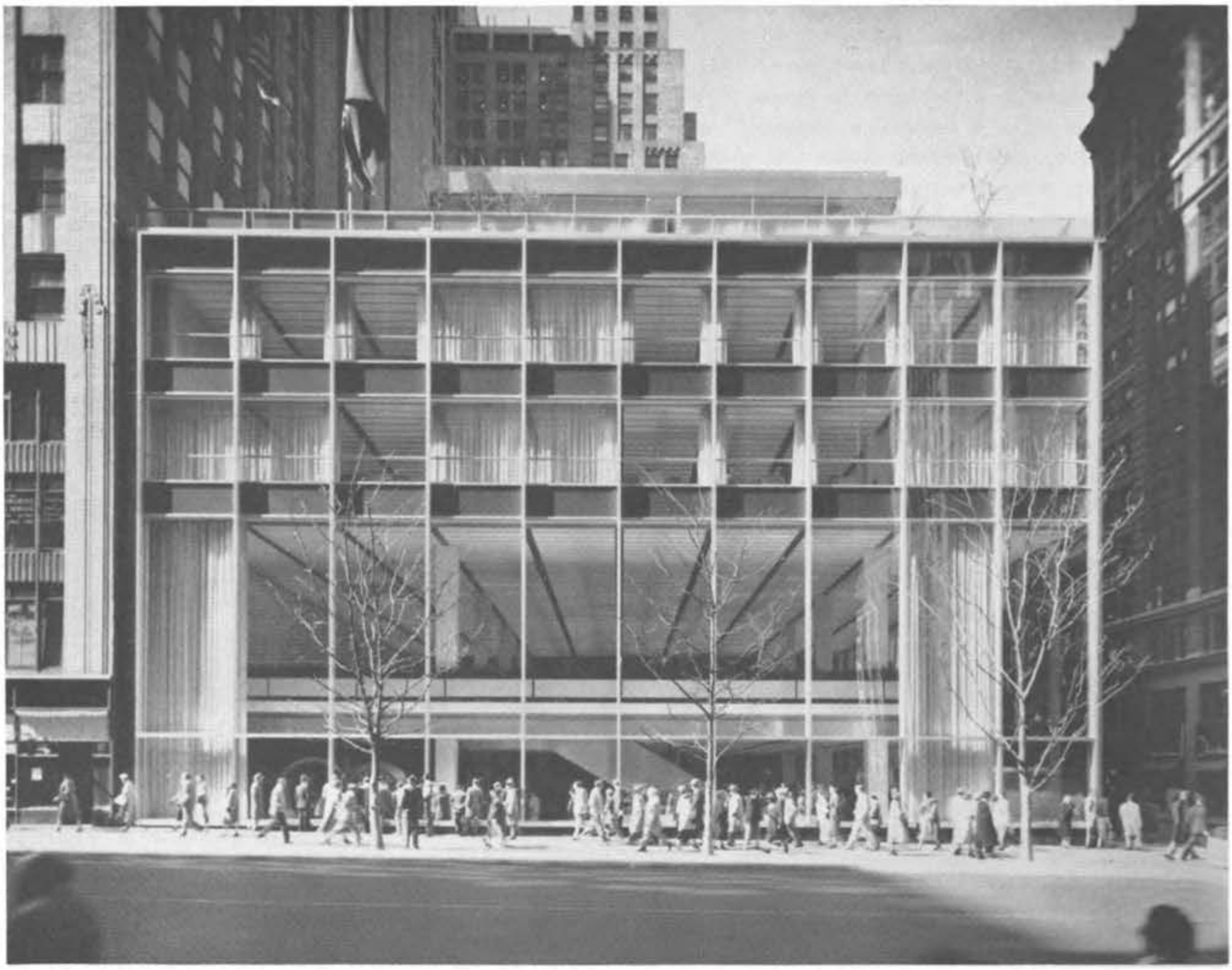


Fig. 3.2—Entire Fifth Avenue side of the building is glass, unbroken by doorways, to allow passers-by a full view of the inside activities.

may be distracting to them, but it is a healthy condition from our customers' viewpoint and that is the only viewpoint that is important.

For those officers seated next to the windows on the street floor—and for their customers—during banking hours we draw the huge 32-foot translucent Fiberglas drapes. This offers sufficient privacy without destroying the "look-through" effect of the glass walls.

Because we consider ourselves a showcase for banking, we try to take maximum advantage of our glass walls. At special seasons of the year—notably Easter and Christmas—our two main banking floors bloom with flowers of the season. These displays attract attention and customers. Although our banking hours are from 9 A.M. to 3 P.M., we consider it good business to keep our showcase lit. So all lights in the building are kept on until 1 A.M. every night, weekends especially included, because of New York's many tourists.

I know you would like to have the cons as well as the pros of this business of living in a glass house. I haven't given you the bad points because, in our experience, we have found none of real importance. Nor have our customers found much to criticize. We did receive one letter from a neighbor which goes to prove that even the finest of architects, builders and engineers can't think of everything. This neighbor located on the 12th floor of an adjacent building wrote us that her constant visual contact with us was the sight of our roof and the air conditioning blower over which ran a constant stream of muddy water. She wound up by saying: "If you will only toss a bit of bright vegetable dye into the water your beautiful bank will lack for nothing." I understand our engineers, Syska & Hennessy, are now studying the color charts.

Our doors as well as our walls are of glass. I'm told they are tempered glass. We have had two instances where the glass in doors, when sharply struck, has

Fig. 3.3—Night view demonstrates "look-through" quality of the building. Note 30-ton vault door in lower left corner.

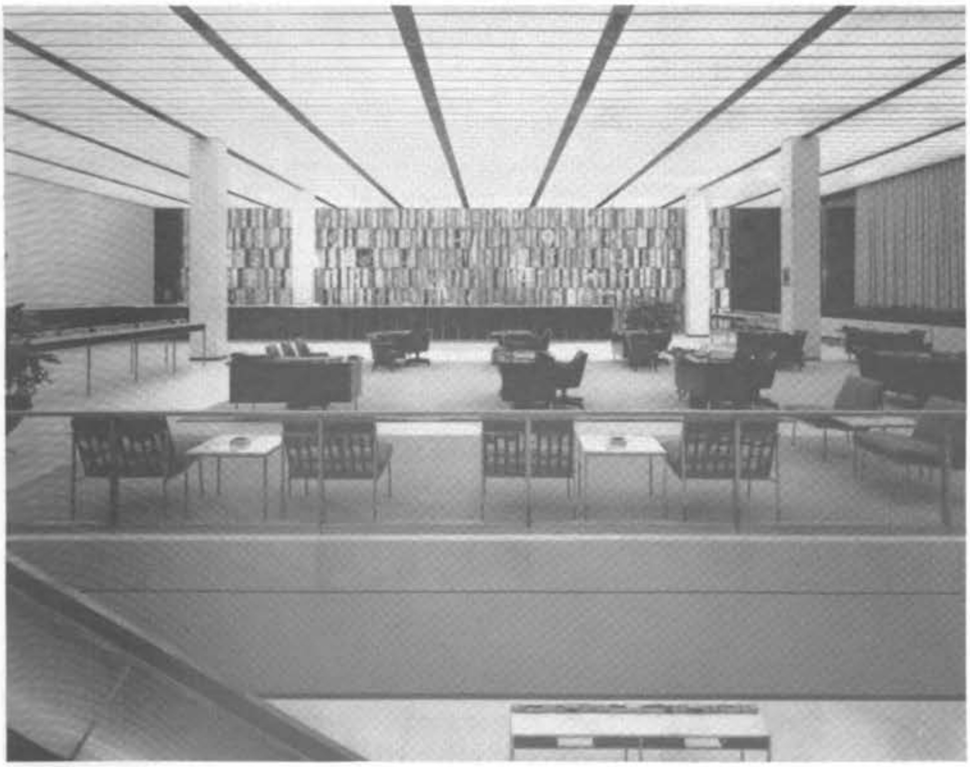


Fig. 3.4—Senior officers, foreign and trust departments and 24 teller positions for commercial accounts are located on the second floor.

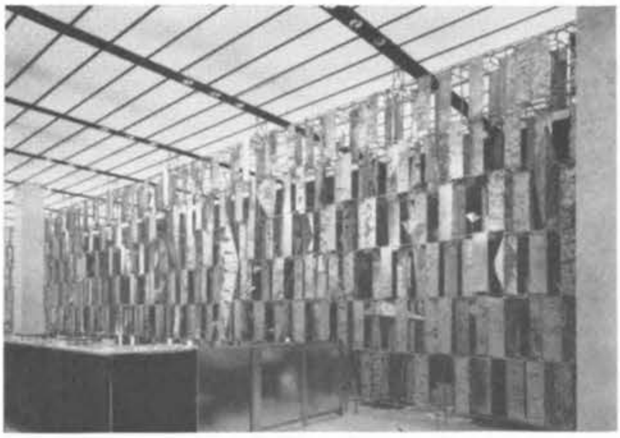


Fig. 3.5—This sculptured metal screen by Harry Bertoia acts as backdrop for the second floor. Of copper, brass and nickel fused to steel panels, it weighs six tons; is 70′ wide, 16′ high and 2′ deep.

shattered. For the sake of our customer relations, and our insurance premiums, I hope these were isolated phenomena.

Those of you who are nature lovers may be interested to know that we quickly found that the humidity range for humans and for green plants isn't the same. Therefore, we had to learn to water our plantings by hand twice a day and to spray the foliage in order to keep them alive in temperatures and under humidity conditions that were comfortable for people.

We thought we would have problems about customers staying away from paying and receiving teller positions most visible from the street. Instead, these positions have proved the most popular, which perhaps suggests that there's more than a little ham in most of us. It was more a matter of business prudence than of customer complaint that caused us to move our teller positions for handing out large payrolls to the less visible second floor from the more visible first floor. After all, one of our branches commended itself to Willy Sutton's attention and we didn't want to encourage any of his pals.

I think the best testimonial I can give you for this business of living and working under glass is that if we had it to do over again we can think of no single major feature of the architecture, of the design, or of the glass that we would do differently.

By Herbert S. Greenwald *
Builder-Developer

PROBLEMS REQUIRING CONTROLS: VIEWPOINT OF THE OWNER

I think most of you know what the 860 Lake Shore Drive building looks like. It not only has two sides, it has four sides of glass. Today I can hardly bring myself to think about a masonry skin for a building. We are building four more buildings in Chicago at this very moment—in fact they are being occupied today—which have four walls of glass, and in Detroit, where we are doing an entire city within a city, we will have some 30 or 40 structures, most of which will have four walls of glass.

I would like, however, to start out by telling you some of the problems that the apartment house manager and owner must cope with in buildings of glass. We are not only exposed to view, we are exposed to the winds, and in Chicago our winds are well known. We are 30 stories in the air. We are exposed to the lake. We are exposed to the sun. We are exposed to all sorts of elements. It isn't only a question of dressing better, it's a question of what you do when you're undressed.

The first form of consumer resistance we meet is fear. People are fearful of falling out of windows. They fear their babies will fall out. They fear the glass will shatter in the high winds in Chicago, and some of them actually have the neurotic problem of acrophobia. One tenant on the 28th floor put upholstered chairs clear around the perimeter of the living room, which had two walls of glass. Seven months later I visited there, and the chairs were gone. I asked the reason and he replied, "We have cured our acrophobia."

The second thing that people worry about a good deal is draperies. In one of our buildings we actually gave them draperies because we wanted the facade of our building to look right, since we could only get clear glass. Then, they wanted their own colors and their own materials. Some were still in the benighted era of what they call "venetian blinds."

Some of them had decorating problems of a different nature. Some had moved in from Slumburbia where they put these red lamps in the so-called picture windows, and we had that problem for a while. They had to learn how to decorate. When you give them a wall that's glass, you don't have a spandrel there. They have to find out how to decorate an apartment in which they don't have as much wall space, or at least what they think of as wall space.

They also find that their huge, ornate Italian dining room suite, which they only use on rare occasions, looks a little bit gauche to them—not to us, because we can't see it from the street. Another thing they worry about is privacy. They get the feeling, even though they're 30 stories up in the air and facing the lake, that somebody is going to watch them dressing and undressing. I guess their greatest need on many occasions is to see but not to be seen.

In 860 Lake Shore Drive we had another problem. We resisted the lures of some of our friends, some of the glass salesmen who thought we ought to have Thermopane, and therefore some of the walls were cold in winter and hot in summer. Another problem was with ventilation. The code requires that you keep a certain number of windows available for ventilation. Therefore, we put in hoppers, and sometimes when the wind was too strong there were problems with those.

---

* Herbert S. Greenwald is especially well known as the builder of the Promontory Apartments, 860 Lake Shore Drive, 900 Lake Shore Drive, and the Commonwealth Promenade, all in Chicago. In the past 10 years Mr. Greenwald has built more than $75 million worth of apartment houses and other types of buildings and, as operator of these buildings, is especially qualified to contribute his experiences with buildings that contain unusually large amounts of glass.

We had problems washing the windows. I, myself, hate to see men hanging on the outside of buildings. So at first when Mr. van der Rohe designed the Promontory Building, which was partly brick, we made the windows come in. They were reversible. Then, when we designed 860 Lake Shore Drive, we made it possible to wash the windows on the inside, and it was a nuisance. The tenants didn't like the window-washer coming into the apartment, and they themselves had a pretty difficult job when they wanted to wash the windows inside.

Some of my friends who like masonry on the outside of a building complain that glass buildings leak. There have been rumors, and I have heard a good many of them, about moisture penetration. My punch-list men on the job generally refer to that as "inordinate condensation." Well, there's inordinate condensation in some cases, but more likely than not there has been some moisture penetration.

On some buildings—I'm glad to say not mine—the architects have been unaware of the problem of the sight line, and they have put great big bars right where you must sit and look at them. I'm glad to say Mr. van der Rohe's good thinking eliminated that problem in our buildings, but it is a problem in glass buildings in general.

As I said, we are not only building in Chicago, but also in Detroit now, and we are encountering some cities which have codes on fireproofing. They don't consider glass sufficiently fireproof for a spandrel wall, and it represents a real problem.

Moving from the early part of 1946 when we did Promontory, which was 8 per cent glass, to the '50's when we started to do all-glass buildings, how have we solved some of the problems? We haven't been able to solve the decorating problem. We don't attempt to do it. We leave that to the people. And, amazingly enough, they have learned. People really do learn how to decorate their apartments. It's marvelous to see them move in with their rococo furniture and their red lamps, and to see these things gradually disappear. I have gone into some of these apartments from time to time just out of curiosity, and found that people learn to live with glass walls and like it. That they do like it is evidenced by the fact that every apartment which we sold in the 860 Lake Shore Drive building, which is a glass building and is a co-op—and co-ops have a bad name in Chicago as they do in many other cities in the country—is now selling remarkably higher. People are getting as much as two and three hundred per cent over and above what they paid for their equity in the first place.

The fear of insufficient privacy, the fear of heights, and the fear of falling seem to disappear when the tenants read in the newspapers that people are jumping out of all sorts of buildings with double-hung windows, and they can hardly get their windows open to wash them, let alone to jump out. In our new buildings, as a matter of fact, the hopper on the upper portion of the window doesn't open at all. It's hard to throw anything out of the window, let alone yourself.

They still have some problems about privacy. They would still love to see and not be seen. And here I think our friends in the glass industry have been derelict—and I use that word advisedly—in their duty to the building trade, because I think they could, with research properly applied, give us that type of glass. There is such glass, as you know, but it isn't practicable, economical, or feasible to use on the outside of buildings. But one day soon they should be able to produce a mirrored glass that will last, and that will permit people to look out and not be seen inside.

We, of course, have now come to the point where we'll probably never build a building again that isn't air conditioned. In our buildings today the heating unit and the air conditioning unit are right at the glass, and we eliminate the problem of the hot and cold wall in its entirety. And, of course, we then also eliminate the roasting effect produced by the solar pick-up in a glass building which is just straight plate.

There, too, we were fortunate enough to get some foreign help which we could not here. Again, I want to say that the glass industry in America is derelict in its duty to the building industry, because we could not get help from the glass industry in this country. They kept talking to us about Thermopane. They kept talking to us about that stuff that I heard about yesterday, glass block. They kept talking to us about solar lights. But we finally did get what we wanted, a gray-tinted plate. It was made in America, but the formula had to come from Europe. We wanted gray, which is neutral, because you cannot put green glass in an apartment house building if Mrs. Jones wants to have a coral couch next to it. You have to have something neutral. At our insistence, a tint of warm red was added to the gray, to prevent its being too gloomy on a cloudy day.

We have learned, thanks to the aluminum industry from which we have had good assistance, to control our hoppers so that ventilation problems are now almost non-existent. We have also learned how to wash our buildings from the outside. We don't do it in quite as fancy a way as Skidmore, who designed the Lever Building, but we have a very satisfactory system that works well and will be very economical to use.

One of the things we had a lot of trouble with at the beginning, despite the hurricane tests we performed on our grids, was water infiltration. Nobody knows too much about that, because it's one thing to do it on two stories; it's another thing to do it 30 stories up in the air on the lake in a city like Chicago where you have enormous temperature variations and enormous gusts of wind that come up suddenly.

We actually had to refelt every grid on 860 Lake Shore Drive with heavier felt, and then we had to find a better calking compound, but today we have less maintenance at 860 than we have on masonry buildings which we erected on the lakefront of Chicago.

We think that we are getting closer to it. We desperately need more help from the glazing industry, because we don't yet have satisfactory putties or satisfactory calking compounds. We need a glass spandrel that will contain the fireproofing elements in cities where the code requires that you have a fireproof material, and does not consider glass adequate.

So much for the disadvantages. What are some of the advantages that we find? Mr. Miner has mentioned most of them. We get an enormous sense of freedom in our apartment houses up in the air like that. The glass room seems larger. It brings the outside in. It provides tremendous flexibility of decoration, and of space and view. You can draw your drapes any way you want. We get a lighter building and, therefore, a cheaper building.

A glass-walled building forces the builder to pick a good site. It forces him to do good planning. It forces him to get only the finest kind of building on the site, because it is exposed. And, it is cheaper to maintain.

However, we have been way at the end of the line in the development of glass buildings, because the automobile industry and the airplane industry have had the attention of the glass people, and they have been pushing glass buildings back because they are thinking about masonry buildings. If we are going to make progress with glass buildings, the glass industry must devise a way to put the air conditioning and heating unit in the glass itself.

We conceive of the glass as a skin, and there is no reason why the glass on the outside of the building shouldn't be like the human skin; that is, a sheath which pulls everything together, through which we can breathe in and out. If we had our air conditioning and heating in the glass—they have done this in the chemical industry and it can be done in the building industry—if we had our lighting in the glass, we would then have a situation where, night and day, 100 per cent of the year, we'd have our heating, lighting, air conditioning all from one source, the skin of the building, which is where it properly belongs.

In my judgment, at least, the glass industry has a fantastic challenge and fantastic profit-making possibilities if only it will stop sending salesmen and put its engineers to work at solving these problems, together with the plastics industry, air conditioning, etc.

By Henry Wright *
Architect

EXTERIOR CONTROLS

Air conditioning of office buildings and other large-windowed commercial buildings is a matter of considerable economic importance. It has been possible to demonstrate, in many instances, that the saving in the first cost of air conditioning equipment, due to shading, exceeds the cost of the shading devices themselves, resulting in a net saving to the building owner in over-all building cost, in addition to continuing savings in operating cost. Shading devices are being successfully sold on this basis. In the case of existing buildings which have large, unfavorably-oriented window areas, and where the air conditioning equipment is still to be installed, this approach to window shading is unquestionably sound. There are still a large number of buildings where these conditions apply, which should provide a substantial market for exterior shading devices of various kinds for years to come.

However, in new buildings the picture is a good deal different. In a new building, unless there are compelling reasons why large glass areas must face in the wrong direction from the standpoint of solar heat gain, the conception that exterior shading can be had "free of charge," or at a net saving, collapses. In fact, when buildings are designed with a sufficient awareness of the importance of solar heat gain, it will usually be found that the greatest savings can be effected by giving them the best over-all shape and orientation, rather than by details of fenestration and shading.

* Henry Wright is a Technical Promotion Consultant for Building Products Magazine and conducts his business in New York City. He is a former managing editor of Architectural Forum, and for many years has been a student of solar orientation, sun effects on buildings, architectural sun controls, etc. He is an Associate Member of the American Institute of Architects, a member of the Illuminating Engineering Society and was a member of its Committee on Natural Illumination. He is also technical consultant to many manufacturers and is Climate Control Editor of House Beautiful magazine.

Thus, the question of the economic justification of exterior shading hinges, in new buildings, on over-all architectural design, and this question must always be expored before attempting to settle the secondary question of shading.

This can be readily illustrated by taking, as an example, the case of a suburban office building being planned for the vicinity of New Orleans. As a hypothetical case, let us suppose a large enough piece of land to leave the architect free to employ a shape and orientation calculated to minimize air conditioning load, and an architect disposed to do so.

At the latitude of New Orleans, as shown in Fig. 3.6, there is a tremendous difference in the maximum quantity of sun heat falling on walls facing east and west on the August 1st "design day," and on walls facing north and south. Thus the maximum for walls facing east and west is almost 200 Btu per sq. ft. per hour, whereas the maximum for a wall facing south is less than 50 Btu per hour and that for a wall facing north, 25 Btu.

Fig. 3.6—Maximum solar radiation on vertical walls, August 1, New Orleans, La.

Moreover, in the case of a south-facing wall, about half of the solar radiation can very easily be intercepted by providing small "eyebrow" projections over the windows, since the reason the quantity is so small to begin with is the very steep vertical angle of the sunshine striking this wall.

Thus, this particular "sun rose" diagram very obviously calls for a slab-shaped building facing north and south, with closed end walls and small projections over the south windows. With such a design at this latitude, it is very easy to keep the maximum solar heat gain on each of the four walls below 25 Btu per sq. ft. per hour—which is a very low figure. Moreover, the over-all peak solar load, averaged against the total wall surface, would be only about 10 Btu per sq. ft. for a "slab" four times as long as it was thick.

In such a building, anything further in the way of sun control would be highly redundant. Continuous windows or even all-glass walls on the north and south sides would be entirely practicable from an air conditioning standpoint and, even if such windows were used, air conditioning costs would be remarkably low. This applies to any location at the latitude of New Orleans, which is on the 30th parallel.

The "sun rose" in Fig. 3.6 was prepared by an air conditioning engineer, John Everetts, Jr., in accordance with the procedures followed in determining solar load in designing air conditioning systems for large buildings, and consequently represents one of the bases on which installed tonnage is actually purchased. It says nothing about lamp load and ventilation load, and the latter, in New Orleans, would be a very important component of the load determination. But with respect to solar gain, and therefore with respect to shading, it tells the whole story, which is that in locations as far south as New Orleans by far the best way to control solar heat gain is with a properly shaped and oriented building.

Fig. 3.7—Maximum solar radiation on vertical walls, August 1, Huron, S. D.

Now suppose that, instead of in New Orleans, a building is to be built in Huron, South Dakota, which is near the 44th parallel of latitude. Here the difference in maximum solar irradiation for south, east and west walls is much less than in New Orleans (Fig. 3.7). The east-west figure is the same—almost 200 Btu per sq. ft. per hour. But the figure for a south wall at noon is about 140 Btu per hour, or only 30 per cent less. This means, incidentally, that even a south wall will be hard to shade with a window overhang, since the reason the figure is so large is that the noonday sun is at a much lower vertical angle.

At this latitude and north of it, orientation is a much less critical factor in air conditioning, whereas winter solar heat gain on a south wall can be a real annoyance.

This "sun rose" suggests quite a different approach to the problem of minimizing air conditioning cost, which might be called a "divide and rule" policy. Since the solar load is so nearly equal in three directions, one solution is a square building, dividing the solar load into three "chunks" to be separately digested by the air conditioning equipment at three different times of day.

With this and the annoyance of winter solar heat gain in mind, let's see what would happen with a square building, oriented diagonally to the compass. In such a building, there would be 9 a.m. and 3 p.m. peaks, on the southeast and southwest walls, of about 170 Btu per sq. ft. per hour. Expressed in terms of the entire building surface, this works out to an average of about 60 Btu per sq. ft. per hour, as compared to the 10 Btu we were able to achieve with a slab-shaped structure in New Orleans. Moreover, the 170 Btu peak for the southwest wall would more or less coincide with the peak ventilation load, making this zone a tough air conditioning problem.

A slab-shaped building in Huron, on the other hand, of similar proportions to the one figured for New Orleans, would have an average solar heat gain of 71 Btu per hour per sq. ft. of total surface, as compared with 60 Btu for a square tower. The only virtue of this shape, in Huron, would be that shading might be more feasible.

The moral of this, architecturally, is first, smaller windows and second, shading. By reducing the window area to, say, 25 per cent of the wall area on all four walls, we might bring down the average over-all gain to around 20 Btu per sq. ft. per hour. Shading devices might cut this in half, or perhaps by two thirds, but unless larger windows were used shading would not have a striking economic effect on the over-all refrigeration capacity needed to cool the building, only on the fans and ductwork for the southwest zone, and to a lesser extent in the southeast zone.

This example serves to underscore the fact that it is not possible to generalize as to the savings in air conditioning costs to be achieved by shading devices, and that it is necessary to particularize as to the type of saving achieved. Thus, if we were concerned with cooling only a part of the hypothetical building just described, and this part happened to be within the southwest zone, exterior blinds might pay for themselves in reduced first cost of the air conditioning equipment, even though they would not do so in terms of a building-wide system.

This indicates, in my opinion, that the architect must work closely with his air conditioning engineer in deciding such questions, but at the same time, on large buildings, must make an effort to arrive at the most economical building shape and orientation from an air conditioning cost standpoint, checking his basic assumptions against standard heat load computation procedure. Rough computations for a variety of building shapes can be extremely revealing in this respect.

In New York City, (Fig. 3.8) which is about three degrees of latitude south of Huron, conditions are somewhat more favorable to a south-facing, slab-type building, provided it can be faced almost due south. However, on Manhattan Island, where most tall buildings are built, two specific factors alter the situation. The first is that the Manhattan street system, which controls the orientation of most such buildings, is skewed about 28 degrees with respect to the compass. This is sufficient to destroy a good deal of the advantage of a south orientation, increasing the maximum heat load on the south wall from less than 100 Btu per sq. ft. per hour to about 130 Btu. The second is that Manhattan has what is called in air conditioning

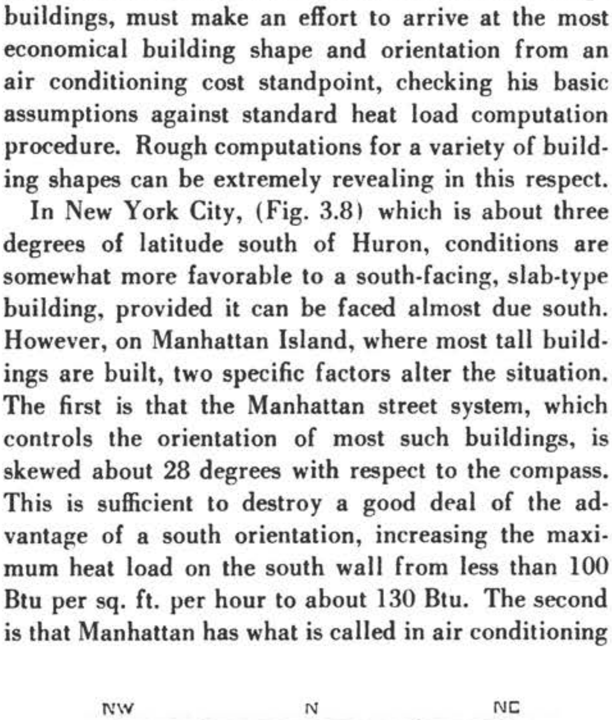


Fig. 3.8—Maximum solar radiation on vertical walls, August 1, New York, N. Y.

load calculations an "industrial atmosphere"—in fact, the figures used for the effect of such an atmosphere are based on readings made in New York City.

This chart, however, shows values for a clear atmosphere. If it were corrected for the smoke in the atmosphere, the east-west values would drop considerably, but the values for north and south would go up, further reducing the advantage of a south-oriented, slab type building.

The skew of the Manhattan street system happens to be such that the peak afternoon solar heat load on August 1st is about equally divided between the south-southwest side of a Manhattan office building and its west-northwest side. By a further coincidence, the angle of the sun with respect to both walls at this time is very nearly 45 degrees in both the vertical and horizontal directions.

For those of you who studied shades and shadows in architectural school, and have wondered why you did, this coincidence provides the answer. Any good shades and shadows man should be able to work out an effective method of shading for a Manhattan office building with a 45-degree triangle, providing he can solve the problem of icing, which has so far prevented the use of sunshades on such buildings.

Even without sunshades, the skewed orientation of Manhattan may be a blessing in disguise. As was suggested for Huron, it tends to break up the over-all air conditioning load and distribute it between the various building walls, and the "industrial atmosphere" helps this process along. Even congestion is in this respect helpful: there is no better form of exterior sunshading than the other fellow's building, and in Manhattan almost no building is subject to the full, theoretical solar heat gain it would get in the middle of an open site.

Figure 3.9 shows the pile-up of solar heat gain for a square Manhattan office building tower that has 50 per cent of its wall area in glass. It demonstrates, among other things, that shading on the east wall of such a building would have little or no influence on the peak over-all heat gain. Shading on the south and west walls, on the other hand, would reduce the peak over-all load, and this would be particularly important because the peak solar load tends to coincide with the peak ventilation load.

The heavy line is an attempt to estimate the probable actual air conditioning load which, owing to the "heat capacity" of the building and its contents, comes somewhat later in the day, and is somewhat less than the peak solar gain.

A diagram such as this, worked out in terms of the actual building shape, is needed to determine the true economic feasibility of any large-scale use of exterior

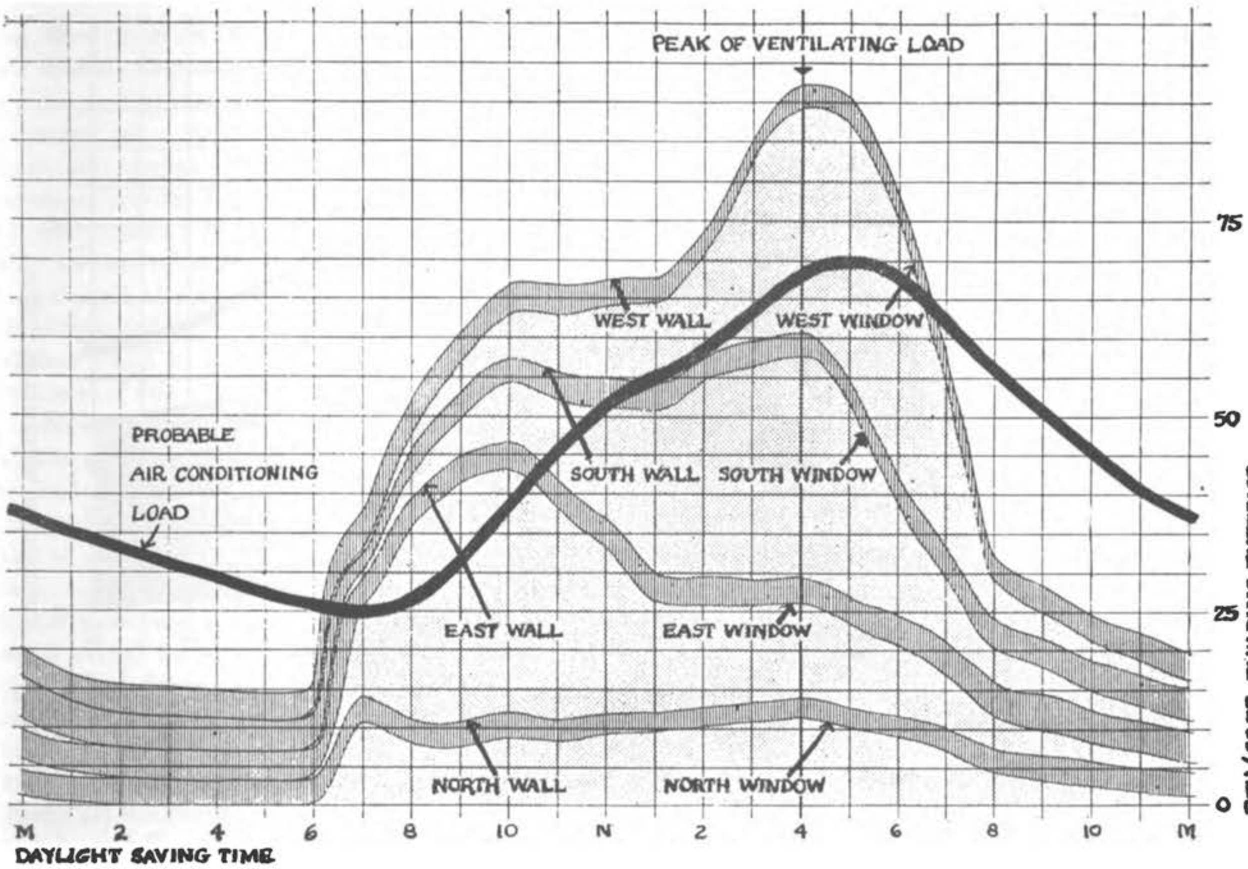


Fig. 3.9—Total instantaneous heat gain due to walls and windows for a square tower with 50% window area, oriented with Manhattan street pattern, August 1.

shading. Presumably, only a reduction in the over-all peak would register as a saving in refrigeration capacity, which means in the instance shown that shading on the east wall would affect only the cost of ductwork and fans for this portion of the building. It is even necessary to take into account how the system will be operated: this line, for example, is predicated on continuous operation; with intermittent operation it would drop more and peak at a higher value, accentuating the effect of south and east shading.

For a building shaped and oriented like the U. N. Secretariat, such a load diagram would obviously be a great deal different. Such a chart would show a "two humped" peak—one peak at about 10 a.m. and the other at about 5 p.m. The probable load curve would peak at about 11 a.m., due primarily to gain from the east window wall. This, in fact, is the experience in air conditioning the U. N. Building.

At the time the Secretariat was being designed, the design was criticized on the ground that it should have been oriented to face Forty-Second Street. Many critics objected particularly to the quantity of glass facing west—forgetting that west, in Manhattan Island terms, is 28 degrees north of true west, and forgetting also the effect of daylight time and the fact that this was an office building, not an apartment house. A heat gain study made at the time showed that if the same building could have been faced due south and north, the summer cooling problem would have been a good deal easier, but that the Forty-Second Street orientation was very little better than the First Avenue orientation from a cooling standpoint. In practice, it has been the east wall that is the offender from a peak load point of view, and only on this wall would sunshading have its full economic effect.

The chart for a square tower with 50 per cent glass area showed a probable peak air conditioning load (due to solar heat gain) of about 70 Btu per hour per sq. ft. of total building exterior. Figure 3.10 shows the same building with 25 per cent window area, and a probable peak load of 50 Btu per sq. ft., or about 30 per cent less. On a large building this difference, expressed in air conditioning cost, would work out to a very substantial amount of money. It would not, however, change the picture regarding the economic justification of shading devices, which would still probably pay off on the south and west walls.

Now, 25 per cent glass area represents the kind of

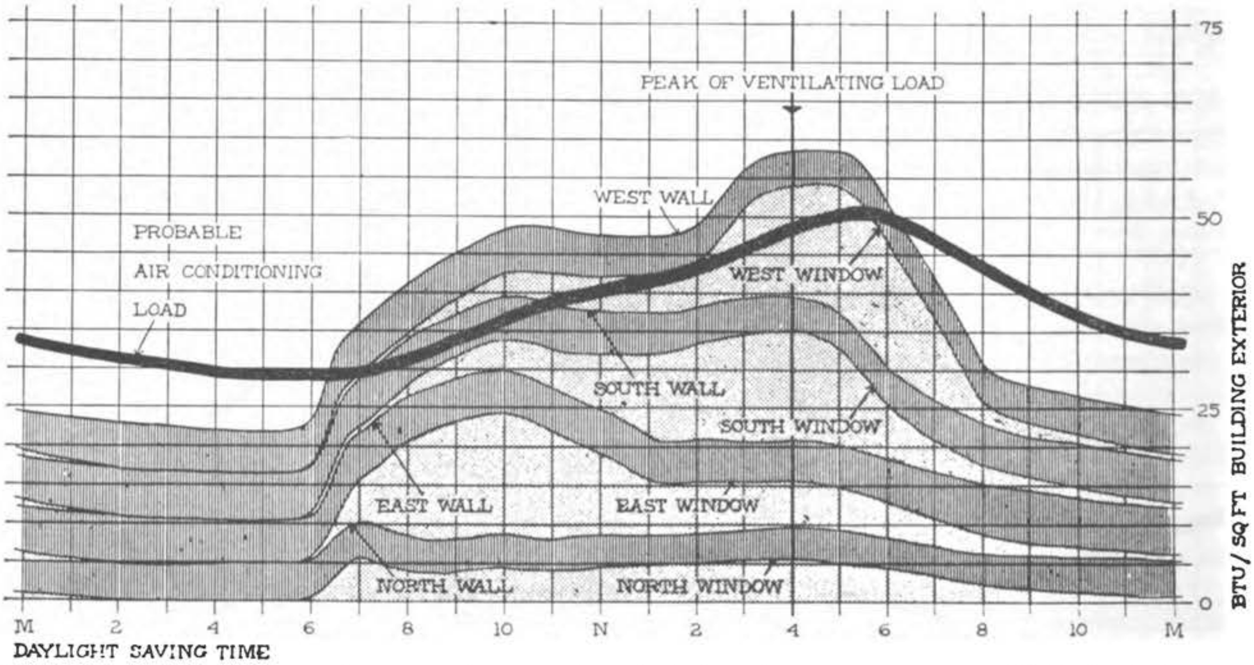


Fig. 3.10—Total instantaneous heat gain due to walls and windows for a square tower with 25% window area, oriented with Manhattan street pattern, August 1.

fenestration typical of Rockefeller Center. It is no accident, I suspect, that substantially this same window pattern has recently been employed by the architects in the largest air conditioned building in the world, the Socony-Mobil Building in New York. The architects have said that they favored this fenestration because of the flexibility it affords in locating interior partitions, as well as for reduced air conditioning costs, but the latter factors were undoubtedly of enormous economic importance.

In my opinion, the tendency to go back to smaller windows in air conditioned office buildings is sound. In fact, it has not yet gone far enough. I would like to have seen the Socony-Mobil windows reduced in height as well, cutting the percentage of glass on the east, south and west walls still further. At the same time, I would also very much like to have seen the north wall of this building, facing Forty-second Street, almost entirely glass, since this would have had a very dramatic effect without adding to the air conditioning peak, and the type of large tenants using the building might easily have planned their use of space to take advantage of glass on one side.

The shape of office building windows is almost undoubtedly due to their having been, for many years, made up of double hung sash. This called for a height sufficient to bring the meeting rail of the windows above the eye-level of a standing person, resulting in a rather tall window. Now that other types are being used, this shape has been retained, in my opinion, mistakenly. People almost always prefer to keep the upper half of a window covered, to cut out sky glare, and now that artificial light is being relied on almost entirely in offices, it has no justification other than habit.

To prove this point, I analyzed a photograph of two bulidings in the Pittsburgh "Golden Triangle" development. By counting the first thousand windows visible from left to right, I determined that at about three in the afternoon 918 of them had the venetian blinds adjusted just as the cleaning crew had left them the night before: covering more than half of the window, and closed. Such a 92 per cent "vote" is a pretty strong indication that the upper half of the window is scarcely more than a gesture to convention, and could be dispensed with.

I am at present designing an office building wall with 12½ per cent of the wall area in glass and external sunshades in the form of metal "hoods" over each of the windows. This arrangement provides sufficient fixed shading to reduce the solar gain at the critical 3 p.m. hour for a Manhattan office building to the equivalent of about 5 per cent glass area. On the inside, the hood over the windows provides a recess for a remote air conditioner with its fresh air intake in the soffit over the window, protected from the weather. The hood is so designed that it will not hold snow and thus will not ice up.

So much for the way knowledgeable achitectural design might reduce solar heat gain and thus minimize air conditioning load and the need for external shading. Now, as to the effectiveness of controls when they are needed. Figure 3.11 shows the heat gain through a plate-glass window in an industrial atmosphere, when protected by a "perfect" sun shade. By perfect, I mean any opaque obstruction which does not reflect sunshine into the building, does not heat above the air temperature sufficiently to reradiate any considerable amount of heat to the glass, and consequently excludes all of the direct solar radiation and part of the diffuse radiation which would otherwise reach the window. As I have already mentioned, the very best sunshade of this type is a neighboring building.

Almost equally good, in a single-story building, is a solid overhang over the window of sufficient depth to shade it completely from the sun's rays. To make this example correspond to the diagram, it is necessary also to assume that there is no unusual reflecting surface, such as white pavement, beneath the window. Under such conditions, all of the direct sun heat and about half of the diffuse sun heat—that from the sky, clouds, etc—is blocked. The other half of the diffuse radiation—that reflected from the ground, adjoining buildings, etc.—is not.

For an unshaded window at the peak hour in New York City, and at the worst possible orientation, the quantity of heat striking the window according to standard heat gain data, is 159 Btu per sq. ft. per hour. The amount which gets through it and into the building is 144 Btu per sq. ft. per hour. With a perfect sunshade, that can be reduced to 41 Btu, or 28½ per cent of the unshaded value.

All such comparisons are necessarily complicated. For a vertical vane type of sunshade, completely closed, the entering heat would be even less, unless and until the vanes became hot enough to reradiate a considerable amount of heat to the glass.

On the other hand, with a louver type sunshade partly open, the amount of heat admitted would undoubtedly be greater than 28½ per cent of the unshaded value, since radiation would enter by interreflection between the vanes. In fact, it is not possible to admit light without admitting heat. The consolation is that sunshine and diffuse solar radiation contain more light proportionately, and less heat by a substantial margin, than any light we have succeeded in producing artificially.

A sunshade designed by Marcel Breuer attempts to filter out the heat which sunshine does contain, and still admit as much light as possible. In conjunction with masonry fins projecting from the wall, dense blue, heat-absorbing glass, placed above the window out of the sight-line, shades it from direct sunshine. Used in this way, the tendency of the heat-absorbing glass to become hot does not add to the air conditioning load, since the glass is free of the building and cooled on both sides by outdoor air.

Figure 3.12 is a heat-flow diagram for a condition

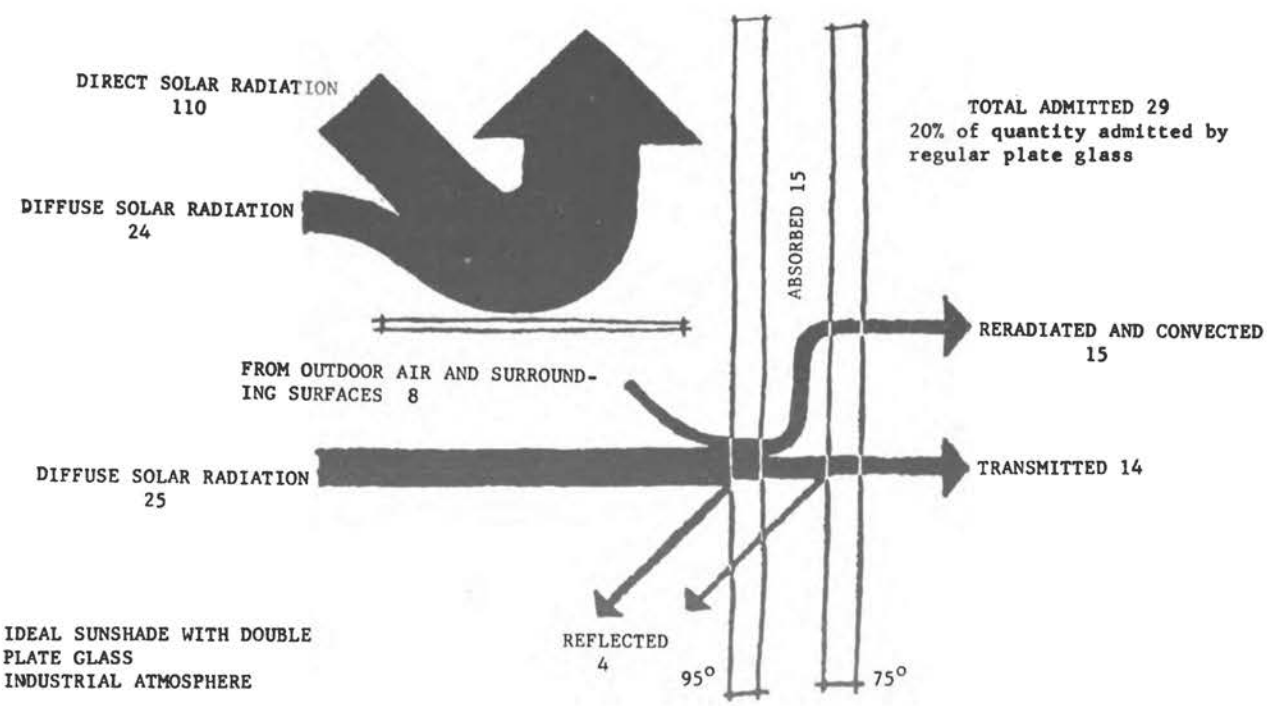


Fig. 3.11—Heat flow diagram for a "perfect" sunshade—plate glass window in "industrial atmosphere"—peak load for worst orientation.

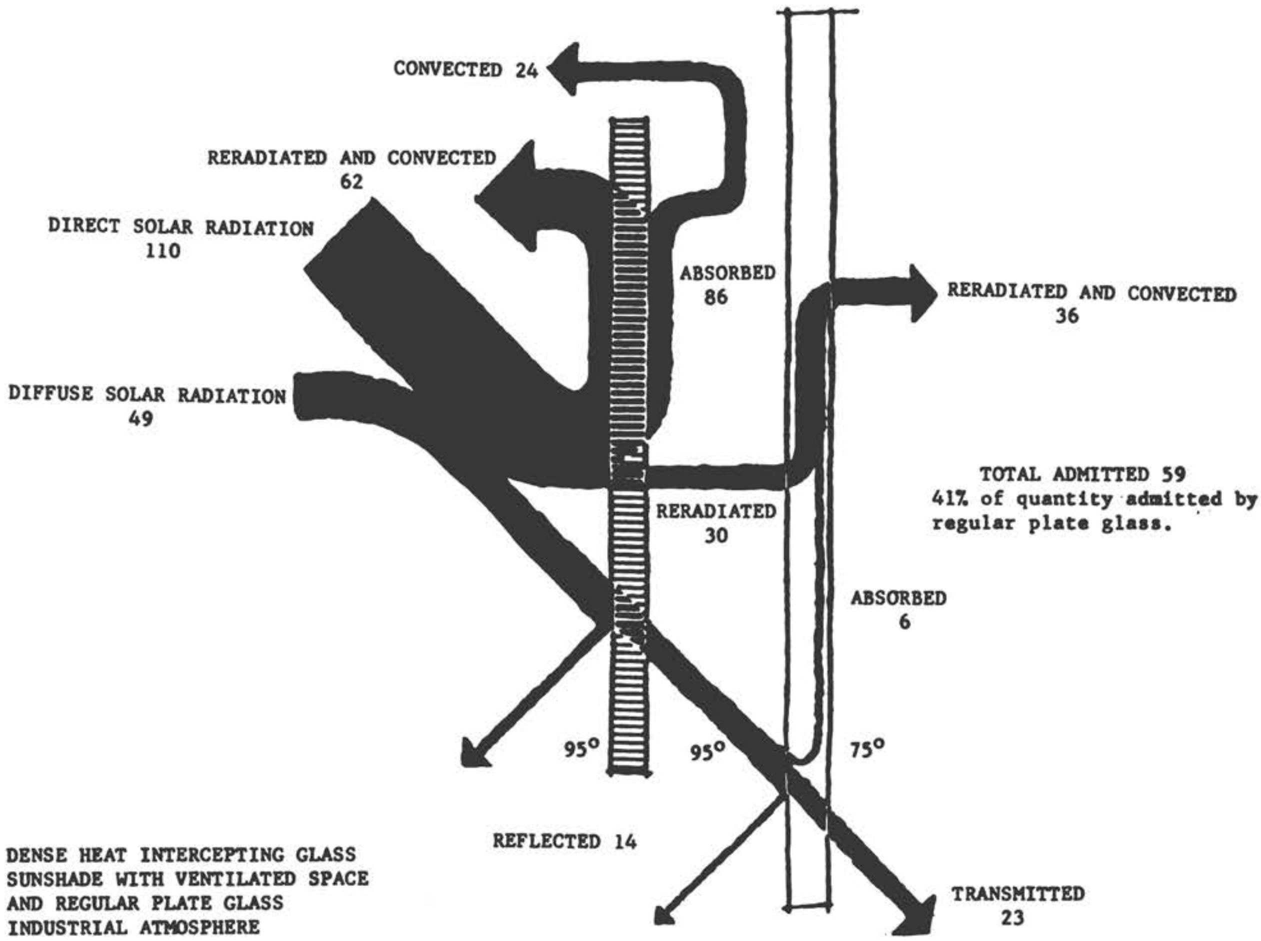


Fig. 3.12—Heat flow diagram for heat-absorbing glass, sunshade and freely ventilated air space.

not quite so good as that we have just seen, since the heat-absorbing glass, in this instance, obstructs the sightline and is in a position to reradiate a good deal of heat to the regular window glass. However, owing to the fact that the space between is freely ventilated, the sunshade is still quite effective, excluding about 59 per cent of the heat which would otherwise enter. Eliminating reradiation from the glass, as in Breuer's design, might increase this, at a rough guess, to about 65 per cent at the critical hour when the window was completely in shadow.

For comparison, the best that can be expected of an internal shade or blind is the Thru-Vu Vertical Blind, which I manufacture. The computation in Figure 3.13 assumes that the shade is white, or nearly white, and thus reflects a great deal of solar radiation back out through the window. Recent tests by the ASHAE have confirmed the net figure calculated, which is that white shades or blinds exclude about 50 per cent of the heat that would otherwise enter, if they cover the window completely and are completely closed.

Thus, in round numbers, we can say that:

(a) An exterior louvered sunshade, completely closed, excludes about three-quarters of the heat which would otherwise enter an unshaded window.

(b) An overhang or hood, and a partly open exterior louvered sunshade, may exclude slightly more or slightly less than two-thirds of the heat.

(c) An interior shade or blind, if white, and if completely covering the window, excludes about one-half.

For any of these methods of solar heat control to have maximum effect on air conditioning cost, it is necessary that they reduce the over-all peak load, including ventilation and lamp loads, which occurs at some particular moment of the design day. Otherwise, they influence the cost of only part of the equipment, and, of course, operating expenses. This means that as the orientation of the windows in question approaches the worst possible, savings are at a maximum; to the extent that such orientation can be

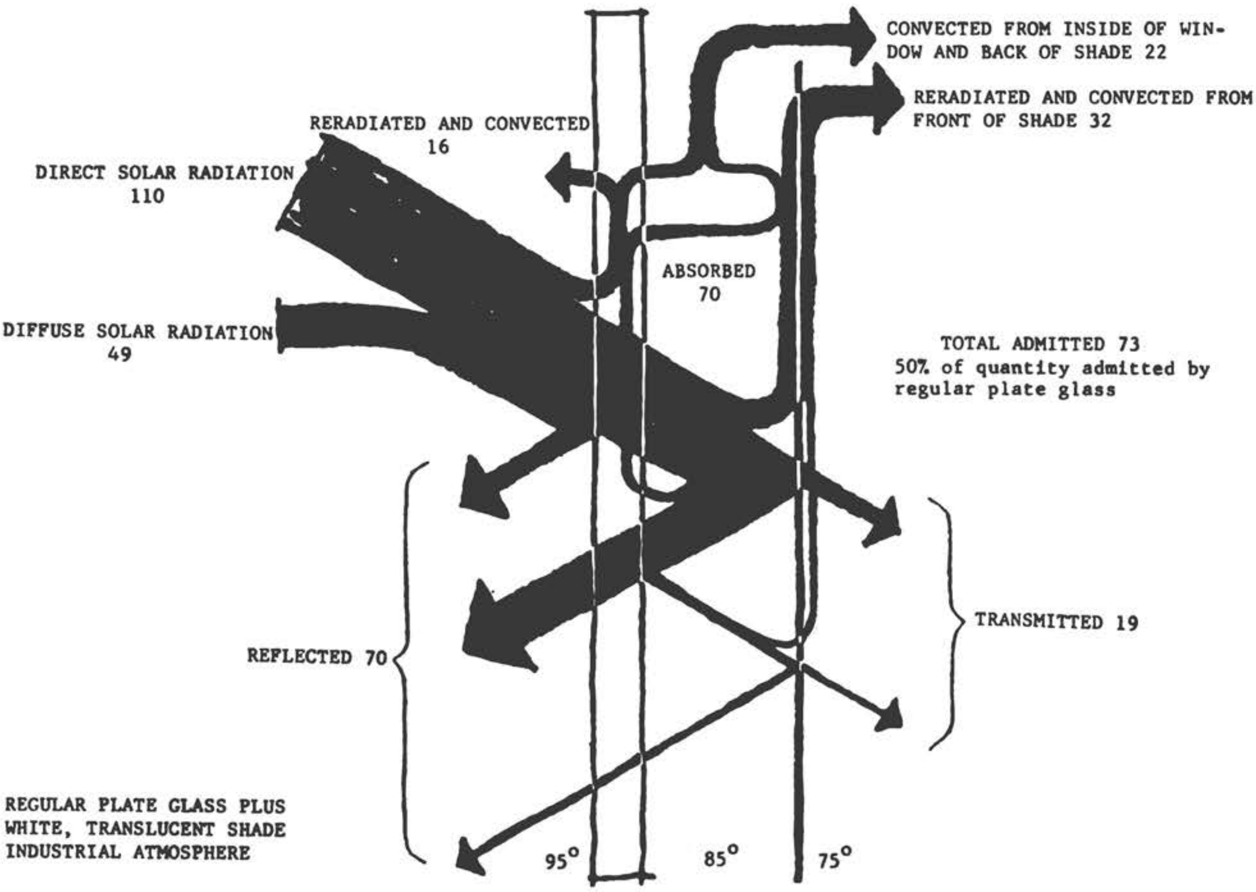


Fig. 3.13—Heat flow diagram for white finish inside window shade or blind completely covering window.

avoided, the magnitude of the saving due to control devices is reduced.

Recently, air conditioning engineers have begun to make the assumption that the occupants of a building, if the space they are in becomes too warm as a result of solar radiation, will lower or close inside blinds, and they are thus giving credit for inside blinds in their cooling load computations. This—if you accept the logic—has a marked effect on the economies of exterior shading solutions, even taking into account the fact that exterior blinds may obviate the need for blinds inside the window. I mention this mostly because, in New York City today, it is hard to get an air conditioning engineer to grant the economic advantage of exterior controls, and to explain how this happens to be true, both with respect to shading devices and special glass.

Fundamentally, exterior shading devices are an excellent way to correct design defects which have been built into many buildings because of our lack of experience with air conditioning. They are also an effective way to further reduce sun load when all appropriate steps have been taken in the design of the building itself to minimize solar heat gain. But they should not be used to justify thoughtless architectural design, or to save imaginary money which need never have been spent in the first place.

When all other factors have been taken into account, blocking a square foot of sunshine which would otherwise enter the building during the peak air conditioning hour can still save five dollars, whether the glass areas are large or small—five dollars of first cost which can legitimately be applied to the cost of the shading device—but this is not an economic justification for unnecessarily facing glass in the wrong direction or for using more of it than necessary.

By Sterling S. Bushnell *
Breneman-Hartshorn, Inc.

INTERIOR CONTROLS

The basic functions of interior window coverings are to provide decorative beauty for the window opening, to control the entrance of light to the desired degree, to provide privacy and to furnish insulation against heat and cold. The architect or builder generally has a choice of four different types: conventional window shades mounted on spring rollers, venetian blinds with either horizontal or vertical slats, cloth draw draperies or various forms of bamboo or woven wood coverings. A fifth form recently used to a limited extent is the slatted, interior wood shutter.

Of these, the spring roller shade is the simplest in design and lowest in cost. It is easy to install, requires little maintenance and provides good insulation against either heat or cold. It can be made of completely opaque materials which exclude all light, or of translucent materials which provide sun protection but do not darken the room undesirably. In addition to the old-fashioned, plain finish fabrics in green, ecru or white, the window shade industry today offers a number of beautifully textured fabrics and many pastel colors which add greatly to decorative possibilities.

Venetian blinds permit a greater flexibility of light control than shades. In addition to the conventional blind with horizontal slats, there are now several blinds on the market with vertical slats (Fig. 3.14). These are generally made in two styles. One style uses metal slats suspended vertically from an overhead traversing mechanism so that they can be opened or closed like draw draperies. The other type of vertical slat blind has slats made of cloth, usually in a width of about 3¼". Most of these do not traverse. Since the slats are of cloth, they are usually mounted so that they are under spring tension to keep them taut. Both types are equipped with a mechanism that permits rotating of the slats to give the desired control of light and ventilation. One advantage of the vertical slat blind is its lower maintenance cost, since it does not collect dust as readily as the horizontal slat type.

Fig. 3.14—Vertical venetian blinds installed in store front.

There has been some objection to vertical slat blinds with metal slats, because the slats may rattle against one another when the window is open. The cloth slats, of course, do not present this problem. The vertical slat blinds are also more difficult to install, since the slats usually have to be assembled on the job, and the more complicated operating mechanism requires a

* Sterling S. Bushnell is Vice President and General Sales Manager for Breneman-Hartshorn, Incorporated, manufacturers of window shades and venetian blinds.

little more maintenance than conventional venetian blinds.

Draw draperies, while they provide good opacity and good insulation against heat or cold, are more expensive than the two types of window coverings mentioned previously, are not as flexible in their control of light and ventilation, and have a limited life in comparison with their initial cost, especially when the window is not also equipped with a roller shade or venetian blind.

Woven wood and bamboo shades or blinds are rising in popularity, due principally to their decorative appeal. Particularly in the woven wood materials, manufacturers are now offering a range of attractive colors with warp threads made of such materials as Lurex, colored cord, etc. In comparison with other forms of window covering, the woven wood or bamboo fabrics have no practical advantages as to control of light or ventilation. Most of them do not provide complete privacy at night when interior lights are on and, because of their rough weave, are not as easy to keep clean as other window coverings.

Woven wood or bamboo shades are usually installed in one of three ways. Some are mounted on spring rollers wtih extra heavy springs, others are rolled up from the bottom by means of lifting cords with an automatic cord lock in the head member, or installations are made with the woven material in a vertical position so that it can be traversed like a draw drape.

The United States Government has set up Federal Specifications for both window shades and horizontal slat venetian blinds. The window shade specifications are designated as DDD-S-251A and the venetian blinds as RR-B-446. Copies of these specifications are obtainable from the Superintendent of Documents, Washington 25, D. C. Figures 3.15, 3.16 and 3.17 show the more common methods of installing shades and horizontal slat blinds.

Efforts have been made in the past several years by the manufacturers of spring roller shades and venetian blinds to standardize on center to center dimensions between the mounting holes for their various styles of installation brackets, so that manufacturers of metal windows could supply windows already bored and

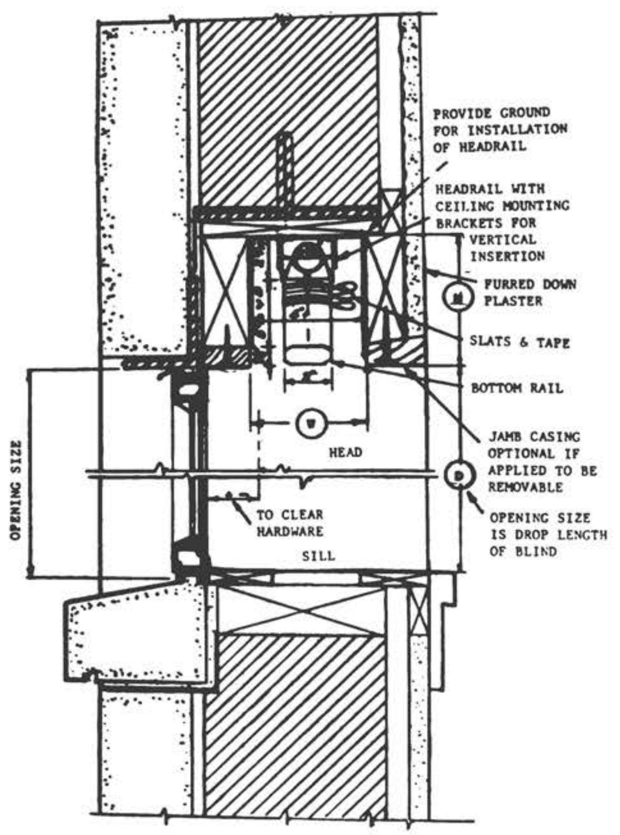


Fig. 3.15—Concealed venetian blind housing.

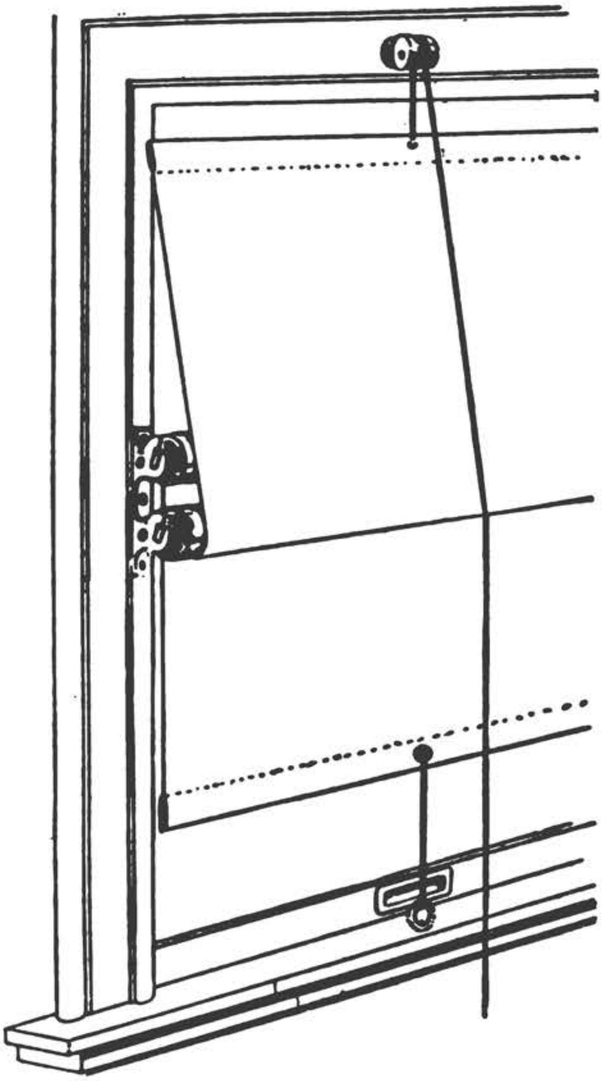


Fig. 3.16—Spring roller shades double hung at center of window.

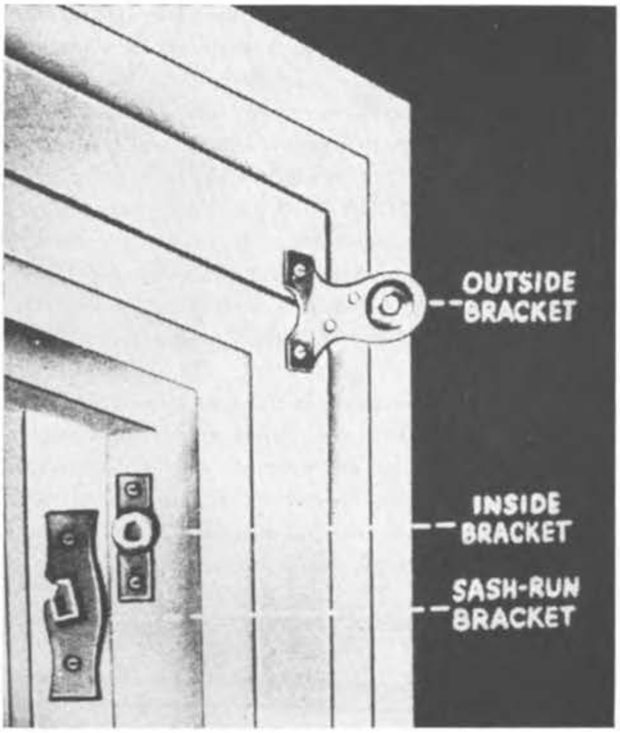


Fig. 3.17—Three types of brackets for installation of spring roller shades.

tapped for easier installation of brackets. Unfortunately, however, very little progress has been made to date, since metal window manufacturers cannot always be sure the holes would fit the bracket dimensions for the particular installation. With the growing use of metal windows instead of wood, this type of standardization could effect great economies.

The problem is not as complicated as it might appear. There is one style of bracket for inside installation of shade rollers which can be used for all window widths up to 78″. For outside installation there are three styles of brackets which would cover practically all widths of windows and all diameters of rollers. If these could be reduced to two standards, namely, one dimension for the inside bracket and the other dimension fitting all styles of outside brackets, it would simplify the problem greatly. Metal window manufacturers are, of course, equipped today to supply windows prebored for brackets if they know in advance what type of bracket is to be used. An operation of this kind can be performed at considerably less expense in the process of manufacture than after the window has been installed in the wall.

Likewise, in the case of the panel wall which is delivered as a complete unit including the window and interior finish, a considerable amount of time and money could be saved if the brackets for shades or venetian blinds were already in place. The shade or blind manufacturer, knowing the dimensions of the window in the panel wall, could then deliver his product directly to the job in the correct size, and it could be installed by unskilled labor or maintenance personnel, since the job would not require tools.

It has been interesting to note the schedule of window sizes recommended as standard dimensions by the American Standards Association and NAHB. These recommendations, covering wood, aluminum or steel windows, call for only two window lengths and five widths in terms of rough openings. It is also interesting to note that a survey made by Producers Council shows that while all of these sizes are available in wood or aluminum windows, only two-thirds of these sizes are available today in steel windows.

All of the suggested dimensions were selected to conform with the 4″ module. If these standards are accepted and adhered to, the manufacturers of venetian blinds and spring roller shades could in turn produce standard sizes that would guarantee a perfect fit. Such standardization on the part of both window and window covering manufacturers would show real economies for the builder and home owner.

This whole question of standardization in the field of interior controls is one which has been discussed at great length for many years, but very little seems to have been accomplished. Whether this is due to inertia on the part of the manufacturers or to the impracticability of the suggestions for standardization is difficult to decide. It is probably the former. Some progress now seems to have been made, however, and we hope that this progress will continue so that costs can be reduced at both manufacturing and building levels.

By E. F. Snyder *
Minneapolis-Honeywell Regulator Company

ENGINEERING OF BALANCED CONTROLS

The rapid strides being made by the architectural profession in the design of today's and tomorrow's buildings have placed a new and very welcome burden upon the control industry. The new designs have made it necessary to provide sound engineering of balanced controls and balanced control systems.

The term balanced control as used above, might well give rise to the question, "What do you mean?" To us in the control industry, it means "the provision, under variable influences, of a satisfactory environment by means of an automatic control system." You will note that we did not say comfortable environment, but rather use the word satisfactory to indicate the provision of a desirable environment regardless of what might constitute satisfaction. We, of course, are more familiar with the environment in our homes probably than anywhere else and there, of course, we consider comfort as being the most important factor.

However, there are many places such as schools where an environment which promotes the learning processes is considered more important than complete physical comfort. Manufacturing areas might use worker productivity as their criterion, whereas in certain hospital areas an environment which promotes the healing process might be the most valuable. Certain storage areas might require specialized environment to reduce contamination. There is no one single yardstick by which the control results can be measured other than satisfaction of the desires for the particular area under control.

You might well ask what factors should be considered in the engineering of balanced controls, and here we would like to say that we do not confine our thinking to the years-old concept that air temperature, air motion, relative humidity and purity are the controlling factors. We feel that today we must extend our thinking beyond these factors and look into the fields of lighting and color dynamics as being a part of our environment. Even beyond that, we find that noise and radiant temperatures play a large part in determining satisfaction with our environment. Any control system which does not consider and positively control all of these factors, is only a partial system. It is not complete.

We might, at this point, add as a guess that a control system which considers every point outlined above is complete only as we see it today and may be woefully lacking in coverage a few years from now. Perhaps then, ionic characteristics of the air will be more important than any single point heretofore considered. We do not know the answers to all of the facets of control today, but this field is moving forward and increasing its over-all knowledge, just as is the science of architecture.

One of the advances in architecture which directly concerns the control industry is the practice today of using larger areas of glass in the exterior walls of buildings. This practice provides no new problems for the control industry, but emphasizes some which were considered secondary in the past, and turns the spot-

---

* Edwin F. Snyder, Jr., is Supervisor of Control Application in the Commercial Division of the Minneapolis-Honeywell Regulator Company. He has been associated with this firm since 1945, following four years in the Army supervising the design and construction of eight air bases and serving overseas with the 101st Airborne Division. He has a Bachelor of Science in Mechanical Engineering from the University of Michigan and is an active member of the American Society of Heating and Air Conditioning Engineers.

He is a member of ASHAE's Technical Advisory Committee on Panel Heating and Cooling, its Committee on Research, Chairman of its Technical Advisory Committee on Air Cleaning, and of its Coordinating Committee on Air Contaminants. From 1951 through 1952, he was President of the Minnesota Chapter of ASHAE, and is the author or co-author of a number of papers on controls and control systems.

light on others which had been recognized but ignored in the past years. We have reached the point now where the latter cannot be ignored any longer, and the former have become primary problems instead of secondary.

These large expanses of glass in exterior walls mean first of all that our heat transfer factors for exterior walls are different than the ones commonly encountered in the past. Secondly, our surface temperatures on these exterior walls are different than the ones previously worked with. These two factors alone affect the choice of controls as well, of course, as the choice of heating and air conditioning equipment and systems, so that their beneficial effects may be magnified and their detrimental effects minimized as much as possible.

Direct sunlight playing against a large glass area will transmit a terrific amount of heat energy to the interior of the building. The sunlight striking the floor may raise the temperature of that floor many degrees above the air temperature and thus provide a radiant heating panel for the occupants of the room. This might tend to decrease the heating load during the heating season, but by the same token, it will tend to increase the cooling load very materially during the cooling season. Thus, any control system must provide the optimum environment under these conditions. A large glass area on the south or west side of the building is of necessity going to offer a different kind of problem than that same glass area on the east or north side of the same building.

On the other hand, we cannot say that, just because an area is located on a certain side of the building, conditions within that area will be the same. Conditions will vary from one room to another, even on the same side of the building, depending upon many factors such as occupancy loads, degree of activity within the space, amount of artificial lighting, number of heat generating devices, kind of dirt producing devices, items which might tend to increase or decrease the relative humidity, and many others too numerous to mention.

Because of the many factors which contribute to environment in a given space, it is felt very strongly that each room should be considered on its own merits. The environment within that room or space should be controlled directly from the conditions within that same space, with little or no regard given to surrounding rooms or spaces. This means, in essence, individual room control. Anything less requires a compromise with results.

Today, the architect and consulting engineer have a wide choice of controls which they may select to accomplish a given job. In a broad sense, they can choose amongst pneumatic controls, electric controls and electronic. Each of these control types has certain features which are desirable.

In general, today's style of architecture has put the spotlight more squarely on the electronic types than on either pneumatic or electric, because of the increased need to detect minute changes quickly. The large glass areas prevalent in buildings do not increase the thermal lag on an exterior wall, but rather, tend to decrease it. Changes in temperature felt outdoors are more quickly felt inside and, as mentioned previously, solar heat is transmitted very rapidly and in large volume through these same glass areas. These two factors alone mean that changing outside conditions are going to be felt very quickly within the building and any control system must recognize and take action on these changes just as quickly as they occur. The conditions within a space may change the demand from heating to cooling within a one-minute period and the controls must keep up with these changes.

So far, we have been discussing the effect of this new trend in design on interior temperatures. Let's look at another factor which has been introduced by this trend. This is the amount of natural light which enters through the same large areas of glass. Previously, quite a lot of dependence was placed upon artificial lighting to maintain a given light intensity level and there was not too much variation imposed on the space by variations in outside conditions. However, with larger glass areas, there is a considerably greater variation in interior light level due to variations in outside conditions.

Our lighting engineers tell us that there are certain optimum levels which promote efficiency and reduce fatigue. There are also certain economic levels to be considered. In order to maintain this optimum condition, it may be necessary during periods of low outside intensity to provide artificial lighting to bring the inside level up to the desired point. In view of this, we must say that a control system is not balanced unless we control interior light intensity along with other conditions previously discussed.

The control of light intensity has been accomplished quite successfully by several different methods. One approach to this problem, used to some extent in schoolrooms, is to provide various banks of light with each bank under separate control. These banks are arranged parallel to the outside windows with as many of them under separate control as practical. When the outside light intensity begins to decrease, the banks furthest from the window can be turned on to maintain the desired level at that point, and as the outside light intensity continues to decrease, additional banks nearer the windows can be turned on, until all of the lights are on, and still the desired level is maintained within the space.

Another method, which has been used quite successfully, is to modulate the banks by means of saturable reactors, so as to eliminate the step effect of the previous method. Of course, this system requires incandescent bulbs and the rather expensive saturable reactors. On the other hand, there is some economy, since it has been found that bulb life is ten times normal if voltages are maintained at 80% of rated voltage or less.

The choice between modulating and two position multi-stage control is simply a matter of economics. If the costs were similar, modulating control would be preferred, because:

1. Changes in illumination from the interior lights would be less perceptible.

2. An additional economy would be enjoyed through operating the incandescent lights at reduced voltage.

However, because of the several thousand dollars of additional cost for automatic dimming equipment, modulating control is considered economically practical only for large buildings in which the design permits regulation of a large number of lights from a single control system.

This becomes practical in a large, one story building in which all of the rooms can be equally lighted, regardless of orientation, through specially designed ceiling and roof sky lights.

Since the modulation system would not be economically possible in many new buildings for reasons given above, the two position multi-stage control is preferable at present. See Figure 3.18. Although an installation has actually been successful with as few as two stages of lighting, three or four stages are considered more desirable because of the added flexibility. It is interesting to note that tests in an actual schoolroom have disclosed that there was no personal annoyance from having as high as 50 per cent of the artificial lights turned on at once, when needed to maintain the desired light level at the desks.

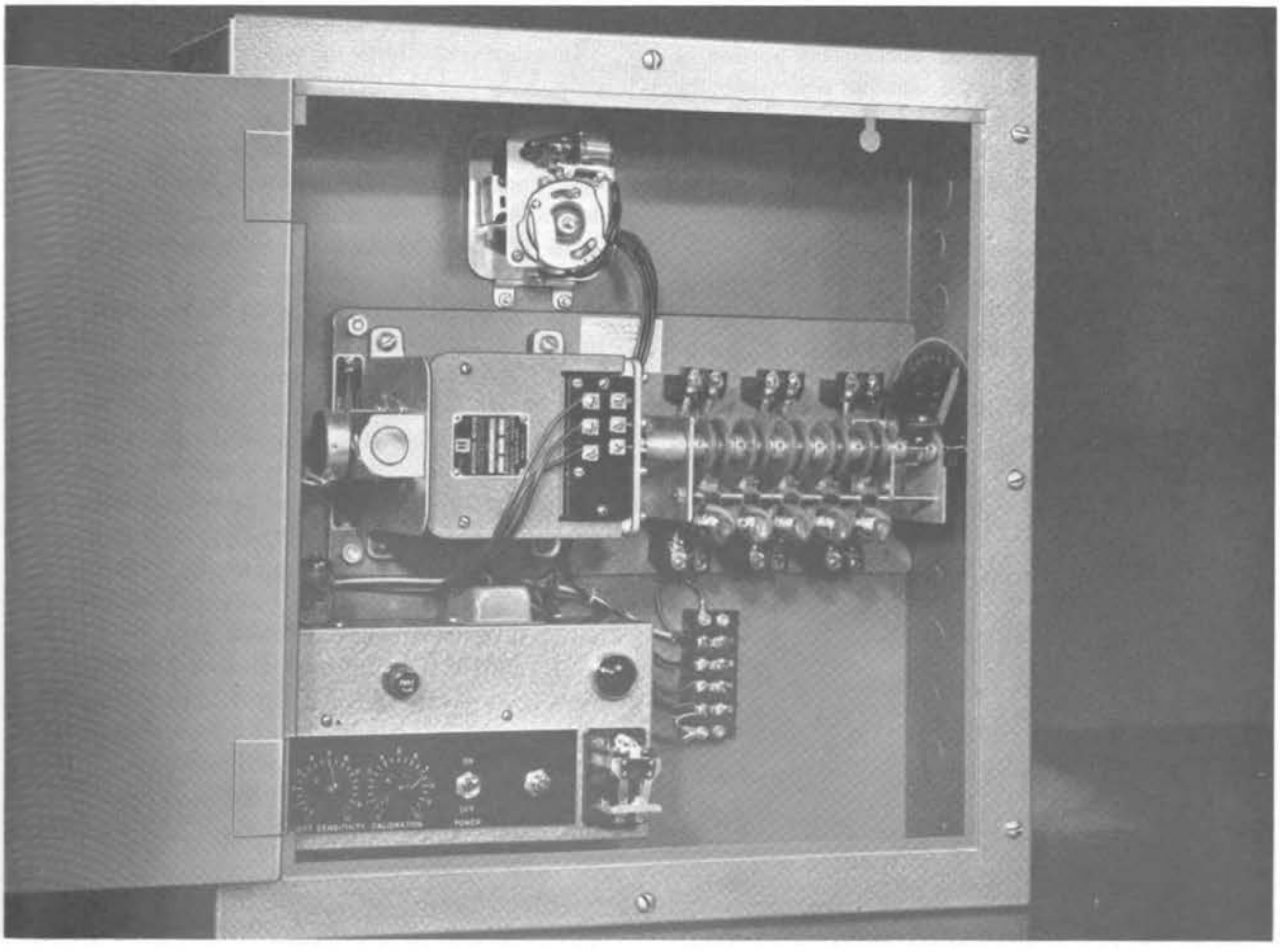


Fig. 3.18—Two position multi-stage control for interior lighting.

Because of the simplicity of this system compared to modulating, it is feasible to divide the building into zones selected according to exposure to outside light. For example, considering a simple rectangular building, the south exposure would constitute one zone, the west exposure another, the north another, and the east another. A photo tube (see Fig. 3.19) mounted externally facing the same direction as the zone it controls will operate through its own independent panel to turn on the internal lights as required.

Theoretically, the photo tube can be mounted internally in the space, or externally. In an interior location, the photo tube measures the light intensity as it occurs in the space and turns on the interior lights as required to maintain its setting. However, it is usually difficult to mount the photo tube inside correctly and satisfactorily. The exterior mounting is usually preferred for the following reasons:

1. Since the cause for a change in interior light is a change in outdoor light intensity, changes in exterior light intensity, which are proportional to interior light changes, can be measured directly.

2. In conventional buildings, it is difficult to locate the photo tube in a room to take care of the entire area within the room, because the portion of the room farthest from the window will reach the point where light is required before the area near the windows.

3. There may be momentary changes in one room which would cause a correction in the light intensity not present in other rooms within the same zone.

4. An outdoor mounting precludes any possibility of tampering with the photo pick-up which might occur if it were inside.

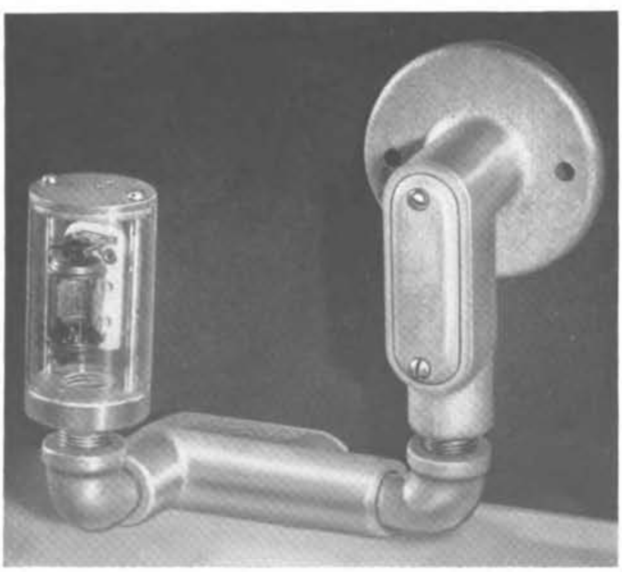


Fig. 3.19—Exterior mounted photo tube.

Owners usually desire a da-nite switch, so that the system can be on automatic control during the work hours. At the close of work in the afternoon, it is desired to turn all the lights to the "on" position, so that they can be turned on or off manually as desired during the "out of work" hours.

In the modulating system, the photo tube located outdoors measures the average light intensity and pilots a saturable reactor or magnetic amplifier dimmer to reduce the voltage on the inside lamps as required. The system is characterized so that the voltage to the lamps varies in such a way as to make the relationship between changes in light input in the control space linearly proportional to changes in outdoor light intensity.

Figure 3.20 illustrates the over-all circuit. Instead of the output of this system being a step controller with multiple switches, it will pilot a saturable reactor or magnetic amplifier dimmer.

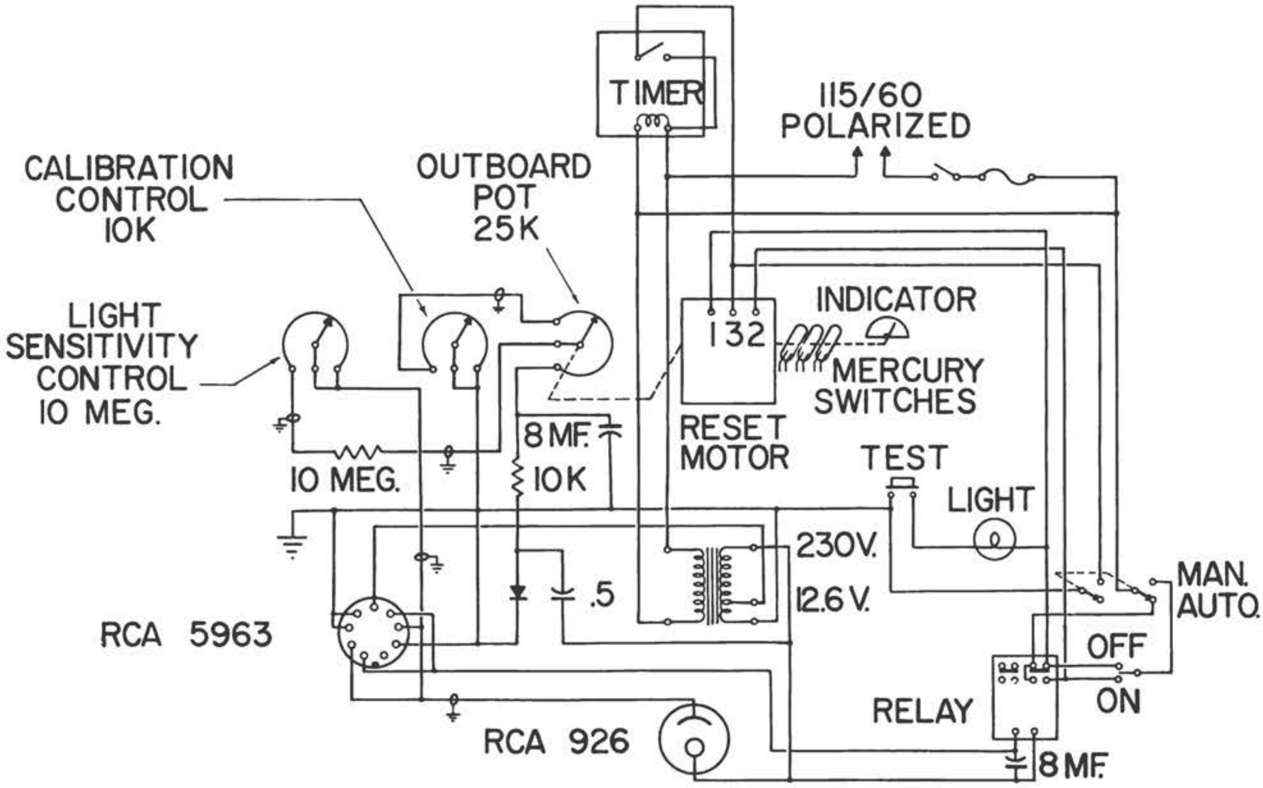
Figure 3.20 illustrates the circuit two position multiple stage control which is applied to each zone. The outdoor photo tube positions a reset motor which turns on stages of light in sequence as required to maintain the proper light intensity inside.

In a normal building the windows are on the outside walls only and the lighting stages are arranged with the interior lights in rows parallel to the outside wall. As the need for interior light increases, the row of lights farthest from the windows is turned on first. As the outdoor light intensity decreases, the rows of lights (2 to 4) are turned on in sequence from the innermost row to the outermost row.

A new arrangement has been proposed by Dr. Darrel Harmon in which the room is divided up into stages. In this case, the internal lighting in the zones is turned on in a sequence according to the manner in which they are numbered. This is purported to give improved light effect at the desk tops.

The remarks made thus far have been directed toward the increase of space lighting only to maintain the level above some minimum. There is also the problem of reducing intensity when a maximum level has been reached. Lighting engineers tell us that high levels of light intensity are not undesirable provided there is no glare. Glare from natural lighting is normally controlled by the use of overhang, venetian blinds or jalousies. These latter two means can also be put under the same sort of automatic control, if it is desired, by use of the same equipment described above.

Certainly controlled lighting is a necessary part of environmental control but it is still far from the final step. Another factor to consider is the psychological



LIGHT DIM - MOTOR OPENING TO INCREASE SPACE LIGHTING
LIGHT BRIGHT - MOTOR CLOSING TO DECREASE SPACE LIGHTING
NO LIGHT - MOTOR IN BALANCE

Fig. 3.20—Over-all circuit two-position multiple stage control.

and physiological impact of interior color. Psychologists tell us that different colors have very different emotional effects on individuals. For example, it has been reported that green tends to soothe and calm some emotionally stimulated persons, whereas red has the opposite effect.

In the not too distant future we will have interior surfaces of materials that will reflect and absorb portions of the spectrum so that their color can be changed at will. Teachers will change the interior color to keep interest and learning levels high, and office and plant managers will change colors to keep the effects of physical and mental fatigue to a minimum.

In conclusion, a control system, to be complete, must consider and control, on a balanced basis, all phases of the interior environment. This cannot be done economically in all cases today, but as knowledge increases, we are drawing closer to perfection.

Discussion Period—CONTROLS

MR. HENNESSY: You have heard the whole circuit of the control problem, and I am sure it has excited a certain amount of interest. I'd like to start off the questions by asking Mr. Greenwald whether or not he feels that the additional cost of air conditioning due to the larger expanses of glass is within the economic realm of construction today. Does it pose any problem?

MR. GREENWALD: Everything you do that's new poses a new problem. You might have asked me the same question 50 years ago when we didn't know about air conditioning. The answer is, when you sum up the the totality of your buildings, what are you looking for? We know that in designing a good building with a good architect and a good engineer, if you design carefully, the cost of air conditioning a glass building doesn't begin to compare to the excessive costs of maintaining a skyscraper of masonry which has to be tuck-pointed and which leaks almost continually.

Or you might ask me another question: Do aluminum windows warrant the cost? Well, I think of the many years I tried to maintain buildings with wood and steel windows and the excessive cost we had there. The answer to that question is "certainly."

Air conditioning is a cost. Certainly it gets to be a little more costly in any glass building, but it's worth every dime you pay for it. And, if the research people just give us what we need, the time will come when it will be just as cheap to air condition a glass building as it will be any other building.

MR. HENNESSY: To skip to the other owner, Mr. Miner, are the large plates of glass in the exterior of your building of tempered plate? And, has there been any moisture penetration in the Manufacturers Trust Building?

MR. MINER: No, there's been no moisture penetration. The walls are half-inch plate glass. They are not the Thermopane. And we have had no trouble. As I explained before, we only have about an hour of sunshine. We're in among the other skyscrapers around us, so we have no temperature control problems that are not well taken care of by the peripheral heating and air conditioning arrangement.

G. E. JOHNSON (Reflectal Corp.): Will you elaborate on the so-called problem of icing as regards sunshades?

MR. WRIGHT: In New York City it's commonly believed it would be quite dangerous to use external sunshades since they might accumulate snow which would then turn to ice. There has been experience with ice collecting on the spire of the Chrysler Building, and sometimes they have to rope off the surrounding streets. I don't think anybody knows too much about this. I have assumed that a hood over a window in a New York City building would either have to have a snow-melting arrangement or a very steep slope that would shed the snow. This is all entirely guesswork on everybody's part because there isn't experience to go by.

C. B. MONK (Structural Clay Research): Considering the symmetrical solar load on the east and west walls, what factors contribute to greater cooling loads from a western exposure over an eastern exposure?

MR. WRIGHT: It's usually assumed that the west will be the main offender because the load will come at least at the same general time of day as the peak temperature and the peak ventilation load. However, as a specific case—and what I have been trying to emphasize is that you can't generalize with any accuracy—take the case of the United Nations Building. It was believed that the west wall would be the offensive wall from an air conditioning point of view. Several factors have combined to make the east wall the prime offender. One of them is the skew of the building with respect to the compass, dictated by the street system. Another is daylight saving time and the fact that it's an office building. It's true in New York City office buildings that the west side of the building is not usually occupied at the time that the principal solar load hits the west wall. It faces 28 degrees north of west actually, and with daylight saving time it's quite late in the day before that load registers.

Any of these assumptions have to be checked out in terms of the specifics of the orientation, the atmospheric conditions and the use of the building. An apartment house in New York City facing what we call west in Manhattan is very bad, while an office building facing that way makes comparatively little difference.

R. A. BOYD (University of Michigan): How does the exterior photo cell for the control of electric lights take into account the directional effect of the incident daylight?

MR. SNYDER: Normally a photo cell would be located on the same wall as the zone of lights with which it was tied in. Other than that, there has to date been no attempt to focus it more directly either by partially rotating mount or some other divice.

T. S. DORRANCE (Consultant): Will you enlarge on your apparent dissatisfaction with such insulating glass as Thermopane? Have you used it with unsatisfactory results?

MR. GREENWALD: First, Thermopane costs too much. Second, I used Thermopane when it first came out and found that after a while there was marked failure in a number of the plates. Third, we like to think that heat will bleed off of a building as well as come into a building. And fourth, it costs too much.

E. C. TAYLOR (Carbon & Carbide Chemicals Co.): What have you found to be the most successful gasketing and calking materials?

MR. GREENWALD: We haven't found a satisfactory one yet. I think we're getting there. We're experimenting with all sorts of compounds. This area is such a vast one that I don't think the industry recognizes the problem we face in a city like Chicago where we have enormous temperature variations in solar pickup from the sash and from the plate itself. They don't realize the effect this would have on the oils and putties, for example. So we are trying to master compounds. We have tried neoprene with unsatisfactory results.

JOHN EVERETTS, JR. (Charles S. Leopold, Eng.): What type of control can be used to compensate for large changes in instantaneous solar loads in all-glass wall areas?

MR. SNYDER: The electronic controls will respond almost instantly to a very small change in whatever condition they are designed to measure. The limiting factor is not necessarily the ability of the control system to react to change, but rather whether the basic heating or air conditioning system can respond quickly enough.

And don't forget that there is an additional lag, even beyond the heating and air conditioning itself, and that is the transfer of that change in energy through the space. That is another lag which must be considered and which will affect the overall operation of the system.

M. D. FOLLEY (Architect): What exterior control louver or shield do you suggest for the southwest through the northwest orientation that will allow a view in New York latitude?

MR. WRIGHT: Well, my own feeling about New York City office buildings would be to use a type of egg crate that would provide side shading and top shading to about an equal extent and which you could look through, although it would confine the view like the blinders on a horse.

This quite probably wouldn't provide a hundred per cent shade for a given square of glass at the critical hour, but if it provided 75 per cent shading, which is fairly easy with a two-way shield at a 45-degree angle, that would make a very substantial difference in load. Again I underscore the fact that I'm talking about one condition only, namely, a building oriented with respect to the Manhattan street system in that particular latitude and climate condition.

The movable type of external louver, which I didn't have time to discuss at any length, is very widely used in parts of the country. It's manipulated or automatically controlled to cut out the sun load, and a great deal of the time can be wide open.

C. F. HUDDLE (General Motors): What value do you place on heat-absorbing glass?

MR. GREENWALD: I place every value on it. It's a very important factor in designing a glass building. My only problem is that at the moment there is only one color, or almost only one color. We're using this gray. We have yet to go through a few summers with it and really find out just how much it does to our heating and cooling problem. It was a step in the right direction to begin with, but it's only the first step. Even the glass industry itself today doesn't know exactly how much it does cut.

When the time comes—and I hope it will shortly—that the glass industry knows precisely what effect the tints in the glass have and the air conditioning engineer can then work toward it, I think we will be able to obviate the problem of how you cure polio by sunshades and find the vaccine that will prevent polio in the beginning.

PART IV

DESIGN APPLICATIONS

Chairman

Leon Chatelain, Jr., FAIA

Partner,
Chatelain, Gauger and Nolan, Architects

RESIDENTIAL DESIGN: ARCHITECT'S VIEWPOINT

By William Keck *
George Fred Keck, William Keck, Architects

In turning to the dictionary for a definition of the word "window," we find that it is a noun, derived from an old English word "windowe" or "windoge" with a second derivation from the Icelandic word "vindauge," literally, "wind eye." The definition is: "An opening in the wall of a building for the admission of light or of light and air when necessary. In modern buildings this opening has usually a frame on the sides in which are set movable sashes, containing panes of glass or other transparent material." I take exception to the definition to the extent that today many windows do not necessarily have to be movable and in some instances the glass or other obscure material is not even set in a frame.

When we look back into history and try to analyze the development of windows to their present state we find a complex growth which is far beyond the scope of this relatively short discussion. I do wish to point out, however, the importance of a few things and their influence on the subject matter.

In cold climates, such as the northern part of our world, it became necessary in the fight for survival with the elements to keep window sizes down to a relatively small area because of the cold. Also, few materials such as we have today were available; glass had not yet been invented. Conversely in the hot, arid regions of the world the intense heat had to be kept out of the house. Early window coverings were skins, then probably light-colored cloth and/or parchment, long before glass was made.

Early windows were openings in masonry or other type of wall construction which had to be spanned with lintels of one material or another in order to bring the structural loads down. Consequently, the size and frequency of such openings was definitely limited. In England in the Middle Ages a continuous ribbon type of window was invented in some of the half-timber houses. Here the loads were carried down more frequently with smaller mullions in an effort to obtain more light. Farther north, in Scotland, in one of the lesser castles near Dundee, we find examples of windows which were kept quite small, for protection against the elements as well as against man. One of the original pieces of glass is still intact after these many years. Set directly in the masonry with no frame around it, its only purpose was to admit a small amount of light. It was high above the outside ground where no one could reach it and it was so small that no one could climb through if it had been reached. It was not necessary to open the window, for the fireplaces, kept going most of the year in this cool, damp climate, did an excellent job of ventilating.

Today, of course, we have a far greater choice of materials and methods of providing windows. We can carry our loads from floors and ceilings down on a skeleton type of framework, making the entire outside an envelope of glass, if we so desire.

With the increasing use of glass the problem of heating as well as comfort becomes an important one. Back in 1933 our office designed the House of Tomorrow for the World's Fair held in Chicago. (Fig. 4.1). When the Fair was held over for a second year, we offered to allow one of the major glass companies the use of the house for the winter in an effort to determine more accurately the cost of heating such a structure

* William Keck has been a partner in the architectural firm of George Fred Keck-William Keck, in Chicago, Illinois, since 1946. He has a Bachelor of Science in Architecture from the University of Illinois, and has studied at the Chicago Institute of Design. From 1931 until the war, he worked in the office of George Fred Keck, Architect. During the war, he was employed in site planning for the Corps of Engineers, and also was in the Naval Reserve.

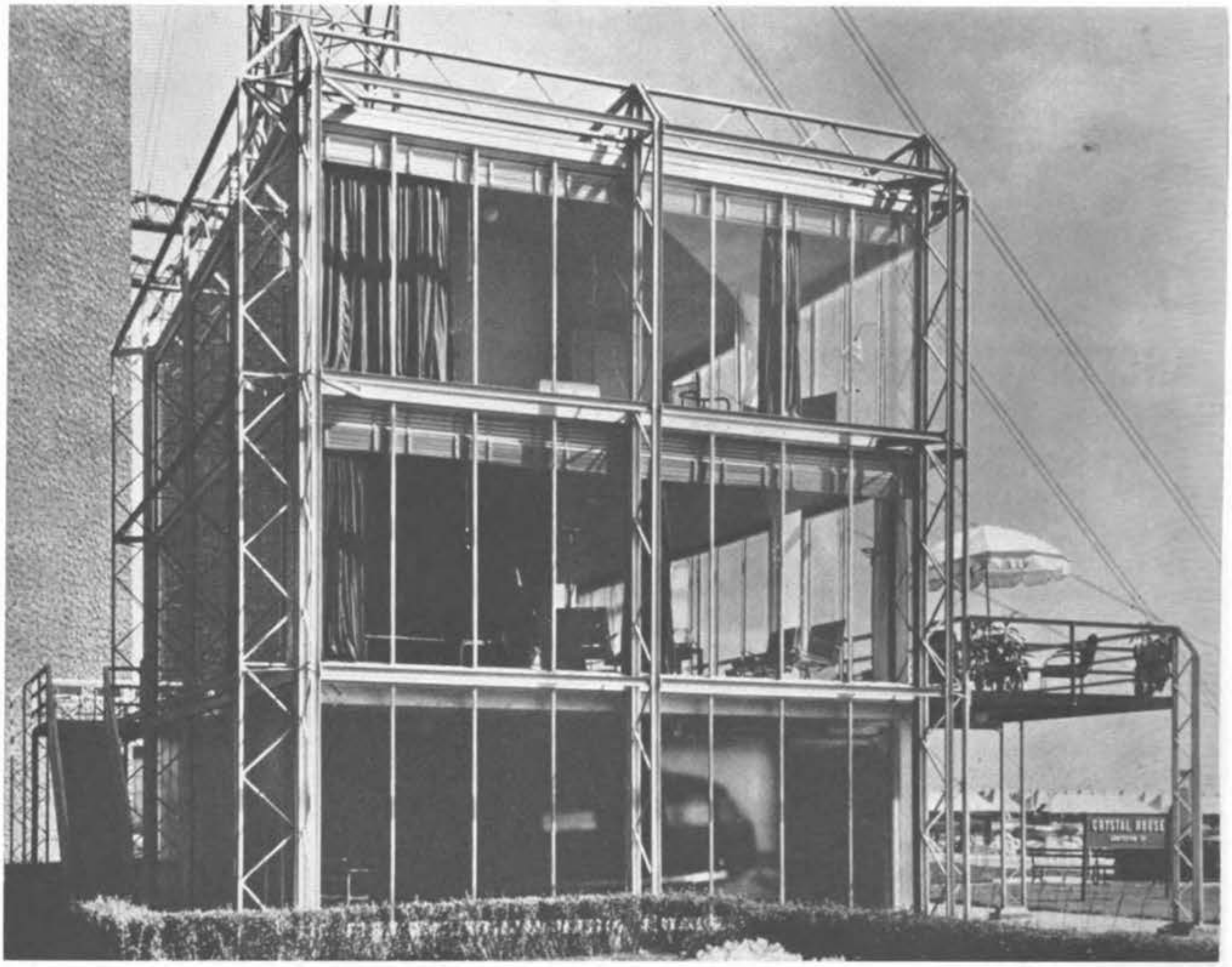


Fig. 4.1—The Crystal House, designed for the Chicago World's Fair, 1933-34, by George Fred Keck, William Keck, Architects.

during a heating season. At that time heating engineers would not guarantee that they could heat the house with any degree of comfort at a reasonable cost. Here was an excellent opportunity for practical research which, unfortunately, was turned down. Nevertheless, we found in the relatively cold month from October 15 to November 15 that the fuel consumption was remarkably low for the temperatures encountered. This was the beginning of considerable research on the subject of solar radiation which finally brought us to the conclusion that, given a large amount of glass, by orienting it to the south with proper protection it was possible to reduce the actual cost of heating, in spite of the increase in heat loss through the glass.

We know that the sun is low in the heavens in the winter and high in summer. Considerable technical data concerning heat gains from the sun is now available in one form or another in various textbook tables. At the time we first began looking for information on this subject some twenty years ago, very little had been published. All we could find at that time was some research done by the U.S. Weather Station at the University of Chicago where they had been keeping a daily record of a unit of heat measure on a horizontal surface within a glass container similar to a clear electric lamp bulb. Taking a five day average from their records for clear days in the month of February, we found that the following statistics held true:

Hours	9 to 10	10 to 11	11 to 12
Gram calories per sq. cm.	13.96	20.2	24.7
Hours	12 to 1	1 to 2	2 to 3
Gram calories per sq. cm.	27.0	23.6	16.8

After calculations too lengthy to give here we found that we could predict a saving in heat in the amount of 10 to 15 per cent. Nothing special was done in our architecture except to organize the glass areas in the houses in such a position as to trap the sunlight after it entered the glass in the form of light and was subsequently converted to heat when it touched the floor or other objects within the house.

One of the difficulties with the use of large amounts of glass is the excess heat which enters unwanted. The shutters developed in our early American architecture solved that problem quite well. They provided safety when closed, as well as privacy and protection from the sun. Unfortunately, they later developed into pure decoration. Another solution for protecting the window area was the rolling shutter on the outside. This has been used in Europe extensively in the past as well as today. Exterior venetian blinds give us another form of protection. Overhangs properly placed on the south side of a house also give protection from the summer sun.

When large pieces of double glazing were first placed on the market our office accepted the fact that here was a mechanically joined material which was brittle and the less it was moved, the less chance there was to break the seal. It was at this point that we divorced the functions of light and ventilation. In so doing, the large areas of glass could be fixed and the ventilation supplied through adjacent areas which could be placed strategically where they would be most effective, either above and below the window, or adjacent to it.

Here was a new freedom in design. It was now possible to work out a system which would give adequate ventilation and still give adequate light with greater control. We can now keep our glass areas free of screening which cuts out the light, impairs vision and causes the glass to get dirty quicker, since the screen filters and holds the dirt for the first rain to redistribute. We can now bring our bedroom windows down to the ground with a reasonable sense of security. By placing louvers on the ventilating areas we can leave the vents open during all but the most severe storms and not have a flood. This is most desirable during a summer thunder storm where the usual procedure is to have to swelter during the storm because we have no way to protect our windows, or when we are away for an evening and would like to give the house a chance to cool off.

One of the major problems that any architect faces today in the race against increasing costs is that of giving the client additional space. This is one place where the large window comes to our aid. With the use of large, concentrated glass areas reaching to the floor, it is now possible to open the end or side of a room visually with a relatively small amount of enclosed space. The room just keeps on going out into this open space. This can be accomplished just as well on a small piece of property as on a large one; however, it can not be done by placing a lamp on a table in the so-called picture window.

There was a time in the history of the present system of double glazing when, because of the difficulties encountered in the method of sealing the glass, the product was taken off the market for a period of time. At that time our office developed a system of double glazing, including the solution to the storage problem of screens and storm sash, by making an adaptation of our old friend, the double-hung window. (Fig. 4.2). By providing a pocket over the window and placing the head at the meeting rail of a double-hung window, it becomes very easy to provide storage space for the screen and storm window when not in use. The upper sash becomes the storm sash and makes a simple method of solving the problem.

In fixing the glass and separating the function of ventilation, it becomes possible to place the ventilating units at many different spots. They can be placed above and below the window area, or the glass panes can be grouped together with the ventilating units at the sides of the room or at other positions. Occasionally, because of the proximity of a neighboring

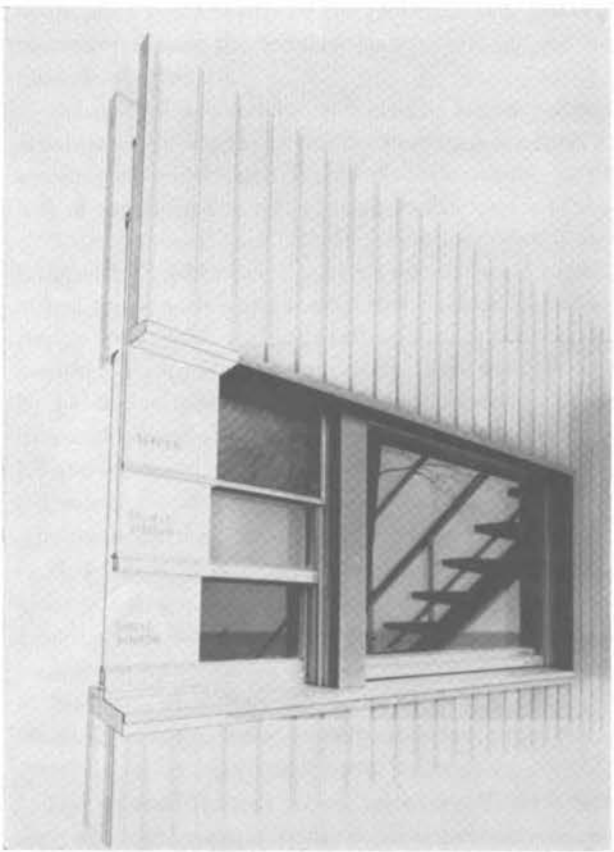


Fig. 4.2—Aluminum window designed by George Fred Keck and manufactured by Adams and Westlake, as installed in 1940 in a residence in Menasha, Wisconsin.

building, or for some other reason, it is preferable and possible to use just the ventilating unit alone.

What of the future? This is very difficult to predict with any degree of accuracy. I will say, however, that the future undoubtedly will bring us many new developments. These will be determined by the scope of materials available, as well as the fertile imagination of the mind of man. We have at the present time a variety of available materials; these include metal and wood for frames, with glass as the medium for admitting light. As the plastics industry has developed in recent years, we have developed still another medium for the transmission of light. We already have our double-hung windows, our casement sash and our sliding windows as possibilities. As new materials are developed we will enlarge the scope of the future, which will in turn change our basic planning as it is known today. When the early Phoenicians discovered glass by melting sand under a fire, little did they realize that some day pieces of this substance would cover the entire side of a house. So it is today as we look into the future.

By James T. Lendrum *
University of Illinois

RESIDENTIAL DESIGN: RESEARCH VIEWPOINT

A standard analytical technique which is common practice in many fields, including building research, is the process of subdividing a large, complicated problem into a series of small problems which may be solved individually.

Sometimes, in a field as relatively new as housing research, the individual or component problems are somewhat difficult to identify. In the case of glass, however, this is not necessarily true. For a long time, a great many forward-looking architects have been asking themselves: "Why do we use windows?" They come up with three answers. We use windows because we obtain light from them, because of the view or vision which is possible through them, and because of ventilation which we have long associated with the process of "opening the window." Unfortunately from the homeowner's standpoint, and to the frustration of the architect, the three functions call for vastly different sized areas, located with different and conflicting orientations, and at quite unrelated heights from the floor. No one location or orientation seems proper for light, vision, and ventilation.

Actually, one of the three qualities which we associate with windows really has nothing whatsoever to do with the most important material which goes into the window, glass. I refer, of course, to ventilation.

The use of windows for ventilation is an archaic habit which could easily be traced to the times when animal skins were hung over openings in the crudest of shelters. Obviously, quantities of fresh air would come in through the opening, and when the skin was replaced with glass the development problem was made more complicated by the feeling that it was still necessary to use the window to provide for the admission of fresh air.

Because of our mechanical ingenuity we have almost eliminated the window, even the operating window, as a source of ventilation. We do elaborate things in the way of weatherstripping; of storm sash which is placed over the principal sash to reduce heat loss—but it also reduces the infiltration of air; we operate wind tunnels to test the windows to see what can be done to further reduce this cold air infiltration during the winter months. I suppose we should add that painters are, by habit, inclined to see that the windows are pretty thoroughly sealed closed, and few homeowners that I have observed use windows for ventilation during the winter months. So, the unimportant function of a window might be considered that of ventilation.

This leaves us with only one real reason for using glass in a house, that is, for the vision which it allows. I realize that this statement is in direct contradiction to a comment by an earlier speaker. My remark is limited to housing, where we can do a better job with mechanical means, often at considerably less expense and certainly under very much better control.

The second function which we expect from a window, the admission of light, is an important one and certainly adds to the mental well-being of the occupant. Unfortunately, we have no data on the amount of light required for the various household tasks

---

* James T. Lendrum is the Director of the Small Homes Council of the University of Illinois. He has a Bachelor of Architecture degree from the University of Michigan, and a Master of Architecture from the University of Illinois, is a member of the American Institute of Architects and a Registered Architect in Illinois.

He has served the Federal Government as a consultant on housing, and is presently a member of the Architectural Standards Committee of the Federal Housing Administration, a consultant to House and Home magazine, and serves several industry research and advisory committees. He is also a member of the American Concrete Institute, the American Society for Testing Materials, the National Safety Council, the Building Research Advisory Board and the Building Research Institute.

which are carried on during the day. Some of these tasks are at fixed work centers in the kitchen, not all of which are properly located with respect to windows so as to provide satisfactory natural light.

While I admit windows are obviously important from a lighting standpoint, they are, in theory at least, not indispensable, for they may be replaced entirely by artificial sources. In fact, a great many homeowners who are forced to commute long distances often find that they are leaving home so early in the morning that it is still dark. By the time they reach their homes again in the evening the sun has set. During the winter months, it is entirely possible that a man may never see his house, inside or out, during the daylight hours, except on weekends. Obviously, a carefully designed and controlled source of artificial illumination is necessary, and as far as lighting is concerned his house could be completely windowless.

Glass doesn't seem to have too much active competition from other materials, even though there are some which have that one quality of transparency which is important with relation to the vision which we associate with windows. Therefore, rather than discussing why we should use glass let's look at some of the problems connected with the material as it is used in residential construction.

First, there are the psychological problems. Of course, these are the most difficult of all to identify and solve. The second major group of problems is based on the physical limitations of people. For these it is possible to establish standards and offer solutions. In addition, there is a group of problems which are completely technical in nature and, therefore, quite different from the more abstract psychological and physical problems. Many of these, such as heat loss and heat gain, have been discussed elsewhere, so I will not elaborate on them.

Chief among the psychological problems is that of fear. Perhaps you have realized that fear is an important item in the selection of windows or in the use of glass in residential construction. It is not the fear of something new or different, such as contemporary design, that disturbs, but rather the fear of personal safety. This is the reason many homeowners hesitate to accept glass in the large, simple, unbroken areas which many of us accept as the most practical and best use of the material.

Instead of admitting the existence of certain, perhaps not too well identified, fears the prospective homeowner will attempt to rationalize and explain to the architect or builder a dislike for the "auto showroom effect" of the large pane of glass. Actually, the problem is a simpler one—it is the realization that occasionally individuals fall. Children are impetuous and are inclined to run, increasing the possibility of accident. Older persons with failing vision and slowing reactions are prone to fall. Therefore, a large pane of glass with no means of arresting a fall presents a potential hazard.

Fortunately, there are simple means of overcoming this. You may be familiar with many of the window designs developed by the Small Homes Council. In these you will find that the maximum piece of glass is approximately four feet wide. This provides for a vertical structural mullion, or at least a substantial division in the glass, at spaces that are well within the reach of the outstretched arms of a person who may be falling against the window. The addition of these simple vertical divisions immediately creates confidence in the mind of the person walking near the window and, quite possibly, that confidence may in itself help to eliminate the hazards of falls.

Along with the vertical divisions at approximately four foot intervals, we feel that there is a real psychological advantage in introducing a horizontal division somewhere near the height of a coffee table or the seat of a chair. This, while not a protection against falls, except possibly for small children, does reassure the homeowner that a chair will not be accidentally shoved through the view window which so beautifully expands the field of vision and adds to the apparent size of the room. Thus not only breakage, but the fear of falling glass, is removed.

Some of the other fears in connection with large areas of glass are not so easy to allay. Any petty thief knows how extremely simple it is to cut through an 8″ x 10″ pane of single-strength glass, reach in, unlock a double-hung window, and have immediate access to a house. The homeowner, however, seeing the wood muntins and small divisions, has a feeling of reassurance quite different than the feeling given by a large sheet of plate glass, which actually would be more difficult as far as breaking and entering is concerned. Nor is there any simple answer to the oft-repeated question regarding replacement costs and breakage. The larger areas naturally require heavier glass, which may resist some minor blows, but which will break and is expensive to replace. The four-foot unit may be a reasonable compromise between the two extremes.

One other important psychological problem connected with fear is that of vision—wrong-way vision. In many areas, there seems to prevail a rather pronounced reluctance to be seen sitting at home reading the paper. Drapes must be drawn, curtains pulled, or blinds closed, in order to cut out possible viewing from the outside. This ties in immediately with the problem of vision into bedrooms having large glass areas. Perhaps this is the reason, in the western states at least, there are carefully fenced-in yards providing sun terraces and controlled private gardens outside of bedrooms even on the smallest of lots. Careful planning and control in the location of glass areas, together with the development of the yard as an outdoor living area, are the best solutions to this.

Unfortunately, these psychological problems are very real and cannot be solved by merely supplying technical data to a governing body or building code inspector. They require relatively long periods of education on the part of homeowners and builders. Nor do I feel that these fears are entirely groundless. I have seen an active teenager go through a glass wall —unfortunately the sliding glass door was closed. His cuts were serious, and I have often wondered if a few simple horizontal divisions such as I have mentioned would have called his attention to the door and eliminated an accident. Probably many of my architect friends will consider me too conservative, but I feel that people are sufficiently important that their psychological problems, such as their fears, should be respected, and windows and vision areas designed accordingly.

If we accept the premise that the primary purpose of introducing transparent areas in the outside walls of our homes is for vision and not for the admission of light or ventilation, then the physical problems—the problems involved with the interruption of that vision —are extremely important.

I have just asked for glass to be divided in increments of approximately four feet by vertical dividers to provide safety to the homeowner, and I have asked for a horizontal division approximately the height of a chair seat. Such a wall should be entirely satisfactory in a living room. I would find it equally pleasant in a dining area and personally would have no objection whatsoever to its use in a bedroom, provided the lot development was such as to protect my privacy. The upper part of such a window might be unacceptable to some who want glass in smaller areas, also. I realize that in many homes a window of this type would not be satisfactory either in a dining or bedroom area and in few cases would it be acceptable in a kitchen. Therefore, what are we to do to reduce the size of individual pieces of glass without destroying our vision?

There is nothing more aggravating than to attempt to look out a window and discover that at eye-level there is a heavy, opaque interruption to your view. This might be frame, sash, sill, transom bar, or any other part of a window. If this opaque device is vertical, it is relatively easy to move from one side to the other and see around it. If, however, it is horizontal, it seems to have the uncanny ability to get between you and the particular point at which you want to focus your eyes.

A few years ago, Professor Kapple of our staff measured the eye-levels of a number of people varying from the junior-size miss in flat heels to men tall enough to create envy among basketball coaches. He found, while there is a considerable difference in the eye-level of people while standing, the difference becomes less when they are seated. There are apparently three zones in which horizontal obstructions are most objectionable. These correspond to the range of eye-level of people standing relatively close to the window —because if you are some distance away from the window the dividers become less important—second, the eye-level of people seated in dining-type chairs and third, the eye-level of those seated in lounge chairs. At first glance it would seem that this leaves the designer with a relatively small choice as far as the location of the horizontal divisions concerned. The situation is made somewhat easier if we assume we are designing windows for specific areas—one for the kitchen, presumably to be located over the sink, one

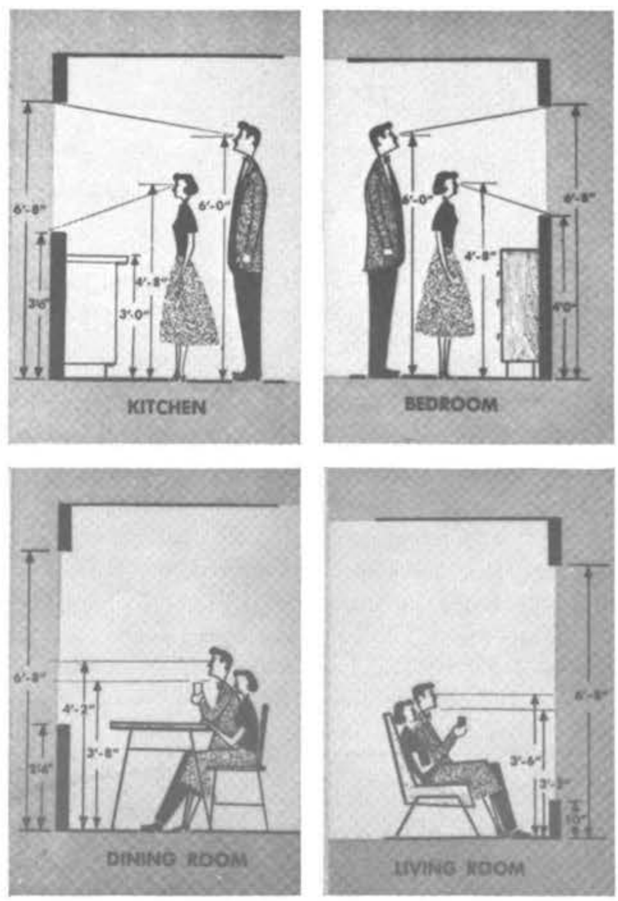


Fig. 4.3—Dimensions in the four sketches show the eye-level range for persons standing, sitting, and sitting at a table.

Fig. 4.4—Small Homes Council Laboratory showing windows on north elevation with ventilating units underneath fixed glass.

for a bedroom, a dining room, which might also be useful in a conservative-type living room, and one for a living room or family room.

For the kitchen and bedroom windows, only the eye-level of a standing person is of significance. The sketches show that one or, if desired, two horizontal divisions might be introduced without jeopardizing the distant view. Similarly, the dining room window, with a 2'-6" sill, can have horizontal rails, none of which fall within the limits of a seated person.

The view from the family room or living room is most important, and the only satisfactory combination is the one I first mentioned.

The sketches of these windows do not look at all like the windows that were used in colonial times. Neither do they look much like the glass walls which some architects currently are finding highly acceptable in custom built houses. They are, however, our interpretation of data obtained from a variety of sources, and we feel they represent a reasonable approach to window sizes for average families.

If you take my earlier comments seriously, you will assume that I would specify that all of these areas would be fixed glass. I would like to point out, however, that with the exception of the upper section of the living room window the glass sizes are such that they might all be operated, or at least the lower section in many of the windows could be an operating sash.

One of the problems quite unrelated to vision which we encounter regularly is how to install the glass in the house. I would like to endorse the comments that have been previously made on standardization of window sizes, and I feel that the construction techniques, the use of building components, systems wherein the window is actually the wall even though there may be

Fig. 4.5—Interior view of windows in faculty residence designed by Small Homes Council.

opaque sections above and below transparent sections, are the only feasible approach to truly integrated housing.

I am glad to see many manufacturers of windows changing from their old approach where limitations on the cutting of glass determined the ultimate framing opening in the house. As more and more manufacturers become conscious of the total approach to house assembly, we are going to find that the cost of glass areas in the wall will be reduced sufficiently so every home will have an opportunity to have major areas of unobstructed vision. If these areas, installed primarily for vision, should have as an incidental and collateral advantage the quality of admitting light, or even fresh air, I would not object too strenuously.

Discussion Period—RESIDENTIAL DESIGN APPLICATIONS

MR. CHATELAIN: I have an unsigned question here for Mr. Lendrum. Why insist on lower sash for ventilation? Or on lower sash bar for visual warning? Ventilation can be elsewhere. Glass can be spotted with painted decoration at wide intervals.

MR. LENDRUM: I won't argue. If you have a painted decoration, I hope that it is an interesting one, not just the "X" that they put across them under construction. But I think that it is entirely possible to have some sort of a division in there. It's like our space dividers—make you think there's a division there and there isn't. A good designer probably could do that.

MR. CHATELAIN: Another unsigned question: When you have lower operating windows only, do you have close-to-ceiling ventilators elsewhere?

MR. KECK: We would prefer to use ventilation well distributed. Our one major difficulty in the Middle West is, of course, as Mr. Greenwald mentioned this morning, our extremes of climate are very, very great. In the winter time no ventilation would be desirable, and in the summer time if you could open the entire side of the house it would be most desirable. We have got to find some kind of happy medium in between those two. We have found that, by taking smaller amounts of it which meet code requirements, but distributing them better, you can do a better job of ventilation.

MR. CHATELAIN: Another unidentified questioner asks: What is the attitude of the merchant home builders towards windows in general, large glass areas in particular? I might, on my own, add something and ask you what does the mortgage banker think of it?

MR. LENDRUM: Well, let's work it backwards. The mortgage banker is really the important one because if he doesn't like it the merchant builder's likes and dislikes aren't very important. I think I can answer that one best by, if you will pardon me, a personal experience. I live in a shed-roofed house with an overhang and a solid glass wall on the south that's about 70 feet long. After we built the house we had a coffee hour to which we invited one of my banker friends, and he took my wife to one side and said, "Do you think Jim could design a house for me that does what this one does on the inside and still looks like a house on the outside?"

V. W. WEIDMAN (du Pont Company): What are the limits on size for horizontally sliding glass panels?

MR. KECK: I don't know of any exact limited. We have used some pretty good sized ones, Arcadia and a number of others that are manufactured. I think it's actually a matter of how far can you go in spanning a wide open space without getting into trouble when the roof starts to deflect and puts some additional pressures on the glass. We have in our houses, however, tried to work on some sort of modular system where we do not span too great a distance horizontally unless there is some very special reason for it.

By Bruce J. Graham *
Skidmore, Owings and Merrill

OFFICE BUILDINGS

Structure and form help to stimulate human activity. Great architecture is conceived of as a form and not as a function. Man puts this form to function. I propose then that great architecture, like great art or great science, creates a new plateau of activity. It is this activity which is the function. Unfortunately, this is why many aged greats, not only in architecture but in science and art, are often descredited and misguided, for as sure as the process of death, their own creativeness is their undoing. Men cannot inhabit the world which they create, for they belong to one in which these ideas did not exist. The truly understanding artist or scientist is humble when faced with succeeding generations, the inhabitants of worlds more advanced than his own.

In the beginning, man found himself with more capacity and energy than required to sustain the process of life in a status quo. It is this which helps distinguish man from other beasts and which has brought him to such an advanced state of evolution.

Each world has been built upon that immediately preceding it and at no time can it be said that there was a necessity to change. However, by this ability to create new concepts and ideas without necessity, man has been able to expand his activities along paths not even suspected by man himself. Beginning with prehistoric man, the concept of architecture preceded its application with a function. The concept of a pyramid as a form precedes its use as a tomb; the great cathedral of Chartres far exceeds in volume any functional participation in religious services. So it is today, that man continues to expand his realm by conquest of ideas. However, our structure has, due to our large population and history of accelerating creativeness, become so complex that we cannot think in terms of single ideas or single men producing any individual change, but rather the works of various minds in various fields combining to produce new form, structure and abstracts.

In architecture, buildings are forms and structures conceived of in this day, not by one man, but by many minds and techniques. We conceived in the past century of the skyscraper and have applied to this structure many functions; hospitals, office buildings, residences, churches and the whole gamut of human activity. In fact, our history shows that these functions are interchangeable and buildings first used as hospitals may later be used as office buildings.

What is our technology? This is all the knowledge of man to date. It is the hands of our craftsmen on highly developed machines, the electronic computers operated by skilled engineers. It is not glass blowers in Venice, but the plate glass factories in Detroit and Pittsburgh. It is not wood cutters in Japan, but steel mills in Chicago and the Tennessee Valley. It would be folly to arrive at forms conceived by an individual, petty mind in violation of the progress of which mankind is capable. Search for form cannot be the "holy grail" of a self-sacrificing martyr. It is a process of cooperative activity. Today a chemist cannot progress in the field of medicine without the pharmacologist, the parisitologist, or the mechanized process.

An office building, then, is not designed or conceived for an individual function. Our clients themselves cannot predict what the function within its walls will be ten years hence. Not only does architecture change, but so does business. The character of modern business today is completely flexible and ever-changing. Today, unlike ten years ago, corporation is

* Bruce J. Graham, AIA, is an Associate Partner with Skidmore, Owings and Merrill, Architects. He is an architectural graduate of the University of Pennsylvania and has a Civil Engineering degree from the Case School of Applied Science.

assimilating corporation; men are using machines in offices to an unparalleled degree; accounting alone is an entirely different science. The experienced business man will tell you how much more the younger men understand the business world. So, the problem of office buildings is primarily a problem of controlled, flexible environment for men.

The form we must use is a space enclosed by materials produced by our craftsmen. These materials are changing every day as new ones make older ones obsolete. In the Inland Steel office building in Chicago (Fig. 4.6), we used materials which already are being replaced by others. On the exterior, we use a wall which can be fabricated almost completely in shops, where machines can best control quality and cost. We use materials which are almost completely self-cleaning and at least inert to the industrial atmosphere of nature around them. Glass today has passed from an individual craft to a product produced almost completely automatically, and which can be completely unbreakable. However, today it provides the least depressing enclosure, in that it allows man to live outside of a cave. It has posed problems of control of light. The new grey glass reduces glare, dual glazing reduces radiation, now in the making may be a glass which will reduce glare, heat loss and yet be simply fabricated, a transparent reflector. This will change form, however slightly. As a wall panel, it provides a large unit which can be placed in one operation.

There are many materials being used and developed for the opaque wall. These in turn must also have the same characteristics which we have required of the glass industry. Aluminum used as a skin to encase the fireproofing of structures must serve equally as well as stainless steel, as a self-cleaning wall. It must be fabricated in metal shops—the most common in the nation. We should look, as others have said, not only to our own industry but to the achievements in such fields as the automotive industry, airplane manufacturing, railroad construction and fixture shops. In fact, the building industry trails all these others, not only because of our lack of integration, but the pitiful lack of cooperative research.

In panel construction we are experimenting with a sea of methods and materials. For a low cost wall which can be used in the country, we specify precast concrete panels insulated and finished inside so as to provide a large section which can be installed in one operation. This panel, cast into stainless steel, we use in a city project. Sandwich panels of all sorts are being used, but cannot meet the fire requirements unless they are used as facing. The method worth experimentation is one by which this wall could be replaced in case of damage.

The concept of a completely sealed building has been facilitated by air conditioning. We have found that washing a building such as Lever House from the outside is an inexpensive operation, and one which permits washing the whole building, causing little disturbance to occupants and less leakage of air.

It follows, then, that our building form can be reduced to three basic elements: sun control glass for habitable areas, opaque panels for areas of undesirable views (either exterior or interior), and structure. The task is then one of developing these elements to perfection from a point of view of permanence and cost. The joint has been to date the biggest individual problem and, while sealers have been developed to prevent leakage almost permanently, the problem of coordinating the various crafts involved is still a serious one.

Our office buildings, like all other structures of today, contain other characteristics which distinguish not only office buildings, but modern buildings in

Fig. 4.6—Model of Inland Steel Company office building, Chicago, Ill.

general. We are now air conditioning our buildings, and finally are integrating this new type of air structure into architecture. As yet, a clear understanding of this creative force has not been expressed properly. Again in this field, it is because we are *able* to air condition that air conditioning is a necessity. And further, it is because we *can* control it to almost any degree of temperature or humidity that we are required to do so. New air systems are being devised almost for each building. Every new structure is different than the one before it. Not only do we handle a high velocity supply system, but at Skidmore, Owings & Merrill we are commonly using high velocity return systems as well, and this may well be replaced by the developments taking place at California Tech wherein handling air may become obsolete. This science is one in which architects have not had enough training, but I feel that it is unnecessary, since what we require is the understanding and respect of our very capable mechanical staffs.

Lighting is finally becoming a modulator in architecture today. In a sense, the proper use of lighting architecturally has not been recaptured since the Gothic cathedral and the Japanese house, where natural light for indoor space was converted into colored and diffused light. Today, it is not because the eye requires 100 foot-candles that we use 100 foot-candles, but rather because a fluorescent tube has made such lighting possible. Now that the primitive days of lighting are rapidly coming to a close, we think in terms of the luminous effect of a space, rather than the meter reading at a desk. The use of lighting in office buildings is now being thought of in the same terms as classroom lighting. Color of walls, floors, furniture and other reflectors is as important as the source of light. The eye itself has no limitation that can be read in foot-candles, for people can read outdoors at 1,000 foot-candles, given the proper color for both space and reading matter, as well as they can indoors with 30 foot-candles, again in the proper environment.

The office building distribution of power may be considered by some as unique to office buildings, but there is nothing which makes it different from what a residence should have, other than the cost. I do not propose to put electrical distribution in all buildings such as we did in the Lever House, the Inland Steel office building, or Chase Manhattan, but I maintain that the fact that these buildings are so equipped makes them more than office buildings. There are very few functions that cannot be held within those walls.

Elevatoring today has been one of the great contributions making possible the structures which form most of our cities. Office buildings, in that they are

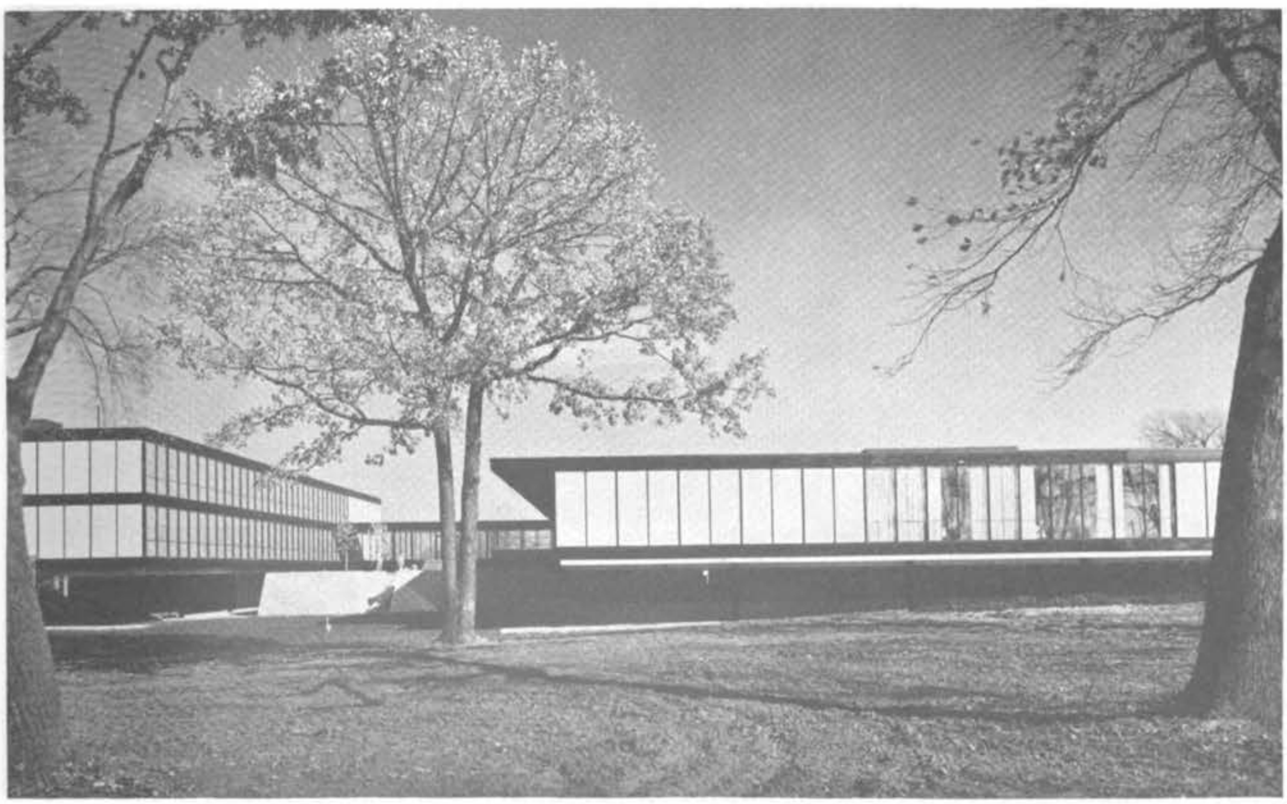


Fig. 4.7—Kimberly-Clark general offices in Neenah, Wis.

Fig. 4.8—Model of the Chase Manhattan Bank building in New York, N. Y.

Fig. 4.9—Model of the Warren Petroleum Corporation building in Tulsa, Okla.

one of our most diversified structures, are the best equipped.. Prior to these machines, multistory buildings inhabited by people were impossible. As they created new forms, society occupied the multistoried building. As a matter of fact, the primary limitation on the height of our buildings is the ability to equip them with elevators. But as these machines develop, limitations of height will change, not because one individual wants to build a big building, but because technology makes this form possible.

The respect which was the medieval builder's has been lost almost completely by vain dreams of individuality, personal acclaim and plain vanity. One of the most satisfying experiences is the unity of the Japanese architecture of five hundred years ago, an architecture understood and beloved by all. I am sure that this unity was the springboard for real individuality and freedom.

Subconsciously, our society contains all the characteristics necessary for such unity. In almost all other activities, we have found that reading the same books, driving the same automobiles and cooking the same food has not prevented truly great men and small workmen from expressing their own views and thinking their own thoughts. I have no fear of an architecture being produced within which we, as architects, are anonymous, for that is what we are today. However, an anonymity which prevents us from learning from each other, from building upon each other's thoughts, is far worse than an anonymity within which ideas grow from other ideas and freedom is expressed by intellectual activity at the forefront of the progress of man.

As it is now, some would have us take five steps backward whenever one man takes one forward. Professionally, it is our duty to present our clients with the best building we can build. This is the duty in which I feel all other participants in the building industry must share. Architecture will without a doubt be returned to the process of building engaged in by our whole technology. By this process of conceiving of the industry as one which builds structures, and not specialists in a function, we are able to understand best those characteristics which all buildings have in common. We cannot then allow ourselves to violate structural principles, mechanical requirements and spacial order as easily as the specialist, who sacrifices all for function and whose activity is frustrated as soon as anything is changed even the slightest. Furthermore, by studying various functions, we have been able to interchange ideas to the benefit of our clients.

Architecture of the office building has been, because of all of these characteristics, the most important contributor to the art today, and further, to the understanding of the new forms evolved by man.

By Morris Ketchum, Jr.*
Ketchum, Giná & Sharp, Architects

COMMERCIAL INSTALLATIONS

The exterior walls of commercial buildings such as specialty shops, chain stores, and department stores, have a dual function:

(a) To enclose and protect the interior sales and service spaces of the store building.

(b) To admit or exclude vision, light, air and the public in accordance with calculated provisions for advertising and display.

This dual function applies to any type of store building, whether small or large, one story or multistory.

The over-all design of the enclosing walls of a store building should, in itself, by its form, shape, pattern and color create trade mark identification for the business contained within. The design can also be broken down, in its second function, into at least two zones—advertising and display. Sometimes, as in the case of a one story store front, these zones are merged into a single unit; sometimes, as in the case of a multifloor department store, there is a separate display zone at ground level and an advertising zone formed by the upper walls of the building. In either case, advertising and display elements are closely interrelated.

Glass plays a vital part in both the advertising and display zones of any store building. Without glass, it would be impossible to display merchandise to public view and at the same time protect it both from the public and the weather; to make a store entrance open and inviting; or to throw open to public vision an entire sales floor. Without glass, sales departments needing natural light for merchandise inspection could not function. Without glass, doors, vestibules, lobbies—the contact point between window shopping and actual buying—could not be made spacious and inviting and minimized as a visual barrier between sidewalk and sales area.

The uses of glass in the display zone of the storefront vary from transparent glazing for shadow box displays (Fig 4.10), show windows and entrance doors to entire walls (Fig 4.11) of transparent, translucent

Fig. 4.10—Store for Ed Steckler, Inc., New York, N. Y., 1939.

* Morris Ketchum, Jr., has been a partner in the architectural firm of Ketchum, Giná and Sharp for 12 years. Prior to this, he had an individual practice for 10 years. He attended Columbia College and holds a Bachelor of Architecture degree from Columbia University School of Architecture. He also studied at the School of Fine Arts in Fontainebleau, France.

Mr. Ketchum is a member and Fellow, American Institute of Architects. He has served as Chairman of the AIA Committee on Research and also of the AIA Committee on National Defense. He has been Vice President of the Architectural League of New York, a member of the Board of Governors of the New York Building Congress, member of the Municipal Arts Society of New York, a Trustee of the Beaux-Arts Institute of Design, and a member of the Subcommittee on Housing and Neighborhood Improvement of the Mayor's Advisory Council of New York City.

Fig. 4.11—Street-level gift department of Hutzler Bros. department store, Towson, Md.

or opaque glass panels. The chief function of enclosing walls within the display zone is to admit vision. Translucent or opaque walls are therefore comparatively few in number and are used to provide contrast value to the visually open portions of the storefront, to frame the entire storefront and the walls and ceilings of storefront lobbies or to conceal an undesirable view of some sales or service area.

Transparent glass walls of almost every type are usually glazed with a single thickness of 1/4" plate glass when glass panel sizes are not over 12 feet in any one dimension. It is only when glass sizes exceed this dimension in width or height that 3/8" or 1/2" plate glass may be required in order to withstand wind pressure and buckling. It is advisable, however, to stick to standard 1/4" thick glass sizes both for initial economy and to avoid extra replacement costs. Overlarge panes also require specially designed and fabricated glazing members at extra cost. Such extra expenditure is only justified if unusual circumstances and an unusual design solution logically demand large scale glass divisions.

Fifty years ago, wood glazing members were universally used for storefront work—today, they are the exception and not the rule. Metal glazing members are in almost universal use. They do not swell or crack, bend or break under severe weather, thus cracking or breaking their glass panes. Metal members can withstand almost any weather condition, require very little maintenance and are capable of holding plate glass in place without undue danger of breakage.

Metal glazing members can be fabricated from steel, stainless steel, bronze or aluminum. Steel glazing is least expensive initially, but must be painted and repainted; stainless steel has little or no upkeep, but is highest in initial cost; bronze has a rich, handsome appearance, but is next in cost to stainless steel and requires constant maintenance; aluminum is handsome, reasonable in cost, and easy to maintain. Hence, aluminum leads the field in storefront glazing.

New aluminum finishes have recently been introduced. They include a natural dull gray finish available in cast aluminum, porcelain enamel on an aluminum base, and anodized aluminum in a variety of colors. So far, these new finishes have not been generally used for storefront glazing. In my opinion, they should be, because their use would open up a new vocabulary of design in that field. Dull gray natural aluminum, for example, would not have the shiny, reflective surface of conventional storefront glazing and would not compete as much for attention with show window displays. Aluminum in color could add graceful charm to a storefront if well handled by a competent designer.

Whatever material is used, the basic operating parts of a glazing molding consists of a fixed member, a removable member and a tightening device (Fig. 4.12).

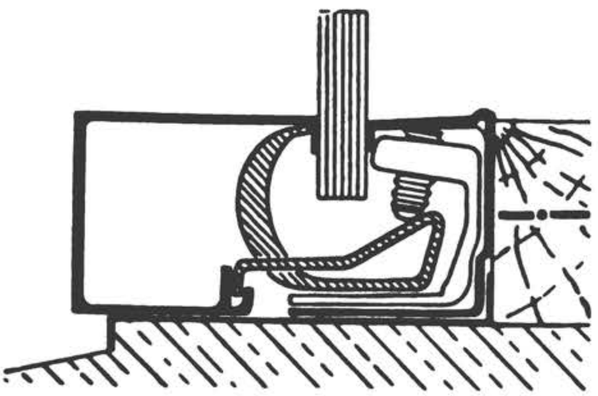


Fig. 4.12—Typical Glazing Molding. (Courtesy of Kawneer Co.)

The fixed frame establishes a permanent connection between the glazing molding and the fixed structural members, or surface of the storefront. The removable member can be taken out to allow glass to be installed or replaced. Both together hold the glass pane in place. The tightening device—either putty or a resilient metal lug—is used to ease the tension between glass and glazing molding. It allows for normal expansion or contraction of the glass panel caused by changes in temperature and for movement caused by wind pressure. Putty is less practical for this purpose than metal as it dries out over the years and loses its resiliency.

It is preferable to glaze a shadow box display case, a show window, or an entire storefront from the outside so that the display areas within are not disturbed when glass is replaced. Therefore, the resilient metal lugs forming the tightening device of the glazing molding are usually held in place by set screws located in the outside removable frame. Sometimes this frame also forms the exterior finish of the glazing molding; sometimes, it is covered with another removable finish frame designed to slip over the first removable molding and to be held in place by another set of resilient lugs, thus concealing the exterior screw heads.

A glazing molding can be used in one of two ways—as an applied or as a built-in molding. While both uses are identical in their operating functions, they vary widely in appearance and in application to storefront design.

Applied glazing moldings are essentially ornamental in character. Their visual function is to act as a "picture frame" enclosure for a show window or store front, or to divide a store front into a series of well proportioned modules. This decorative use is reflected in the multiplicity and variety of stock styles and shapes on the market—from small, neatly formed shapes used to give a crisp accent line to large, bold

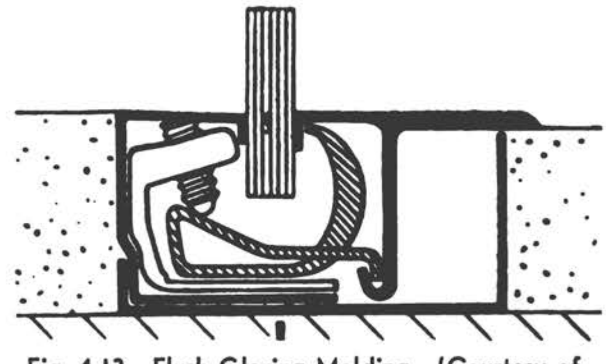


Fig. 4.13—Flush Glazing Molding. (Courtesy of Kawneer Co.)

moldings capable of dominating an entire storefront.

Built-in glazing moldings are used to minimize visually the junction point of a glazed surface with an opaque surface. This treatment carries the observer's eye quickly and directly into the display area within the enclosing glass, whether it be a show case or an entire storefront. The practical and direct way of effecting this is to use built-in flush glazing. Applied glazing moldings interrupt the visual continuity of any surfacing material; flush glazing moldings (Fig. 4.13) are inconspicuous and self-effacing.

Flush glazing can be used successfully at the intersection of any glazed surface with an adjacent wall or ceiling surface. It is impractical to use it by itself as a glazing member at the floor line or around all four sides of a glazed opening. The fourth side must have an applied glazing member in order to permit installation or removal of the glass panel.

Large glazed wall or show window openings need some type of bulkhead (Fig. 4.14) at the floor line

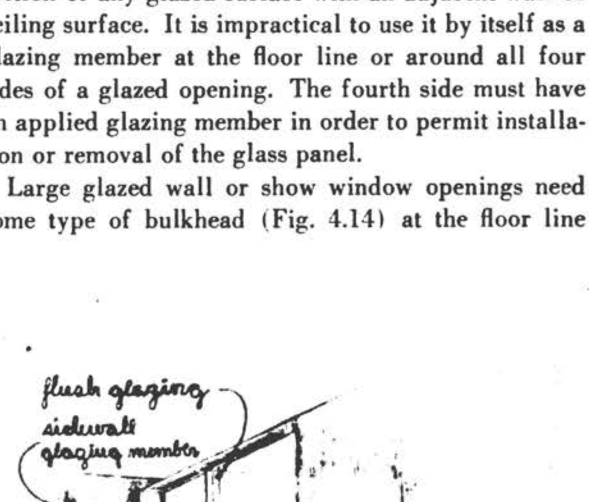


Fig. 4.14—Bulkhead and Sidewall Glazing Member. (Courtesy of Kawneer Co.)

to protect them from damage. A bulkhead may vary in size and shape from a low kick plate to a high platform. By using a bulkhead combined with sidewall and ceiling glazing members, corner mitres can be avoided and the field assembly of the storefront immensely simplified.

In any large and uninterrupted glazed wall, it is necessary to use division bars (Fig. 4.15) in order to keep the glass panels down to standard size. A typical division bar consists of two glazing moldings held in place by a rigid structural member. In a sense, this assembly acts as double flush glazing. The outer appearance of the division bar can be fairly arbitrary. In comparatively low storefronts where vertical division bars above are required, the entire bar can be scaled down to a minimum size and an inconspicuous appearance. Where both vertical and horizontal division bars must be used, (Fig. 4.16) both must be heavier in section and larger in over-all size—the horizontal bars, in order to carry the weight of the glass panels; the vertical bars, in order to carry the weight of both the horizontal bars and their glass panels.

Door frames are actually division bars strong enough to take the weight of any adjacent glass panels and the weight of one or more entrance doors. Built-in door checks concealed in either the top member of the door frame or else in the floor, plus a top or bottom pivot, have superseded side hinges. Such door checks make it possible to use multiple entrance doors without

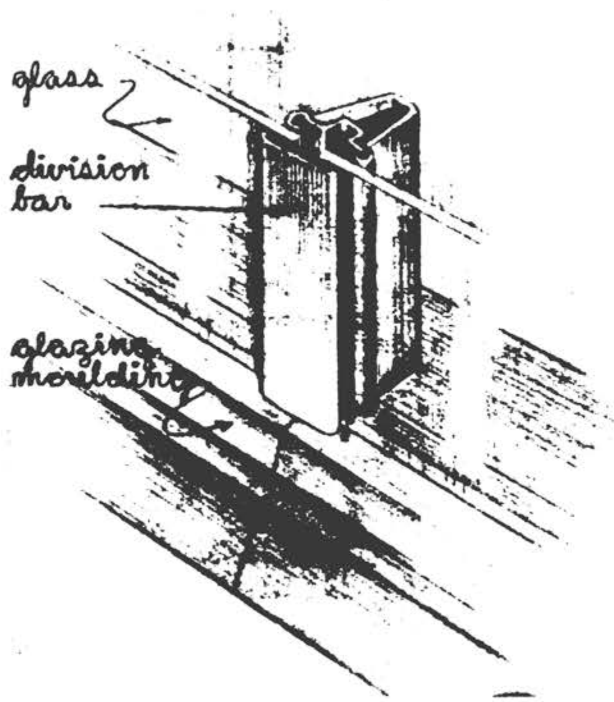


Fig. 4.15—Division Bar. (Courtesy of Kawneer Co.)

Fig. 4.16—Showroom for Artek-in-New York, New York, N. Y., 1943.

intermediate frames. The action of the door check eases the usual strain on the door frame. It must also be strong enough to resist sway and consequent glass breakage.

In the average storefront, there are two basic methods of designing a door frame. One method is to extend the side members of the door frame from floor to ceiling, creating a fixed or movable transom over the door, and to secure them to the structure of both floor and ceiling. Where this type of door frame is located fairly close to a side wall of the storefront, the vertical member of the door frame nearest to the side wall can be stopped at the door head and the top member carried over and secured to the side wall of the storefront. Another method is to mitre the vertical members of the door frame and carry them across as a top member without carrying them to the ceiling above (Fig. 4.17). To do this, the concealed vertical structural members of the door frame must be carried through the floor construction and braced horizontally

Fig. 4.17—Store for Plymouth Shops, Inc., New York, N. Y., 1945.

Fig. 4.18—Entrance doors for Hahn Shoe store, Washington, D. C., 1946.

against lateral sway by means of structural anchorage placed beneath the floor slab.

Door frames, like glazing moldings, can be built into the door assembly. If a solid door or doors, with or without a small vision panel, is used, the same finish used on the door can be carried over the door frame as well. This type of door can have monumental character and distinction especially when used in an open storefront. More often, storefront doors are used to admit rather than to exclude vision (Fig. 4.18). Glass again—this time tempered glass—makes this possible.

Show windows, doors and signs are the principal elements of a storefront. In one-story store buildings, they and their enclosing walls and ceilings form the entire storefront and its merged advertising and display zones (Fig. 4.19). In larger, multi-floor commercial buildings, typified by multi-floor department stores, the upper floors are seldom used for display, but are sometimes used as advertising billboards—in other words, as sign backgrounds. Where such buildings occupy corner lots or free-standing sites, the shape and exterior finish of the building become an even more important architectural and advertising medium.

These upper walls seldom need large glass areas. Glazed surfaces are restricted to wall areas adjacent to those few sales departments where natural light is

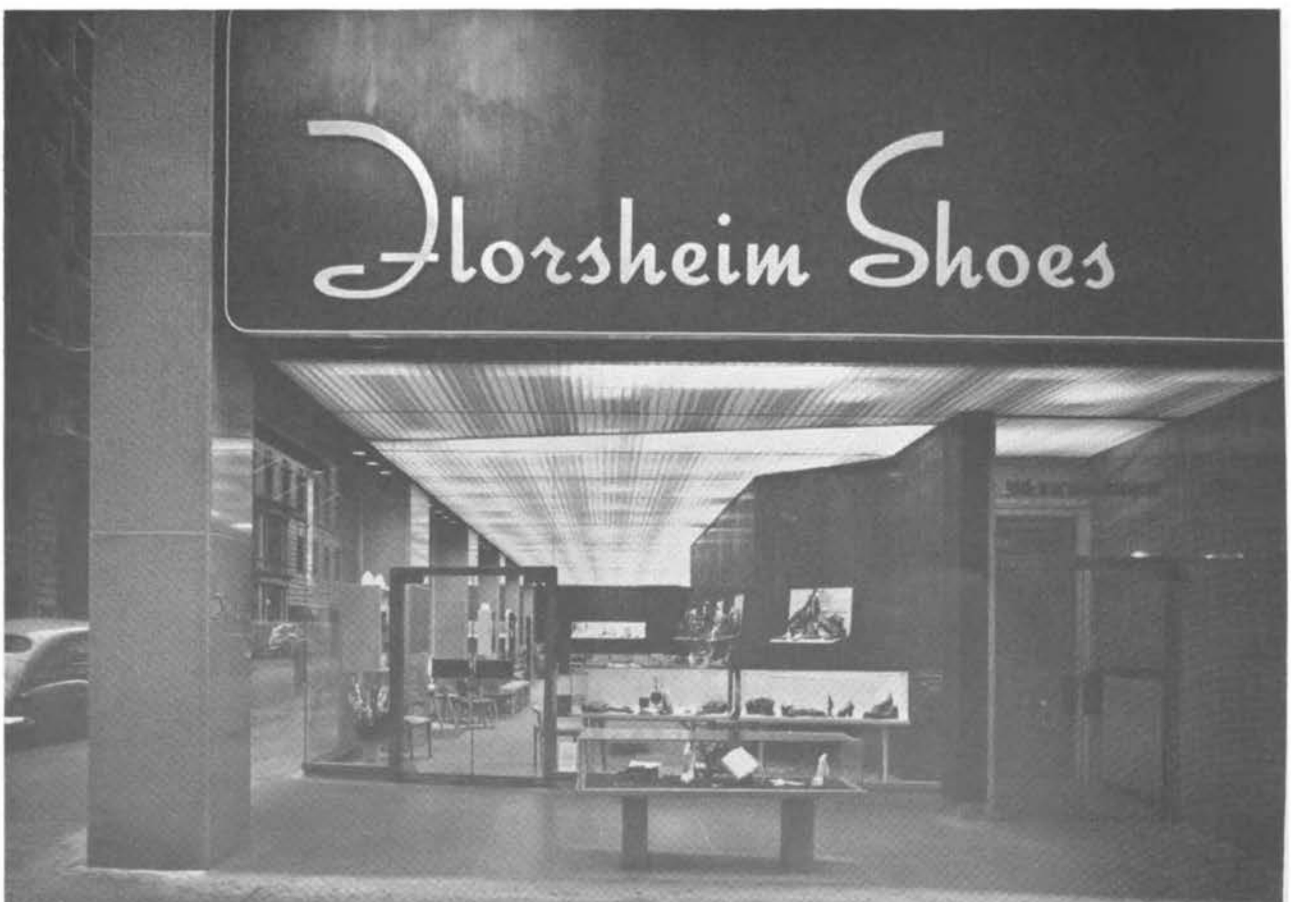


Fig. 4.19—Florsheim Shoe Salon, New York, N. Y., 1947.

desired for merchandise inspection, to administrative and service areas, and, if there is a view, to the store's restaurant. With good artificial lighting and air conditioning, department stores have become almost windowless.

What fixed windows they have, however, should be able to follow changes in location of interior sales departments or service elements. Obviously, this can be accomplished by major changes to the outer walls, but it is preferable to use a modular panel wall system for the building, so designed that any wall panel can be interchanged with any fixed window panel. This approach adds flexible glazing to the flexible planning, sales fixtures, lighting, and interior walls and ceilings, which all help to meet the changing functional demands of merchandising.

Plate glass in the large sizes used today only dates from the middle of the nineteenth century; its modern application to commercial buildings has evolved during the last forty to fifty years. So all of the forms and procedures I have just outlined are subject to change without notice as new materials, new techniques and new design ideas arrive on the scene. Ours is a live architecture, still in process of development, and that is what gives it its vitality, its excitement and its never-ending interest.

By Alonzo J. Harriman *
Architect-Engineer

SCHOOLS

The types of glass that this paper will treat are, mainly: insulating glass, glass blocks, skylights, safety glass, structural glass, tempered glass and colored.

Immediately after the war, 1946-47, all school architects in the country were working and scheming with natural light in classrooms and there were about as many different ideas of how to light elementary school classrooms as there were architects. This was all caused by an article by Dr. Hamons of Texas which blamed poor school lighting as the cause of many student physical ailments, so all school architects, young and old, tried to be first in developing the perfect classroom light-wise.

There was at this time another force affecting the design of elementary schools and classrooms. California, due to its code for structural design able to resist earthquake shock, had developed a one-story school, typical of California. They informed the rest of the world that they had developed the school to end all schools that could house the new activities of an elementary school teaching program. Now mind you, the Californians did not say that bad word "earthquake" in referring to the advantages of the one-story school, but actually this was the necessity that was the mother of invention of the one-story school.

The above statement, relative to California and the one-story schools, is not intended to be detrimental or super-critical, but is brought out to prove that local conditions, social, climatic, financial and others, should be considered in the design of school buildings. To date we have not considered the local factors enough in designing our schools, and we are apt to use the school designed for California as the model for a school in Maine.

It is by the complete analysis of the problem through research that the amount of glass in schools should be determined. In this large country of ours the amount and orientation of the glass should vary. There is no sense in putting large areas of glass in schools where the sun only shines 40 per cent of the time and, even on those days when the sun does shine, the daylight hours are less than the school hours, so daylight becomes the auxiliary rather than the main source of light. It is equally as bad to build an all-glass school in the middle of a glaring desert where relaxation comes from shade.

In other words, a good school design should be functional and the use of materials should be honest, not forced, or they may receive adverse criticism which could stunt the future use of what might be a very good material. Designers are sometimes prone to force the use of a new material which has not been properly tested and the result is an unsatisfactory structure.

A great many states have codes or laws that establish certain minimum requirements in school design, and some relative to the amount and location of the glass in school classrooms. The typical law states that the glass area should be 20 per cent of the floor area, that it should be six inches from the ceiling, and that the ceiling height at the windows should be one-half the width of the classroom, if unilaterally lighted. Figure 4.20 is a typical example.

Since the war most states have changed this law and it is only necessary to have enough glass for a pleasant environment. The ceiling height is determined by the height of the luminaire or lighting fixture. It is inter-

* Alonzo J. Harriman is an architect and engineer whose offices are in Auburn, Maine. He has degrees in mechanical engineering and architecture and has been a practicing architect since 1928. He is a member of the Illuminating Engineering Society, the Harvard Engineering Society, the American Association of School Administrators, the American Institute of Architects and the AIA Committee on School Design.

Fig. 4.20—Lewiston High School.

esting to note that at the meetings in New York State where this rule relative to natural light was changed the eye doctors present all agreed that there was no deleterious effect on the eye from either incandescent or fluorescent light. This change in the rules has, of course, made material changes in the use of glass in schools and we now have some very good schools with interior classrooms. (See Fig. 4.21.)

There are many conflicting ideas as to the use of glass and exposure or orientation. I have my own ideas, which may be rejected by many, but offer them for what they are worth.

1. Region has a definite bearing on orientation of glass, if environment is a major consideration.

2. In cold climates, 100 per cent north exposures, though they may produce the most uniform lighting, are not pleasant during the winter months unless glass is used where sun will shine into the rooms at some time of the day.

3. West orientations are preferred to north in cold climates, but are not as efficient as east or south, due to overheating in spring and fall.

4. In warm climates, north orientation is generally preferred, with 100 per cent shielding of all sun rays on other exposures.

I am one of those who recommend sunshine in classrooms in the northern part of this country even though

Fig. 4.21—Interior typing room in Hillsdale School, designed by John Lyon Reid.

the design may then not conform to the ideal seeing condition of limited brightness ratios. Sunshine during the cold months helps to create a pleasant living environment, and this is our primary consideration.

One subject that should be further considered relative to orientation and glass exposure is ground cover and its effect on classroom environment. We have ground cover ranging from dead black asphalt of play areas with practically no reflection to the same areas covered with clean white snow and almost 100 per cent reflection. Should we have colored glass for glare reduction in screens, or shades that are transparent and not translucent, and thus are not cloistering?

We have just mentioned insulating glass in passing but I should like to discuss here some of our basic thinking. We have found that use of double glazing insulating glass or glass blocks helps materially to reduce the fuel bill and that it pays the greatest dividends during the night hours. (See Figs. 4.22 and 4.23.) We say in our office, although it is not a 100 per cent true statement, that a school heating system should be designed for the unoccupied hours, as this is apt to be the time of greatest fuel consumption. On an average winter day with outside temperatures 10 to 25° above, and an average wind velocity of 10 miles per hour, solar heat and body heat have proven more than enough to offset the heat loss from the building, with mechanical ventilators running from 9 a.m. to 3 p.m. except when doors were open and students were at recess or lunch.

We carried on some experiments with insulating cloth (millium) for shades and drapes. There was no doubt that they made a much pleasanter environment physically due to reduction of the negative radiation from the cold glass, but we were not able to carry the experiment to a definite conclusion as far as fuel savings were concerned.

The use of skylights in schools is illustrated by Figure 4.21 showing the Hillsdale School in California, which is known as a loft type and was designed by John Lyon Reid.

Safety glass is being used in a great many ways and places where children and playthings come in contact with transparent or translucent walls (Figs. 4.24 and 4.25). The type of glass used varies with the architect and use, but both safety and tempered are used. We

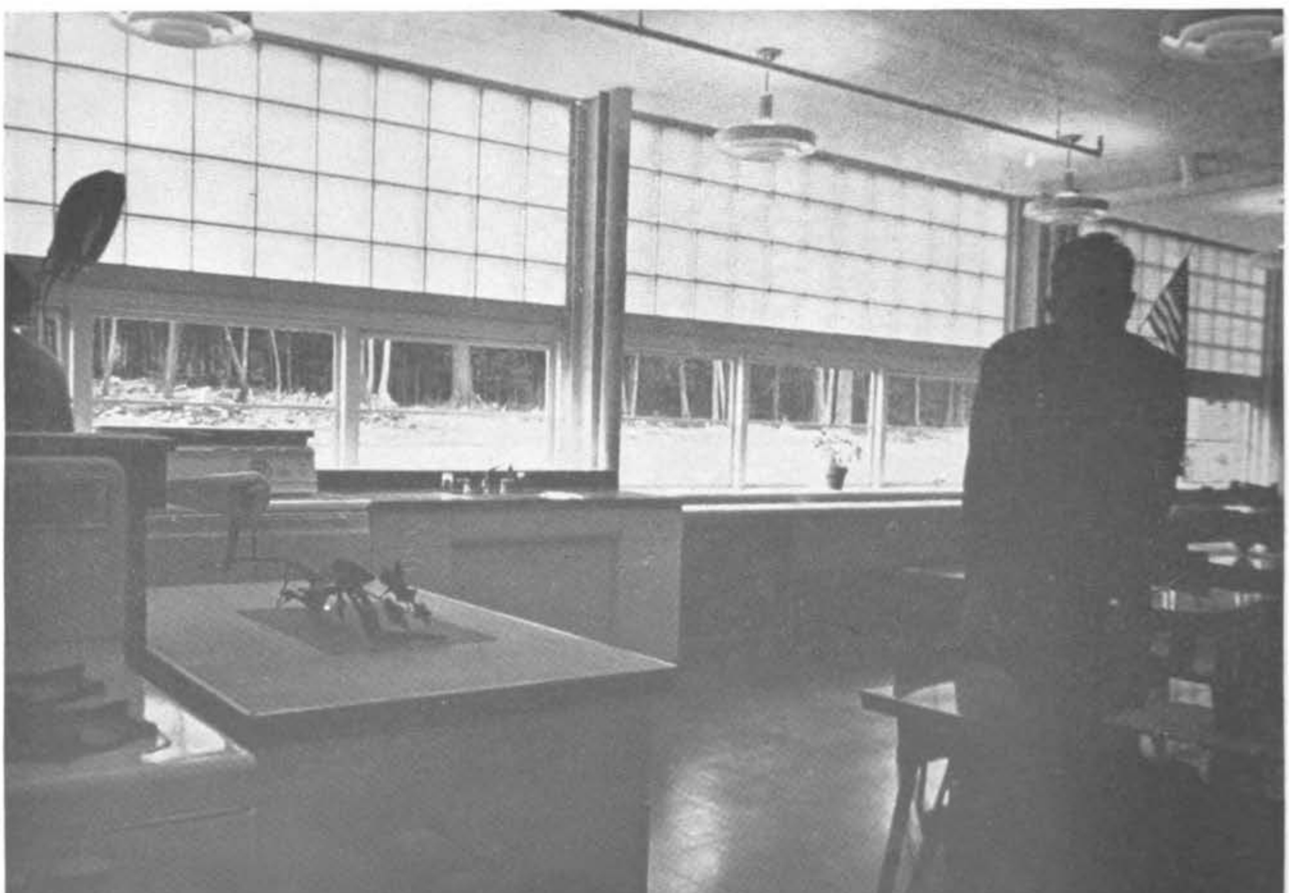


Fig. 4.22—Use of glass blocks in Old Town High School.

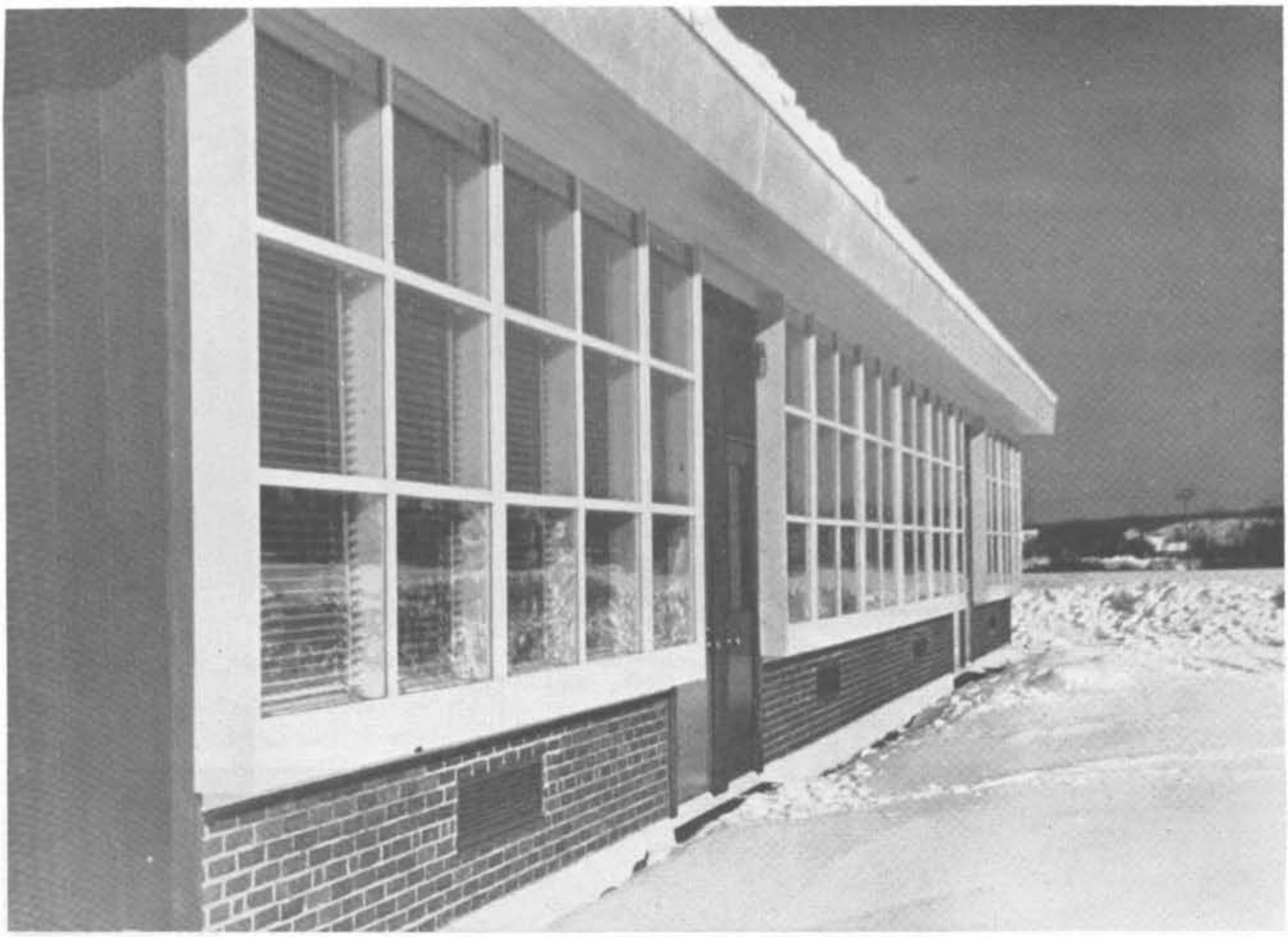


Fig. 4.23—Use of double glazing at Millinocket School.

have recently had brought to our attention an imported safety glass that is also colored, the color being in the middle plastic lamination.

We are now designing a school using tempered, colored, insulated glass for weather protection to replace enameled iron. The insulation is an aluminum coating on the back.

Colored glass in schools is in general of two kinds, one serious, the other playful. The serious use is of tinted glass the color of sun glasses to reduce glare in classrooms and give a more ideal seeing environment. Colored glass is used playfully in kindergartens and sub-primary rooms to color the sunshine coming through the windows and create colored patterns on floor and walls. (See Fig. 4.26.) It is also used to color the world around the school so that the children can look through the colored glass and see a blue or rosy hue.

Fig. 4.24—Use of safety glass in Washburn School, Auburn, Me., designed by Perkins and Will.

Fig. 4.25—Safety glass used in gymnasium of Blythe Park School, Riverside, Ill., designed by Perkins and Will.

Fig. 4.26—Colored glass panels as used in Heathcote School, designed by Perkins and Will.

DESIGN APPLICATIONS

By Thomas A. Bullock *
Caudill-Rowlett-Scott & Associates

In designing for glass and windows in a building in the past, most of us have taken the traditional approach of accepting a certain shape and adapting it to the need for light, air, and view by punching holes in it. This was our school.

The classroom had a floor, ceiling, three solid partitions, and an exterior wall punched with windows and a sill height just high enough to eliminate the students' vision outside . . . although not successful in eliminating their curiosity. The gymnasium was about the same, except a larger box with maybe two walls punched full of holes, located high in the wall.

This approach to design was of obvious concern when we immediately found that shades to cover classroom windows, and paint for gymnasium class areas were necessary accessories to the design. This approach was encouraged by tradition and limited technology permitted it. We know that this approach when applied to school design cannot result in a humanistic architecture or a place for learning in which the atmosphere is friendly to the child.

From our experience with school people, we know that the educational program cannot be "fenced-in"; it requires flexibility. The architecture must help the child grow physically, mentally, and socially. To do this, it must be healthful, functional, non-confining and colorful.

The learning experience does not stop at the exterior wall line, but is obtained on the outside as well as on the inside. In fact, we have found that certain experiences are better acquired on the outside. One school superintendent has said that a good teacher could teach better under the shade of a tree than inside a building, if the weather was perfect. The part about the weather is the catch, of course, but why not consider this as the starting point for developing a new approach, a spacial approach?

With modern materials and methods, we can allow for the fact that space is fluid, without end, and without an inside or outside. With glass and windows, we begin with nature, its spaciousness, view, light, and air. Certainly technological advances have made larger lighting and ventilating holes possible. The spacial aproach can provide a classroom with built-in outside learning environment without worry about the complexities of weather.

Let's try out this new approach by starting with a class—not a classroom. The place is outside in an open field. The class might be studying academic work or playing basketball, for if the temperature, breeze, view, are just right, and the sun is behind a cloud, a teacher could teach, children could learn, and they would love it.

Since outside conditions are always changing, we have to be prepared for sky glare and rain by providing a roof, or umbrella. A fully developed umbrella might require skylighting to raise the light intensity brought on by the induced shade.

To this point, we have conceived only an overhead protective plane. This might be enough for some mild climatic region, but in most areas, and certainly in the southwest, we have wind—lots of it. Now, we must plan a vertical screen as a wind break. It could be at the wall line or away from it, just so it is effective in directing the wind over or around the children.

We must also consider sound, even in the mild

* Thomas A. Bullock is a partner in the firm of Caudill-Rowlett-Scott and Associates of Bryan, Texas, and Oklahoma City. He has been associated with this firm for the past eight years in the design of more than 150 school projects. He is an architecture graduate of Texas A. & M. College and was formerly an instructor in the Department of Architecture at that school.

Fig. 4.27—Glass enclosed corridors and clear glass floor to ceiling, Southwest Elementary School, Clinton, Okla.

Fig. 4.28—Classroom separated from exterior window wall by glare-reducing glass screen.

Fig. 4.29—Umbrella school—wide overhang for sun control and protection of play area, Washington Elementary School, Clinton, Okla.

climate regions, because sound occurs anywhere, and must be considered in design. So, why not a vertical screen to control sound as well as wind?

When colder weather comes, the children must be provided with a thermal screen, so now the vertical wall or screen is required to control wind, sound, thermal conditions and, certainly, view.

In order to provide a screen that will take care of all of these items, we must conceive of a plan that will have convertibility, expandability, and versatility. Remember that the educational program for our children cannot be "fenced-in," and accordingly, demands flexibility.

Such a screen might be one material, but will probably be a combination of materials. We would be the first to agree that an all-glass classroom would need the help of other materials such as brick for the sake of aesthetics as well as functional requirements.

Now if we have really explored all of the possibilities of this approach and have carried them through to the finished solution, we will have a school with all the advantages of the outdoors and controls necessary to maintain the desired environment.

A look at some of our solutions resulting from the spacial approach reveals a large floating cover with vertical wall planes slipping into and projecting outside of the enclosed space. Our experience with glass has been good, and we believe it has made a real contribution to our architecture, but it also has some disadvantages and presents some problems which have not yet been solved. We still have our troubles in integrating a good heating system in a glass school, but it can be done.

The standard question concerning glass breakage has been pretty well answered by the use of tempered glass in the all-glass walled gymnasium of our Tyler (Texas) Junior High School. Long overhangs with high daylight intensity introduced to the playing court by skylights helped eliminate sky glare. The Casady School Gymnasium (Oklahoma City, Oklahoma) has two solid walls of glass and two walls of brick because of orientation and aesthetics. We have reason to be-

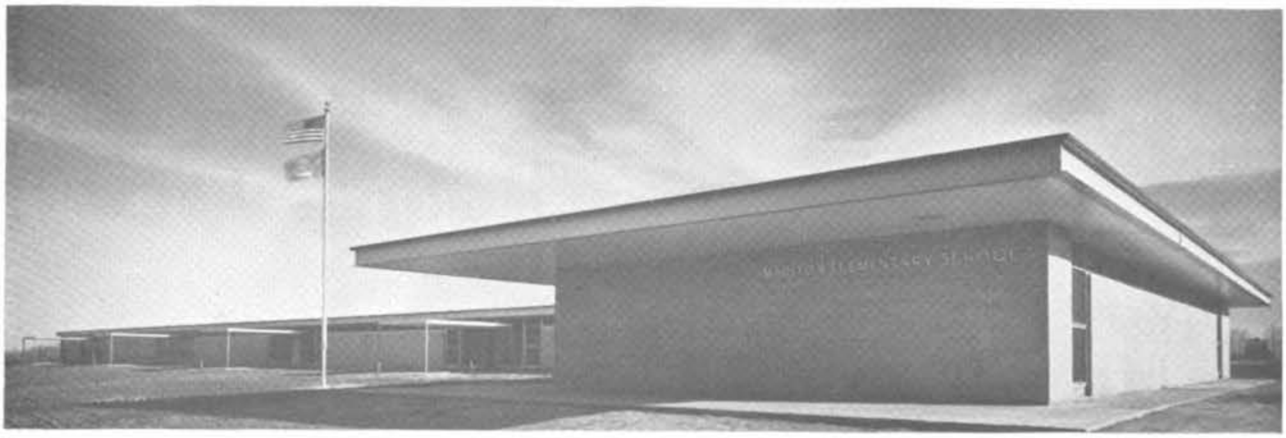


Fig. 4.30—Use of high brick walls on north and west with small glass area for light distribution, Madison Elementary School, Norman, Okla.

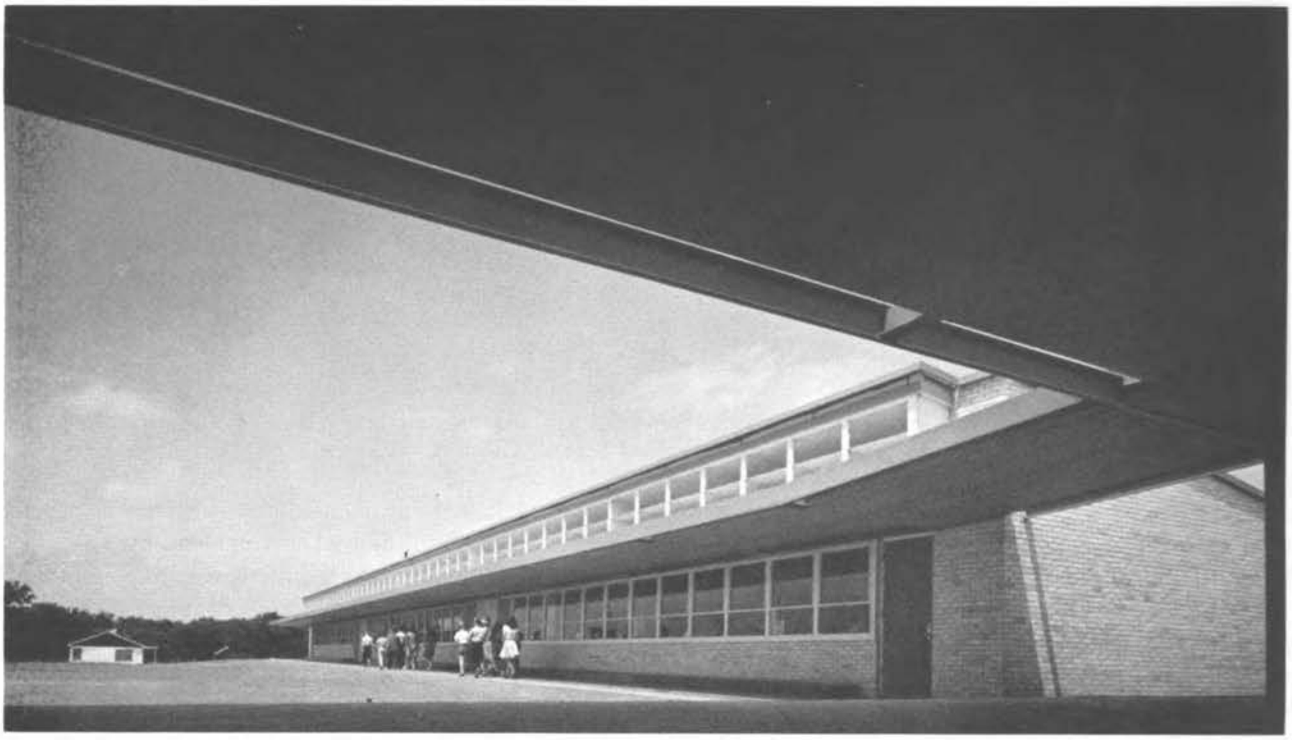


Fig. 4.31—Low glass area used for visual aid and light, protected by overhang; high glass area used for light only with interior horizontal sun control louvers, Westwood Elementary School, Stillwater, Okla.

Fig. 4.32—Combination of clear and glare-reducing glass with roof overhang, Norman High School, Norman, Okla.

Fig. 4.33—Small and large glass areas used together with ample overhang to provide sun and rain protection, Elementary School, Port Arthur, Tex.

lieve that the larger glass sizes are less tempting to break, but we are also concerned that in smaller communities glass is not stocked in large sizes, and delay in replacement causes disruption of the school program.

Glass, as well as any other material, must be used properly in a building. What might have worked in one school might not work in another. A wide roof overhang for glass protection may provide excellent sun control when the school site is surrounded by trees, but when the site is surrounded by an endless prairie, it may have the opposite effect.

Outside walls of glass have brought some objections from visual education teachers. To remedy this, we have just designed our first "room within a room" classroom. In other words, creating a darkened area within the room itself. However, let's keep in mind that glass is visual education in itself. We know that glass provides for children's observation of the weather, of growing things, and also an opportunity for parents to view them at work.

When a classroom is a display case, the students' conduct is better, the teachers' morale is higher, and the continual observation of their activities by other students and teachers builds a fine competitive spirit between classes. Glass, in the exterior walls of a school, can be as much a part of the learning process as a piece of chalkboard.

Discussion Period—DESIGN APPLICATIONS

A. H. FIEDLER (Rust Engineering Co.): Have you had leaking problems with glass blocks in roofs? Have you made provision for loss of light when panels are covered with snow?

MR. HARRIMAN: We have had no trouble with glass blocks in skylights because we haven't used any yet. Those I showed you were somebody else's. The reason is that my uncle and his father were both architects. My uncle won a competition for a school in 1916 that had a lot of skylights in the center of it, and the auditorium and the gymnasium were one over the other in the center of the building. Let me tell you that was the biggest headache that I had in my life. I succeeded my uncle, and I boarded up all the skylights. But to answer the question, as with the pointed roof, it is never the roof that leaks, it is the flashing. The same thing is true of the skylights.

T. W. MOORE (Eastman Kodak Co.): In multistory, air conditioned structures having fixed, non-operable windows, what provisions have been made to provide ventilation during shutdown of mechanical equipment because of an emergency or for maintenance?

MR. GRAHAM: The air conditioning system that we design today consists of a number of parts, and probably the most important part is ventilation—which is the fan system. We divide a building up into sections fed by more than one fan, so that at no time is a building deprived of ventilation, except on electrical failure through the whole area. However, electrical failure in our cities today is so slight it isn't worth considering. In that case it is taken care of by emergency generators, and you also have two fans for every duct system.

M. D. FOLLEY (Architect): One of the best media of teaching today is the use of visual aid materials such as opaque projectors, slide machines and movies. How do you provide "brown-out" for this in the ordinary classroom, not the assembly room?

MR. BULLOCK: It is the cumulative thinking that school people like to get the children up out of their seats and keep them moving. That is why we have created, in some schools, theatres for the use of twenty, thirty or forty—they are small theatres for visual aid. We created a small theatre in a block of classrooms. In other places where we have top light, we haven't got the answer yet. Maybe technology will show us the way. We feel that natural light is very important and have all of our interior classrooms daylighted. Each classroom has glass partitions and fixed glass for about three feet all the way around it. One teacher has devised a way of putting blinders on his children, and visual education is carried on in that way, but no definite solution is available to the problem.

MR. CHATELAIN: Mr. Harriman, what do you do, in the main, about this?

MR. HARRIMAN: We don't have the problem of the skylight, but we have the sidewall, which we cover by use of shades, venetian blinds or drapes, so we can darken the classroom enough for projection. In our experiment with these millium shades, we found that they did an excellent job of darkening and also did an excellent job of insulating.

J. H. TURNER (Hires-Turner Glass Co.): You spoke of the use of two separated sheets of glass—do you have a condensation problem in such an installation? How much air space do you allow between the two sheets?

MR. GRAHAM: We have found the trade-term "plioform." This material is very flexible and retains its flexibility almost forever. It was used in the air-foam industry prior to the building industry and it seals the glass very well—completely, as a matter of fact. It is very adhesive and adheres to both metal and glass—so closely, as a matter of fact, that it is quite a job to use the material. I might add that we use a space of about an inch between the two sheets. This isn't a product of Skidmore, Owings & Merrill, but it is a product that the industry has developed that we are using. Its cost is comparable to glazing—at least in the last job the bids were exactly the same as for the conventional method.

MR. CHATELAIN: We have an unsigned question for Mr. Graham: Would you describe more accurately the glass sun shades for the Tulsa building. Do they stand out beyond the face of the building?

MR. GRAHAM: Yes, we have a balcony completely around the building: north, south, east and west. The reason for this is that Tulsa is very sunny and clear and so glare is a factor in every orientation. Therefore, we are using a glass that is highly absorptive of the sun's rays. However, that glass could not be framed successfully into a building that was completely enclosed, because of its expansion characteristics, so we are suspending it five feet outside of the regular glass facings, and that is followed throughout within the moldings that are expanded from balcony to balcony.

MR. CHATELAIN: Another unsigned question, this one for the school architects jointly. What are the pros and cons of bilateral daylighting? Maybe one of you might want to take the pros and the other the cons.

MR. HARRIMAN: Relative to bilateral daylighting, it is an added cost. It is our contention that we can get a pleasant environment for less money. In considering our particular climate, and this is true of northern New York State and the northern part of this country, we have fifty per cent overcast weather during the school year. Therefore we think we should spend more of our money designing a system that will take care of all conditions—which is artificial light. So, instead of putting the money into bilateral daylighting, we have put it into artificial lighting.

In addition, artificial lighting is much better, as a rule, because we can control it. We can put it where we want it. In the activities program you can light it like a factory and have the light on the subject and on the work in progress. Also, in this way we can design an indoor classroom, as we call them, with the short length on the outside and the long length inside, thereby reducing the area and the cost, and carry on our activities in the inner part of the classroom under artificial light, where we can see much better.

This is a frank approach to our problem. Until we can get away from hot spots and diffusing better than we have, we like our system better.

MR. CHATELAIN: Have you something to add to that Mr. Bullock?

MR. BULLOCK: We have a lot of daylighted schools. We would also like to have night use as well as day use, but let's be realistic—how many schools are going to use the facilities at night, and how long at night? Questions like that lead us to our conclusion of bilateral daylighting. We do, for the majority of our buildings, depend on daylighting where the weather is consistent as far as sun conditions are concerned.

MR. KETCHUM: When you use glass blocks in the upper part of the window walls, do you get glare from those glass block walls?

MR. HARRIMAN: The reason we used glass blocks is that the superintendent insisted on it so he wouldn't have to put on shades or blinds. I have not noticed any glare in them.

MR. GRAHAM: One of the big problems, it seems, in school design, is the complete changing of programs of education—the size of the class, the type of teaching, the mechanical methods, etc. What provision do you recommend for the changing type of school, or is that provided for in your construction now?

MR. BULLOCK: As I mentioned, almost without exception our walls are frame construction. We don't have the more commercial type of fabricated partitions. We can't afford it. They are too high priced. But we do plan that these partitions will be moved, so we support them by pipe columns or independent columns.

MR. HARRIMAN: We have been working on a school with partitions between the classrooms. The school in Hagerstown is designed that way. They carry on the new program and the old program within the school without moving the partitions, by just moving the furniture.

Bibliography of Selected References

RL

1. "Analysis of Thermal Behavior of Glass Block Panels by Thermal Circuit Technique" by A. N. Cerny and G. V. Parmelee, ASHAE Research Report (to be published).
2. "Air Flow Through Conventional Window Openings" by T. R. Holleman, Research Report 33, Texas Engineering Experiment Station, College Station, Texas, November 1951.
3. "Building Research Station Digest No. 70," Building Research Station, Garston, England.
4. "Building Research Station Digest No. 80," Building Research Station, Garston, England.
5. "Calculation of Daylighting by Protractor Method" by Higbie and Szymanowski, IES Transactions No. 25, pp. 213, 1930.
6. "Calculation (The) of Illumination from Sun and Sky" by William Kunerth and Russell D. Miller, IES Transactions No. 28, pp. 347, 1933.
7. "Daylight Illumination on Horizontal, Vertical and Sloping Surfaces" by Herbert H. Kimball and Irving F. Hand, U. S. Weather Review, December 1922.
8. "Daylight Illumination on Horizontal, Vertical and Sloping Surfaces," Report of the Committee on Sky Brightness, H. H. Kimball, Chm., IES Transactions No. 18, pp. 434, 1923.
9. "Daylighting Design with Adjustable Horizontal Louvers" by J. W. Griffith, E. W. Conover and W. J. Arner, Illuminating Engineering, 1957.
10. "Daylighting Design with Overhangs" by J. W. Griffith, E. W. Conover and W. J. Arner, Illuminating Engineering, Vol. LI, No. 3, pp. 241, March 1956.
11. "Design Data for Slat-Type Sun Shades for Use in Load Estimating" by G. V. Parmelee and D. J. Vild, ASHAE Research Report No. 1485, ASHAE Transactions, Vol. 59, 1953.
12. "Duration and Intensity of Sunshine'" by Frank Benford, IES Transactions No. 42, pp. 527; pp. 877, 1947; No. 43, pp. 533, 1948.
13. "Footcandles for the Forgotten Man" by S. K. Guth and A. A. Eastman, Illuminating Engineering, Vol. LI, No. 3, pp. 251, March 1956.
14. "Further Study of Geometrical Calculation of Illumination" by Z. Yamauti, Researches, Electrot Lab., Tokyo, p. 194, 1927.

RL

15. "Geometrical Calculation of Illumination" by Z. Yamauti, Researches, Electrot Lab., Tokyo, p. 148, 1924.
16. "Glass Block Fenestration and the Interreflection Method" by E. C. Spencer, V. J. Stakutis, H. F. Kingsbury and R. W. McKinley, National Technical Conference of IES, Preprint No. 1, August 1951.
17. "Heating, Ventilating Air Conditioning Guide," 31st Edition, Chapter 6 (Physiological Principles), ASHAE, 1953.
18. "IES Handbook," Second Edition, Tables 7-1 and 7-2.
19. "IES Handbook," Second Edition, Figures 7-3 and 7-4.
20. "IES Handbook," Second Edition, Table 7-5.
21. "IES Handbook," Second Edition, Table 7-6.
22. "IES Handbook," Second Edition, Table 9-18.
23. "Illumination Distribution from Surface Sources in Rooms" by H. H. Higbie, IES Transactions No. 31, p. 163, 1936.
24. "Illumination Distribution Measurements from Surface Sources in Sidewalls" by Higbie and Bychinsky, IES Transactions No. 29, p. 206, 1934.
25. "Importance (The) of Ground Reflection in Daylighting" by J. W. Griffith, O. F. Wenzler and E. W. Conover, Illuminating Engineering, Vol. XLVIII, No. 1, p. 35, January 1953.
26. "Integral-Equation (The) Solution of the Daylighting Problem" by D. E. Spencer and V. J. Stakutis, Journal of Franklin Institute, Vol. 252, No. 3, pp. 225, September 1951.
27. "Interreflections in Rooms by a Network Method" by P. F. O'Brien, Journal of the Optical Society of America, June 1955.
28. "Lighting Calculations" by H. H. Higbie, Chapter V, John Wiley & Sons, Inc., New York, 1934.
29. "Modified Lumen Method of Daylighting Design" by J. W. Griffith, W. J. Arner and E. W. Conover, Illuminating Engineering, Vol. L, No. 3, pp. 103, March 1955.
30. "Natural Lighting of Buildings in Sunny Climates by Sunlight Reflected from the Ground and from Opposing Facades" by R. G. Hopkinson and P. Petherbridge, Proceedings of the Conference on Tropical Architecture, Note No. E435, Building Research Station, Garston, England, 1953.
31. "Prediction of Daylight from Sloping Windows" by Higbie and Levin, IES Transactions No. 21, pp. 273, 1926.

32. "Proposed Standard Solar Radiation Curves for Engineering Use" by P. Moon, Journal of Franklin Institute, Vol. 230, No. 5, November 1940.
33. "Radiant Energy Emission of Atmosphere and Ground—A Design Factor in Heat Gain and Heat Loss" by G. V. Parmelee and W. W. Aubele, ASHAE Research Report No. 1442, ASHAE Transactions, Vol. 58, 1952.
34. "Relation (The) between Illumination and Visual Efficiency, the Effect of Brightness Contrasts" by H. C. Weston, Report No. 87 of the Industrial Health Research Board, Medical Research Council, London, 1945.
35. "Sky Brightness and Daylight Illumination Measurements," Report of the Committee on Sky Brightness, H. H. Kimball, Chm., IES Transactions No. 16, pp. 255, 1921.
36. "Solar and Total Heat Gain through Double Flat Glass" by G. V. Parmelee and W. W. Aubele, ASHAE Research Report No. 1348, ASHAE Transactions, Vol. 54, 1948.
37. "Shading (The) of Sunlit Glass: Convection and Radiation Gain from Slat-Type Sun Shades" by G. V. Parmelee and D. J. Vild, ASHAE Research Report (to be published).

RL

38. "Temperature, Sunshine and Wind," Atlas of American Agriculture, Part II, Section B, U. S. Govt. Printing Office, 1928.
39. "Time Analysis of Sunshine" by Frank Benford and John E. Boch, IES Transactions No. 35, pp. 333, 1940.
40. "Variation of Intensities of the Visible and of the Ultraviolet in Sunlight and in Skylight" by William Kunerth and Russell D. Miller, IES Transactions No. 27, pp. 82, 1932.
41. "Variation in the Total and Luminous Solar Radiation with Geographical Position in the United States'" by Herbert H. Kimball, U. S. Weather Review, November 1919.
42. "Visible and Ultraviolet in the Light Obtained from the Sun" by William Kunerth and Russell D. Miller, IES Transactions No. 28, pp. 347, 1933.
43. "What is a Draft" by Henry Wright, Herman Nelson, Div. of American Air Filter Co., Inc., Moline, Ill. (8 p. brochure).

Conference Attendance List

Abberley, Elbert K., Vice Pres., Turner Construction Co., 150 E. 42nd St., New York 17, N. Y.

Ahern, Frank L., Chief Safety Officer, National Park Service, Interior Bldg., Washington 15, D. C.

Ammerman, John M., Production Mgr., Perfit Products Div., 1200 E. 52nd St., Indianapolis, Ind.

Anderson, James A., Chief Engineer, Breneman-Hartshorn, Inc., 1050 W. Western, Muskegon, Mich.

Appel, John M., Asst. Mgr., Glazing & Panel Sales, H. H. Robertson & Co., 2400 Farmers Bank Bldg., Pittsburgh 22, Pa.

Arkin, James, Consultant, Architectural Woodwork Institute, Natl. Woodwork Mfrs. Assn., 332 S. Michigan Ave., Chicago 4, Ill.

Ballantyne, E. R., Div. of Bldg. Research, Commonwealth Scientific & Industrial Research Organization, Commonwealth of Australia, Graham Road, Highett, S. 21, Victoria, Australia.

Barbee, Jack, Wash. Repr., Coast Pro-Seal & Mfg. Co., 1035 Investment Bldg., Washington 5, D. C.

Batchelor, Harry H., Governor, Society of Residential Appraisers, 14 W. Saratoga St., Baltimore 1, Md.

Beaujon, Jan R., Jr., Engineer, Procter & Gamble, 8921 Cottonwood Dr., Cincinnati 31, Ohio.

Below, Robert F., Designer, Republic Steel Corp., 6100 Truscon Ave., Cleveland 27, Ohio.

Bennett, Wells, Dean, University of Mich., College of Architecture & Design, Architecture Bldg., Ann Arbor, Mich.

Beyer, Arthur, General Engr. (Research) Veterans Adm., Munitions Bldg., Washington 25, D. C.

Biggs, Richard, Mgr. Product Development, Crucible Steel Co., 405 Lexington Ave., New York 17, N. Y.

Bird, Frederick C., Chief Draftsman, Daniel, Mann, Johnson & Mendenhall, 1145 19th St., N.W., Washington, D. C.

Blaine, William M., Pres., Breneman-Hartshorn, Inc., 2045 Reading Rd., Cincinnati 2, Ohio.

Blair, John O., Architect, The Detroit Edison Co., Detroit 26, Mich.

Bliss, Robert H., Vice Pres., Bliss Steel Products Corp., East Syracuse, N. Y.

Bloomfield, Byron C., Secy. for Prof. Development, A.I.A., 1735 New York Ave., Washington 6, D. C.

Borges, Robert D., Research Engr., P.P.G., Creighton, Pa.

Boyd, Robert A. (Dr.), Research Physicist, Daylighting Lab., Eng. Res. Inst., University of Mich., Ann Arbor, Mich.

Briggs, Lee, New York District Mgr., William Bayley Co., Grand Central Terminal Bldg., New York 17, N. Y.

Brown, J. Sanger, Architect, New York Life Insurance Co., 51 Madison Ave., New York, N. Y.

Brown, H., National News Bureau, Los Angeles, Calif.

Brown, Morris H., Standard Building Products Co., 14200 Cloverdale, Detroit 38, Mich.

Brown, Paul B., Project Administrator, Harley-Ellington & Day, Inc., 153 E. Elizabeth St., Detroit 1, Mich.

Brown, Russell L., Sales Mgr., Brown Mfg. Co., 1940 Linwood, Oklahoma City 6, Okla.

Brown, Stanley J., Asst. Sales Mgr., Brown Mfg. Co., 1940 Linwood, Oklahoma City 6, Okla.

Browning, Getty, Eng. Div., M.C., Office of The Chief of Engineers, Washington 25, D. C.

Bullock, Thomas, Partner, Caudill, Rowlett, Scott & Assoc., 1611 North Broadway, Oklahoma City, Okla.

Bushnell, Sterling S., Vice Pres. & Gen. Sales Mgr., Breneman-Hartshorn, Inc., 2045 Reading Rd., Cincinnati 2, Ohio.

Chatelain, Leon, Jr., Architect, Chatelain, Gauger & Nolan, 1632 K St., N.W., Washington, D. C.

Cipa, Alexander F., Chief Spec. Writer, Harley, Ellington & Day, Inc., 153 E. Elizabeth, Detroit 1, Mich.

Clark, Walton C., Research Engineer, Public Bldgs. Service, 19th & F Sts., N.W., Washington 25, D. C.

Clingerman, Robert L., Consulting Eng., William Bayley Co., Springfield, Ohio; Wash. address: 3701 Massachusetts Ave., N.W., Washington 16, D. C.

Conrad, Edward G., Architect, Conrad & Simpson, 1110 Hann Bldg., Cleveland 15, Ohio.

Couch, Frank L., Chief, Specification Dept., Smith, Hinchman & Grylls, Inc., 800 Marquette Bldg., 243 W. Congress St., Detroit 26, Mich.

Cutler, Robert W., Partner, Skidmore, Owings & Merrill, 575 Madison Ave., New York 22, N. Y.

Davis, Thurlow W., Tech. Dir., Breneman-Hartshorn, Inc., 8 East Utica St., Oswego, N. Y.

Demarest, William, Asst. Dir., Construction Dept. & Research Inst., National Association of Home Builders, 1625 L St., N.W., Washington 6, D. C.

Diebold, Warren R., Product Designer, Cincinnati Milling Machine Co., Marburg Ave., Cincinnati 9, Ohio.

Dominick, Theodore, Owner, Theodore W. Dominick, Architect, 1308 18th St., N.W., Washington 6, D. C.

Duckworth, Carl W., Salesman, Hires-Turner Glass Co., 1027 N. 19th St., Arlington, Va.

Dugan, John L., Tech. Eng., Pennsylvania Wire Glass Co., 1612 Market St., Philadelphia 3, Pa.

Dujardin, Thomas H., Glazing Committee, Flat Glass Jobbers Assn., 85 North Broad St., Galesburg, Ill.

Dunacan, Rea E., Product Mgr., Koolshade Sunscreen, Reflectal Corp., 310 S. Michigan, Chicago 4, Ill.

Dunn, Lawrence M., Head, Architectural Section, Sales Development Div., Aluminum Co. of America, P.O. Box 1012, New Kensington, Pa.

Elbert, Carl J., Mgr., Facilities Branch, Bureau of Yards & Docks, Dept. of the Navy, Washington 25, D. C.

Ellis, Pat A., Sales Mgr., M W Distributors, Rocky Mount, Va.

Evans, Charles L., Mgr., Architectural Products Div., Fenestra, Inc., 2250 E. Grand Blvd., Detroit 11, Mich.

Everetts, John, Jr., Eng., Charles S. Leopold, Engineer, 215 South Broad St., Philadelphia 7, Pa.

Fiedler, Albert H., Chief Architect, The Rust Engineering Co., 575 Sixth Ave., Pittsburgh 19, Pa.

Finkel, Julian B., Plant Eng., J. S. Thorn Co., 8501 Hegeman St., Philadelphia 36, Pa.

Fischer, Robert E., Assoc. Editor, Architectural Record, 119 W. 40th St., New York 18, N. Y.

Foley, Willis A., Hires-Turner Glass Co., 1027 19th St., N., Arlington, Va.

Folley, Milo D., Partner, Sargent, Webster, Crenshaw & Folley, 2112 Erie Blvd., East, Syracuse 3, N. Y.

Ford, C. H., Procter & Gamble Co., M. A. & R. Bldg., Ivorydale, Cincinnati 17, Ohio.

Fraser, William H., Manufacturers Trust Co., 5th Ave. at 43rd St., New York, N. Y.

Freeman, William W., Partner, Freeman-French-Freeman, Architects, 158 Bank St., Burlington, Vt.

Fry, Louis E., Prof. of Architecture, Howard University, Washington 1, D. C.

Fryer, Frederick L., Faulkner, Kingsbury & Stenhouse, Architects, 1200 18th St., N.W., Washington 6, D. C.

Fujikawa, Joseph Y., Architect, Mies van der Rohe, 230 E. Ohio, Chicago, Ill.

Funaro, Bruno, A.I.A., Assistant Dean, School of Architecture, Columbia University, Morningside Hgts., New York 27, N. Y.

Garlick, Gardner G., Vice Pres. & Tech. Dir., Protection Products Mfg. Co., 2305 Superior Avenue, Kalamazoo 99, Mich.

Gertler, Sidney, Industry Specialist, U. S. Dept. of Commerce, 14th & E Sts., N.W., Washington 25, D. C.

Glaser, Samuel, Architect, Samuel Glaser Assoc., 234 Clarendon St., Boston, Mass.

Goldman, Frederick H., Chief, Public Health Engineering, D. C. Dept. of Public Health, 300 Indiana Ave., N.W., Washington 1, D. C.

Gordon, Peter B., Vice Pres., Wolff & Munior, Inc., 222 E. 41st St., New York, N. Y.

Graham, Bruce, Assoc. Partner, Skidmore, Owings & Merrill, Architects, 100 W. Monroe St., Chicago 3, Ill.

Greenwald, Herbert S., Builder, 135 South LaSalle St., Chicago 3, Ill.

Griffith, James W., Asst. Prof. of Engr. Research & Dir. of Daylighting Research Lab., School of Engineering, Southern Methodist University, Dallas, Texas.

Gurney, G. Harmon, Chief Architect, New York Life Insurance Co., 51 Madison Ave., New York 10, N. Y.

Harriman, Alonzo J., Architect and Eng., Treasurer, Alonzo J. Harriman, Inc., Auburn, Maine.

Haussmann, William M., Chief Architect, National Capital Parks, 19th & C Sts., Washington 25, D. C.

Havlicsek, Alex, Eng., E. K. Geyser Co., 915 McArdle Roadway, Pittsburgh 3, Pa.

Heaphy, James C., Sales, Litewall Co., 10616 W. 7 Mile Rd., Detroit, Mich.

Heineman, Alfred J., Market Research Mgr., Curtis Companies Inc., Clinton, Iowa.

Helene, Sidney J., Architect, Veterans Administration, Room 2716, Munitions Bldg., Washington, D. C.

Hennessy, John F., Pres., Syska & Hennessy, Inc., 144 E. 39th St., New York 16, N. Y.

Herbst, Robert, Asst. Gen. Mgr., Ponderosa Pine Woodwork, 105 W. Monroe St., Chicago 3, Ill.

Hingston, George, Exec. Secy., Steel Window Institute, Cheltenham, Pa.

Holtz, Robert T., B. F. Goodrich Chemical Co., 3135 Euclid Ave., Cleveland, Ohio.

Horowitz, Harold, Assoc. Staff Arch., Building Research Institute, 2101 Constitution, Washington 25, D. C.

Hough, Albert R., Vice Pres., Hough Mfg. Corp., 1029 S. Jackson St., Janesville, Wis.

Huddle, C. F., Research Staff, GMC, P.O. Box 177, North End Station, Detroit 2, Mich.

Humke, Roger K., Supervisor, Technical Service Lab., Minnesota Mining & Mfg. Co., 411 Piquette, Detroit 2, Mich.

Humphreys, Ellis, Vice Pres., Mississippi Glass Co., 88 Angelica, St. Louis 7, Mo.

Jackson, L. M., Tremco Mfg. Co., 3701 Kinsman Rd., Cleveland 4, Ohio.

Jarvis, Everett A., Mgr., Hires-Turner Glass Co., 1028 19th St. No., Arlington, Va.

Jaros, Alfred L., Jr., Partner, Jaros, Baum & Bolles, Consulting Engineers, 415 Lexington Ave., New York 17, N. Y.

Jennings, Burgess H., Chmn. Dept. Mech. Engr., Northwestern University, Evanston, Ill.

Johnson, Gustav E., Eastern Sales Mgr., Reflectal Corp., 310 S. Michigan Ave., Chicago, Ill.

Johnson, Herbert, Sr. Eng., Arthur D. Little, Inc., 30 Memorial Dr., Cambridge 42, Mass.

Judd, Charles M., Production Mgr., Breneman-Hartshorn, Inc., 2045 Reading Rd., Cincinnati 2, Ohio.

Kapple, William H., Res. Asst. Prof., Small Homes Council, Univ. of Ill., 31 E. Armory, Champaign, Ill.

Keane, Gustave R., Chief of Production, Eggers & Higgins, 100 E. 42nd St., New York 17, N. Y.

Keck, William, Partner, George Fred Keck-William Keck, Architects, 612 No. Michigan Ave., Chicago 11, Ill.

Kelly, Clyde W., Chief Eng., Fenestra, Inc., 2250 E. Grand Blvd., Detroit 17, Mich.

Kerruish, Robert H., Staff Mech. Eng., Structural Clay Prod. Res. Found., Geneva, Ill.

Ketchum, Morris, Jr., Partner, Ketchum, Giná & Sharp, Architects, 227 E. 44th St., New York 17, N. Y.

Kingsbury, Howard F., Dir., Daylighting Res. Center, Pittsburgh Corning Corp., Port Allegany, Pa.

Klein, Robert, Pres., Alum. Window Mfgrs. Assn., 74 Trinity Pl., New York, N. Y.

Knebel, Herman, Research and Development, S. H. Pomeroy Co., 25 Bruckner Blvd., New York 54, N. Y.

Koehler, C. R., Editor, Bldg. Research Institute, 2101 Constitution, Washington 25, D. C.

Kreuttner, J. W., Vice Pres., Buensod-Stacey, Inc., 45 W. 18th St., New York, N. Y.

Kruckman, Margaret H., (Glass Digest), Kruckman News Service, #46, 1316 New Hampshire Ave., N.W., Washington 6, D. C.

Kuyper, H. S., Dir. of Mfg., Roscreen Co., 105 Main St., Pella, Iowa.

Lamont, Albert D., Arch. Rep., Pittsburgh Plate Glass Co., 1545 New York Ave., N.E., Washington 2, D. C.

Lance, Ormie C., Secy.-Mgr., Nat'l Woodwork Mfg. Assn., 332 S. Michigan Ave., Chicago 4, Ill.

Laurin, Richard, Adv. & Sales Promotion Mgr., American Window Glass Co., Farmers Bank Bldg., Pittsburgh 22, Pa.

Lebon, Charles B., Chief Eng., Arcadia Metal Products, 801 S. Acacia Ave., Fullerton, Calif.

Lecraw, Charles S., Mgr., Bldg. & Construction Industries, Market Dev., U. S. Steel Corp., 525 Wm. Penn Place, Pittsburgh 30, Pa.

Lendrum, James T., Dir., Small Homes Council, Univ. of Ill., Urbana, Ill.

Linforth, Edward M., Plastics Lab., Rohm & Haas Co., Bristol, Pa.

Lloyd, Albert L., Architect, Public Housing Admin., Washington 25, D. C.

Love, Nash, Chief Eng., Wm. H. Singleton, Inc., 1240 Jefferson Davis Highway, Arlington 2, Va.

Lutz, Godfrey, Turner Construction Co., 150 East 42nd St., New York 17, N. Y.

Lykens, J. Blair, Secy., Pennsylvania Wire Glass Co., 1612 Market St., Philadelphia 3, Pa.

MacDonald, Torrence H., Meteorologist, U. S. Weather Bureau, 24th & M Sts., N.W., Washington 25, D. C.

MacKinnon, John A., Chief, Heating Branch, Bldg. & Materials & Const. Div., Dept. of Commerce, BDSA, Washington 25, D. C.

Mara, Paul V., Dev. Eng., Kaiser Aluminum & Chem. Sales Inc., 228 N. LaSalle, Chicago 1, Ill.

Marlow, James Carroll, Mgr., Air Conditioning & Heating Div., Robert & Co., Assoc., Inc., Architects & Engs., 96 Poplar St., Atlanta, Ga.

Martin, Thomas P., Res. Eng., Pittsburgh Plate Glass Co., Creighton, Pa.

McCallum, Angus, Kivett & Myers & McCallum, Architects-Engs., 1016 Baltimore Ave., Kansas City 5, Mo.

McDavitt, Murray, Prin. Eng., Owens-Illinois Glass Co., Toledo, Ohio.

McIntosh, Harold W., Vice Pres.-Tech., American Window Glass Co., 2000 Farmers Bank Bldg., Pittsburgh 22, Pa.

McKinley, Robert W., Tech. Repr., Pittsburgh Plate Glass Co., Creighton, Pa.

McNulty, Al, Turner Construction Co., 150 E. 42nd Street, New York 17, N. Y.

Merritt, Frederick S., Sr. Editor, Engineering News-Record, 330 W. 42nd St., New York 36, N. Y.

Metz, Carl A., Partner, Shaw, Metz & Dolio, 208 S. LaSalle St., Chicago 4, Ill.

Meyers, Alfred F., Arch. Repr., Reynolds Metals Co., Box 208, Camden, N. J.

Miles, E. Charles, Tech. Ser. Eng., Pittsburgh Plate Glass Co., #1 Gateway Center, Pittsburgh 22, Pa.

Miller, Joseph, Architect, 1640 Wisconsin Ave., N.W., Washington 7, D. C.

Mills, Charles P., Customer Service, Michael Flynn Mfg. Co., 700 E. Godfrey Ave., Philadelphia 24, Pa.

Miner, Harold S., Vice Pres., Manufacturers Trust Co., Fifth Ave. at 43rd St., New York 36, N. Y.

Mochon, Donald, Assoc. Head, Dept. of Architecture, Rensselaer Polytechnic Institute, Troy, N. Y.

Monk, Clarence B., Jr., Structural Clay Research, Geneva, Ill.

Moore, Theodore W., Arch. Proj. Eng., Eastman Kodak Co., 343 State St., Rochester 4, N. Y.

Morgan, Albert H., Tech. Dir., Natl. Assn. Plumbing Contractors, 1016 20th St., N.W., Washington 5, D. C.

Muessel, Dan C., Mgr., Arch. Prod. Dev., Kawneer Co., Niles, Mich.

Nelson, Otto L., Vice Pres. in Charge of Housing, New York Life Insurance Co., 51 Madison Ave., New York 10, N. Y.

Nevins, Donad L., Dir. of Sales, House Glass Corp., Point Marion, Pa.

Ormston, Harry E., Architect, South Langley Lane, McLean, Va.

Orr, Leighton, Head, Phys. Testing Dept., Pittsburgh Plate Glass Co., Creighton, Pa.

Parsons, Douglas, Chief, Bldg. Tech. Div., Natl. Bureau of Standards, Washington 25, D. C.

Patman, William F., Adv. Dir., Michael Flynn Mfg. Co., 700 E. Godfrey Ave., Philadelphia 24, Pa.

Peterson, Robert L., Arch. Sales, Kaiser Aluminum, 919 N. Michigan, Chicago, Ill.

Perilstein, Max, Pres., United Plate Glass Co., 127 Anderson St., Pittsburgh 12, Pa.

Pierson, Orville L., Plastics Lab., Rohm & Haas Co., Bristol, Pa.

Poiesz, Clamens J., Spec. Eng., U. S. Public Health Service, Washington 25, D. C.

Queer, Elmer, Prof., Penn. State University, State College, Pa.

Quick, Henry B., Gen. Sales Mgr., Lemlar Mfg. Co., 715 W. Redondo Beach Blvd., Gardena, Calif.

Rannow, R. L., Sales Eng., Ind. Div., York Corp., 100 E. 42nd St., New York 17, N. Y.

Reardon, William F., Real Estate & Const., General Electric, 202 State St., Schenectady, N. Y.

Reed, Benjamin E., Maintenance Eng., Navy Dept., Bureau of Yards & Docks, Washington 25, D. C.

Reed, Robert H., Assoc. Res. Arch., Texas Engr. Experiment Station, College Station, Texas.

Reschke, Robert C., Sr. Assoc. Editor, Practical Builder, 5 S. Wabash Ave., Chicago, Ill.

Reynolds, Shelton E., Mgr., Govt. Arch. Rels., Pittsburgh Plate Glass Co., 1545 New York Ave., N.E., Washington 2, D. C.

Rich, Murray L., Chemist, L. Sonneborn Sons, Inc., Belleville, N. J.

Ridings, Domer F., Jr., Sales Prom., Blue Ridge Glass Corp., Kingsport, Tenn.

Robertson, William G., Vice Pres., Henry Adams, Inc., 2315 St. Paul St., Baltimore 18, Md.

Rodgers, Gilbert, Arch. Editor, Masonry Building, 5 S. Wabash, Chicago, Ill.

Rogers, Tyler S., Tech. Consultant, Owens-Corning Fiberglas Corp., Toledo, Ohio.

Rossing, Harvey C., Eng., American Tel. & Tel. Co., 195 Broadway, New York 7, N. Y.

Ryan, John, Copywriter, Kenyon & Eckhardt, Phila. Natl. Bank Bldg., Philadelphia, Pa.

Saner, George G., Fabric Sales, E. I. du Pont de Nemours & Co., N-11508, Wilmington, Del.

Scheick, William H., Exec. Dir., Bldg. Research Inst., 2101 Constitution, Washington 25, D. C.

Schuchman, George W., Mgr. Contract Ser. Dept., Libbey-Owens-Ford Glass Co., 608 Madison Avenue, Toledo 3, Ohio.

Schutrum, Lester F., Res. Supv., ASHAE, 7218 Euclid Ave., Cleveland, Ohio.

Schmitt, Paul J., Daylighting Eng., Mississippi Glass Company, 88 Angelica St., St. Louis 7, Mo.

Schwers, Arthur F., Asst. Mgr., Sales Eng., Window Products, Truscon Steel Div. Republic Steel Corp., Albert St., Youngstown, Ohio.

Scott, Julian H., Standard Bldg. Prod. Co., 14200 Cloverdale, Detroit 38, Mich.

Semiatin, Morris, Photographer, Del Ankers Photo, 2424 G St., N.W., Washington, D. C.

Shaftel, Oscar, Features Editor, American Builder, 30 Church Street, New York 7, N. Y.

Sherwood, Richard M., Devel. Eng., Aluminum Co. of America, New Kensington, Pa.

Shuler, Clyde F., Architect, William Heyl Thompson, 2315 Architects Bldg., 17th & Sansom, Philadelphia 3, Pa.

Shull, John M., Arch. Ser. Eng., Reynolds Metals Co., 19 E. 47th Street, New York 17, N. Y.

Sim, Raymond, Pres., Washington Woodworking Co., 912 4th Street, N.W., Washington 1, D. C.

Smariga, Julian, Struc. Eng., U. S. Public Health Service, Washington, D. C.

Smith, Russell W., Tech. Asst., Producers Council, 2029 K St., N.W., Washington 6, D. C.

Smith, Warwick L., Architect, Stephenson & Turner, 374 Little Collins St., Melbourne C. I., Victoria, Australia.

Snyder, Edwin F., Supv. Control Application, Minneapolis Honeywell, 2747 Fourth Ave. So., Minneapolis 8, Minn.

Snyder, Marvin K., Bldg. Res. Eng., Butler Mfg. Co., 7400 E. 13th, Kansas City 26, Mo.

Solvason, K. Richard, Res. Officer, Div. of Bldg. Research, Natl. Research Council, Ottawa, Ont., Canada.

Spencer, Roger D., Mgr., Twindow Sales, Pittsburgh Plate Glass Co., #1 Gateway Center, Pittsburgh 22, Pa.

Stark, Charles H., Mgr., Constr. Methods Dept., Kimble Glass Co., P.O. Box 1035-36, Toledo 1, Ohio.

Stenhouse, John W., Faulkner, Kingsbury & Stenhouse, Architects, 1200 18th St., N.W., Washington 6, D. C.

Stevens, John H., Sr. Architect, Libbey-Owens-Ford Glass Co., Toledo 5, Ohio.

Strugats, George H., F. H. Sparks Co., 222 E. 41st St., New York 17, N. Y.

Swan, W. Stanley, Arch. Sales, Pilkington Glass, Ltd., 27 Mercer Street, Toronto 2, Ont., Canada.

Taylor, Edward C., Arch. Staff Eng., Carbide & Carbon Chemicals Co., McCorkle Ave., So. Charleston, W. Va.

Thompson, Charles H., Gen. Mgr., Sales & Distr., William Bayley Co., Springfield, Ohio.

Thompson, Harold J., Agricultural Eng., U. S. Dept. of Agriculture, AERB, Plant Industry, Beltsville, Md.

Tilghman, George C., Architect, Daniel Mann, Johnson & Mendenhall, 1145 19th St., N.W., Washington, D. C.

Titrington, George F., Eng., Portland Cement Assn., 837 National Press Bldg., Washington 4, D. C.

Todd, Charles I., Dist. Mgr., Arch. Rels., Pittsburgh Plate Glass Co., 579 5th Ave., New York, N. Y.

Topping, Charles H., Sr. Arch. & Civil Consultant, E. I. du Pont de Nemours Co., Wilmington 98, Del.

Turner, J. H., Hires-Turner Glass Co., Arlington, Va.

Twietmeyer, Harold E., Res. Staff, GMC, Box 188, No. End Sta., Detroit, Mich.

Vest, Newton P., Exec. Secy., Masonry Institute, Inc., Washington Bldg., Washington, D. C.

Vild, Donald J., Tech. Ser. Eng., Libbey-Owens-Ford Glass Co., 1701 E. Broadway, Toledo 5, Ohio.

Vosbeck, Wm., Architect, Jos. Saunders Assoc., 1757 K St., N.W., Washington 6, D. C.

Watkins, Arthur M., Asst. Editor, House & Home, 9 Rockefeller Plaza, New York 20, N. Y.

Weatherstone, Alan, Vice Pres., Kawneer Co. Canada, Ltd., 60 Isabella St., Toronto 5, Ont., Canada.

Wiedman, V. Wesley, Res. Supv., E. I. du Pont de Nemours & Co., Exp. Sta., Wilmington, Del.

Wenzler, Otto F., Mgr., Tech. Sales, Libbey-Owens-Ford Glass Co., 608 Madison Ave., Toledo 3, Ohio.

Wescott, Charles M., Vice Pres., Sales, American Window Glass Co., Farmers Bank Bldg., Pittsburgh 22, Pa.

Wheeler, Carlton E., Tech. Dir., Res. Div., Dicks-Pontius Co., 160 Dayton Ave., Xenia, Ohio.

Wille, H. S., Mgr., Struc. and Mech. Res., Kawneer Co., Niles, Mich.

Williams, Thomas, Assoc., Faulkner, Kingsbury & Stenhouse, 1200 18th St., N.W., Washington 6, D. C.

Williams, James L., Exec. Vice Pres., American Window Glass Co., Farmers Bank Bldg., Pittsburgh 22, Pa.

Wondisford, Floyd, Chief Eng., Youngstown Mfg., Inc., 66 So. Prospect St., Youngstown, Ohio.

Wright, Henry, Architect, 302 E. 41st St., New York, N. Y.

Wyatt, William, Kawneer Co., Niles, Mich.

Youngblood, Charles, Dir. Res., Mississippi Glass Co., 88 Angelica St., St. Louis 7, Mo.

Zeitz, E. T., Kawneer Co., Niles, Mich.

Zoll, Fred B., Jr, Mgr., Wash. Off., Libbey-Owens-Ford Glass Co., 806 Connecticut Ave., Washington 6, D. C.

THE BUILDING RESEARCH INSTITUTE

The Building Research Institute is a unit of the Division of Engineering and Industrial Research of the National Academy of Sciences-National Research Council. A technical society for the building industry, the primary purpose of the Institute is to promote the integration and advancement of building science and technology. It also acts as an information center and maintains liaison with building research agencies in other countries throughout the world.

The Institute's membership consists of a cross-industry representation of persons particularly qualified by their technical competence and by their interest to contribute to the advancement of building research and technology. Memberships are held by corporations, partnerships, business, professional and trade associations and societies, and individuals. Member organizations select one or more of their officers, directors, partners or employees to act as Official Representatives or Technical Participants to the Institute.

Operating on the principle that the personal exchange of experience and ideas is the basis of the growth of a science, the Institute conducts:

(1) Research correlation conferences on specific design problems and the cross-country application of building products (open to the public);

(2) Workshop conferences and study groups on specific subjects (for BRI members and invited guests);

(3) Annual meetings featuring outstanding technical programs and social events.

THE BUILDING RESEARCH ADVISORY BOARD

The Building Research Advisory Board is also a unit of the Division of Engineering and Industrial Research of the National Academy of Sciences-National Research Council. As a Board of the Academy-Research Council, BRAB may study, on request, any subject of science or technology in its field and advise any department or agency of the Federal Government on technical questions submitted to the Board. BRAB members are appointed by the Academy-Research Council from the ranks of the foremost technologists in the building industry, in government or in educational institutions throughout the country.

PUBLICATIONS

The Building Research Institute publishes and distributes proceedings of its conferences, technical meetings and study groups. With permission from BRAB, it also reprints BRAB reports which contribute to the advancement of building technology. The BRI newsletter, Building Science News, reports monthly on Institute and BRAB activities, as well as on research news of general interest to the industry. The Building Science Directory, founded in 1956, provides a comprehensive guide to sources of information on research and technical developments in the industry. Supplements to the Directory are issued quarterly with an annual index. BRI Abstracts, also issued quarterly, furnish a continuing digest of new building science publications. All of these services are provided to BRI members without charge. Non-members may obtain copies of published proceedings of public conferences and regular issues of The Building Science Directory at nominal cost through the NAS Publications Office.

PRI ... INSTITUTE AND

BUILDIN ... NCE PROCEEDINGS

6121
National Research Council.
Building Research Institute.
Windows and glass in the exterior of buildings.
NAS-NRC pub.478

WALLS, 1950

TERIALS, 1952

952
s, $3.50.

CLIMATES, 1953
hs, $4.50.

, 1954

rts,

charts,

FLOOR-CEILINGS AND SERVICE SYSTEMS IN MULTI-STORY BUILDINGS, 1956
141 pages, 80 illustrations, tables, graphs and charts,
Publication No. 441, $4.00.

MODERN MASONRY, NATURAL STONE AND CLAY PRODUCTS, 1956
163 pages, 87 illustrations and tables,
Publication No. [illegible], $4.50.

These publications are available on order from the Publications Office, National Academy of Sciences—National Research Council, 2101 Constitution Ave., Washington 25, D. C.