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UNITED STATES ATOMIC ENERGY COMMISSION

AECU-3037

WINDOW AND GLASS HAZARDS UNDER WARTIME CONDITIONS AND RECOMMENDED PROTECTIVE MEASURES

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1954

General Services Administration
Washington, D. C.

Technical Information Service, Oak Ridge, Tennessee

Subject Category, ENGINEERING.

Printed in USA, Price 20 cents. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

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WINDOW AND GLASS HAZARDS UNDER WARTIME CONDITIONS and RECOMMENDED PROTECTIVE MEASURES

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INTRODUCTION

The World War II atomic bombs exploded over Hiroshima and Nagasaki caused considerable structural damage to buildings located as much as two miles from ground zero, the point directly beneath the explosion. Damage to windows from the same explosions extended outward eight miles from ground zero. The area of glass damage was approximately sixteen times as great as the area of structural damage and a large percentage of the living casualties were injured by flying glass. If larger bombs are exploded the areas of damage will be increased. For example, as the bomb size is increased by 8 times the radius of damage is doubled. These facts indicate the need for dissemination of all available information regarding glass and window hazards and measures which will in any degree minimize the effects of enemy action. Such measures will also reduce the hazards generated by peacetime disasters, such as explosions, tornadoes and hurricanes.

It is the purpose of this bulletin to summarize available knowledge about the effects of atomic blasts on glazing and window construction and outline, insofar as present knowledge permits, those steps which can be taken at a reasonable cost to reduce the extent of the damage to windows and the number of casualties caused by flying glass.

While it is realised that replacement of window frames, sash and glass in existing structures with more resistant material is not generally feasible, there is no question that use of stronger glass and correctly designed window installations in all new construction, over a period of years, would greatly reduce the damage and injuries resulting from any size weapon detonated over or near any major concentration of population. Any degree of protection which can be achieved by correct practice regarding the opening or closing of windows will decrease the total glass hazard and is, therefore, worthy of consideration.

Windows - Construction and Types

Window frames and sash are generally constructed of wood, aluminum, steel or bronze. The resistance of the frame and sash to blast depends largely on the area of the window, the type of design and the strength and rigidity of the frame members, rather than on the material used.

Generally the weakest parts of a window assembly are the cross pieces (muntins) that divide the sashes into smaller glass areas. Sashes designed with intersecting muntins are particularly susceptible to blast. Individual panes of glass should be limited to an area of three square feet or less, when such action is feasible. This may be accomplished by use of short rigid muntins, either vertical or horizontal, not intersected by other muntins.

Residential windows normally belong to one of three basic types known as casements (inswinging or outswinging), canopies, and windows with double-hung sash. In buildings for public use these same designs may be found and in addition projected and pivoted types, and those with sash hinged at bottom and swinging inward (hopper vents) are common. Sketch No. 1 shows the more common types of windows discussed in this bulletin. No conclusive evidence is available which would indicate the superiority of any one of these types over the others.

Table No. 1 gives some effects of atomic blast on various types of windows and glazing materials, under reflected pressures at three ranges. It is recognized that the data are not conclusive but do give some indications of relative strengths. The reflected pressures of 2, 4.2 and 7.4 psi, on windows facing the blast, would be produced by an atomic bomb such as exploded over Japan at distances of approximately 3, 2 and 1-1/2 miles respectively from ground zero.

Preferable Position of Sashes During Blast

Several factors must be considered in determining whether windows should be opened or closed at the time warning of a probable enemy attack is received. Glass will not stop any appreciable amount of thermal or initial nuclear radiation. If unbroken, it may eliminate radiation hazard resulting from "fall-out", that is, the dropping of radio-active dirt particles as the bomb disturbance subsides. A uniform practice of having all windows open would permit a more rapid equalization of interior and exterior blast pressure and would, therefore, result in less total broken windows from any particular blast than would result if all windows were closed and fewer casualties from shattered-glass would result. Open windows will, to some degree, increase secondary fire hazards and would facilitate entry of any war gases which might be loosed in the area. With increased warning time and probable evacuation of a large part of the personnel from target areas, the contents of buildings where windows were left open would be exposed to the elements and possible looting for considerable periods of time. Certain types of windows, such as outswinging casements, canopies, pivoted and projected vents, if opened, might be slammed shut by the blast and shatter from the impact.

In general, it is recommended that each householder or building superintendent determine the position of the window sash which will result in the least damage to the particular type window construction and glazing which exists in his particular building and take appropriate action under the following general guide-lines:

(a) If the building is to be evacuated, that is, personnel moved away from the expected damage zone, all windows should be closed.

(b) If personnel take shelter in the building and time permits, double hung sash, inswinging casement or hopper vent windows should be opened. Outswinging casements, canopies and pivoted and projected vents should be closed.

(c) Windows left open and remaining unbroken after the blast should be closed as soon as possible thereafter.

Glazing Materials

There are many different types of glazing material in common use, and there are listed below those which are normally found or could be used in the various types of windows which have been discussed in the preceding sections. The following table gives the comparative cost per square foot of these materials, and also the pressures in pounds per square inch that would probably cause shattering. Cost figures should be considered as approximate and variable. The shatter pressures are for the glazing materials only and before considering the substitution of a glazing material that has a higher shatter pressure it should be determined that the sash, frame ahd frame fastenings are capable of resisting the increased loading that will result.

Approximate Cost Per Sq. Ft. in Large Quantities		Approximate Critical Shatter Pressures in pounds per sq. in. for 14" x 20" Panes
$ .28	Single Strength Window Glass - .087"	.30
.37	Double Strength Window Glass - .118"	.55
.50	3/16" Window Glass	1.40
1.12	1/4" Plate Glass	2.50
1.06	1/4" Safety Sheet Glass	2.50
.62	1/4" Wired Glass Figured	2.50
2.12	1/4' Polished Wired Glass	2.50
2.10	1/4" Tempered Glass	12.00
3.75	1/4" Double Plate with 1/4" space	3.50
.79	1/10" Plastic Acrylic	2.40
.98	1/8" Plastic Acrylic	3.70
1.27	3/16" Plastic Acrylic	8.30
1.90	1/4" Plastic Acrylic	14.80

Formula for computing shatter pressures is shown in Appendix A.

Corrugated wire glass and corrugated plastic are used in glazing skylights and in glazing continuous windows that are sometimes installed in the walls of shop buildings. Corrugated glass costs approximately $1.20 per square foot and corrugated plastic, 1/16" thick, reinforced with glass fibers, $0.75. Corrugated glass is very rigid, due to the depths of the corrugations, and in spans of five feet or more has very little resistance to a shock wave and has broken at pressures of less than 1 psi. The corrugated plastic, because it is more resilient than glass, will resist much larger pressures provided it does not pull out of the frame.

Plastic offers greater resistance to a blast wave than untempered glass of equal thickness because the material is more resilient; and if the grooves in the sash are sufficiently deep, the plastic may not be blown out of the frame as the pane bends under load at pressures that would break glass of the same thickness. Plastic of 1/4" thickness has proven in shock tube tests, and in limited full-scale tests against an atomic blast, to be a little stronger than 1/4" tempered glass. Thinner sheets of plastic should be mounted with at least a 3/8" lap in the frame to develop the strength of the material. The fragments of the plastic are not as dangerous as the fragments of glass, since they are not as sharp and pieces of the same size weigh less than half as much as glass. Plastic, however, not being as hard as glass, may be scratched in cleaning and, therefore, would have to be replaced after a number of years.

Safety glass and wired glass may be shattered by the shock wave and the panes still remain in the sash, provided the pressure is not too great. As the pressure is increased, however, this material will be broken into sections of about 15 to 30 square inches, and will be projected into the building at velocities that would cause injuries to personnel or damage to walls or equipment. The sections have sharp edges but usually do not have any long pointed fragments that would penetrate deeply.

Tempered glass breaks under high pressure into pieces of about 1" to 5" in diameter, each piece composed of many smaller pieces approximately 1/8" in diameter, loosely held together. The large pieces projected at high velocities will cause injuries but probably fewer fatalities, since the edges are dull, and like the wire and safety glass, do not have any long pointed pieces.

The single strength, double strength and 3/16" window glass, and 1/4" plate glass, all break into sharp pointed, irregular pieces that form dangerous missiles, provided the pressure of the blast wave is sufficiently high. The sizes of the fragments vary inversely with the strength of the blast; the low pressures breaking the glass into large pieces that may merely fall to the floor near the windows and high pressures breaking the glass panes into many fragments 1/2" to 1" in diameter, projecting them into the building along diverging lines. These lines may vary as much as 45° from the line of the blast and this expanding characteristic of the fragment pattern brings all of a room in line with the missiles except an area near the wall in which the windows are mounted.

The Glazing of Windows

If windows were not glazed, there would probably be little damage to the sash or frames provided the walls in which they were mounted were not damaged by the blast. Therefore, it can be assumed that glazing that offers the least resistance to a blast would cause the minimum of damage to the window construction.

Glazing materials should be selected that will be somewhat less resistant to a blast than the window construction, for it is much better insofar as structural damage is concerned to have the glazing fail than to have the entire window construction destroyed on account of excessive loads being transmitted to the frames from the panes.

Protective Inside Screens

From experience gained in full scale tests with atomic weapons, it has been found that 1/4" hardware cloth, woven with 20 to 23 gauge wire, heavily galvanized, makes probably the most satisfactory screen that can be applied inside of a window to stop the glass fragments. This material should be attached in such a manner that the full strength of the wire will be developed under load. Larger screens with 1/2" square mesh, and diamond mesh patterns of 1/2" x 1.2" and 3/4" x 2", have also been tested but were found to permit fragments to enter the room, which could cause serious injuries.

Heavy fabrics made of flameproof material also would be effective in stopping flying glass. These materials, to give the most satisfactory results, should be well-anchored at the top but not stretched tightly over the opening, otherwise the blast wave would probably tear them loose from their connection to the wall. No material should be used as a screen which is likely to be set on fire by the thermal radiation which passes through the glass with very little loss of intensity.

Venetian Blinds.

Venetian blinds constructed of wood, aluminum, and steel slats, exposed to an atomic blast of 4 psi over-pressure, were completely destroyed. The only blind that stopped the fragments at this pressure was one constructed of black plastic with the slats M-shaped in cross section. This design increases the strength of slats very materially and incidentally cuts out all light. The slats were held at the bottom and sides of the frame by means of a plastic channel, which did not prove of sufficient strength to hold the slats in place. However, the slats were not moved sufficiently out of line of the window by the blast to prevent them from stopping the glass fragments.

The blind was mounted in a window on the side of the building and, therefore, was not exposed to thermal radiation. The corrugated plastic referred to under glazing was 1/32" thick and blue in color, and this material was not affected by the heat, although it was exposed on a building to the full thermal radiation which was severe enough to scorch flame-resistant paint.

If venetian blinds are closed before a blast, they will prevent the thermal radiation from entering a room and setting fire to furniture and curtains. Thermal radiation lasts only a few seconds and most conventional types of venetian blinds, if closed, will materially assist in preventing ignition of combustibles within the building, since the blast wave will not reach the building and damage the blinds until after the heat flash is over. Dark colored wood blinds and cloth tapes might themselves be ignited.

Jalousies

Jalousies made with steel and aluminum slats have been exposed to overpressures of 1, 2 and 4 psi, and there was very little damage to any part of the jalousies except a slight bending of the slats at the highest pressure. A jalousie made with corrugated plastic slats exposed to 2 psi also was undamaged.

The windows behind the metal jalousies exposed to 4 psi were seriously damaged and those exposed to 2 psi were also damaged. Apparently the flexibility of the slats permits the blast wave to pass through the jalousie and damage the rigid window construction without permanently deforming the slats.

TABLE NO. 1 - BLAST EFFECTS ON WINDOW CONSTRUCTION AND GLAZING

(psi - pounds per square inch)

TYPE OF WINDOW	SIZE	FRAME & SASH SECTIONS		GLASS BREAKAGE	
Lightweight wood, double-hung with 12 panes 10½" x 15" Double strength (D.S.) glass	3'0"x5'-6"	At 2 psi Muntins broken Frame intact		At 2 psi All broken	
Lightweight aluminum out-swinging casements: 4 panes 1/8" glass 12" x 16" 4 panes 1/4" glass 12" x 16"	3'2"x4'2"	At 4.2 psi Frame bent	At 2 psi No damage	At 4.2 psi All broken	At 2 psi none of 1/4" broken. 1/8" not tested
Steel intermediate projected: 2 panes 1/4" plate 15" x 40" 2 panes 1/4" safety in vent	3'6"x5'6"	At 4.2 psi Muntin in vent bent	At 2 psi No damage	At 4.2 psi Panes broken only in vent	None at 2 psi
Heavy aluminum inswinging casement: 6 panes 18"x22"x1/4" tempered	4'8"x5'1"	At 7.4 psi Wrecked	At 3.2 psi No damage	At 7.4 psi All broken	None at 3.2 psi
Hopper vents, inswinging, steel: 4 panes 12"x42"-3/16" glass, 1/4" plate, tempered & plastic	4'0"x5'2"	At 7.4 psi Wrecked	At 3.2 psi No damage	At 7.4 psi All broken	At 3.2 psi 1/4" plate and 3/16" broken
Hopper vents inswinging aluminum: 4 panes 1/4" 12" x 42" tempered	4'0"x5'2"	At 7.4 psi Sash torn from frame	At 3.2 psi No damage	At 7.4 psi One pane broken	None at 3.2 psi
Heavy steel double-hung: 3 panes 1/4" plate and 1 D.S. 20" x 30"	4'2"x5'8"	At 4.2 psi Muntins bent	At 2 psi No damage	At 4.2 psi All broken	At 2 psi only D.S. pane broken
Heavy steel double-hung 4 panes 3/16" glass 12"x28"	2'8"x4'5"	At 3.2 psi No damage	At 3.2 psi No damage	At 3.2 psi All broken	At 1.5 psi only two panes broken
Canopy aluminum: 2 panes plate 1/4"x19"x33" 1 pane 1/8"x19"x33"	3'1"x5'4"	At 4.2 psi No damage	At 2 psi Latch broken	At 4.2 psi All broken	At 2 psi 1/8" pane broken

The shatter pressures of flat glazing materials exposed to blast are calculated by the following formula. It should be noted that a varying relationship between incident and reflected pressure exists and glass may break even though the pressure at which it shatters is considerably larger than the incident blast overpressure, due to the increase in overpressure caused by reflection. For example, when the incident blast pressure is 1 pound per square inch the reflected pressure will be approximately 2 pounds per square inch when the direction of the blast is perpendicular to the glass surface. The following table shows this relationship:

Incident Pressure Pounds per Sq. In.	Reflected Pressure Pounds per Sq. In.
1	2
2	4
3	6-1/2
4	9
6	14
8	19-1/2

Shatter pressure, $P = \frac{KRt^2}{A}$, when

P = Pounds per square inch required to shatter.

K = a constant = (approximately)
(62,000 for acrylic plastic
(50,000 for tempered plate
(10,500 for ordinary window glass

t = Thickness in inches

A = Area in square inches

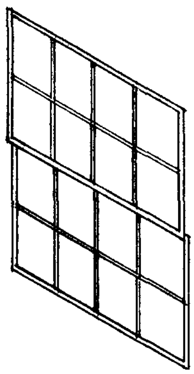
R is a factor related to the ratio of length of short side to the long side of the pane of glass and various values are given in the following table:

Appendix A (Cont'd)

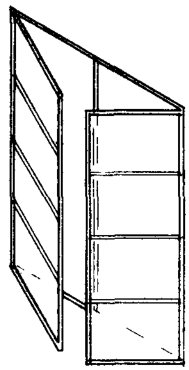
Ratio of Short to Long Side	R Factor
1.0 (square)	1.000
.9	1.005
.8	1.02
.7	1.07
.6	1.14
.5	1.25
.4	1.45
.3	1.8
.2	2.6
.1	5.0

For example, the pressure in pounds per square inch at which an 18" x 36" piece of double strength glass will shatter will be:

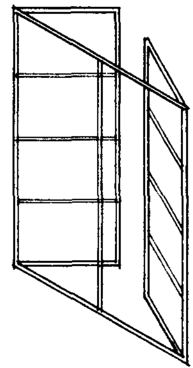
$$P = \frac{10,500 \times 1.25 \times (.118)^2}{18 \times 36} = .28 \text{ pounds per square inch}$$



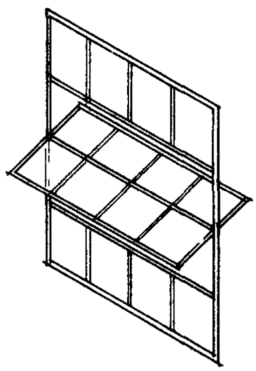
DOUBLE HUNG (1)



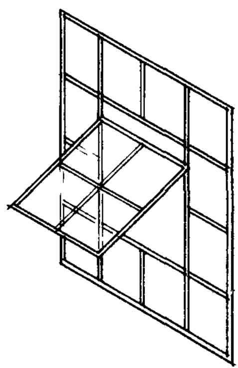
CASEMENT_OUTSWING (2)



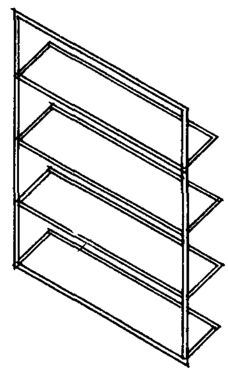
CASEMENT_INSWING (3)



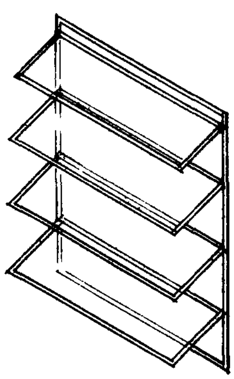
PIVOTED (4)



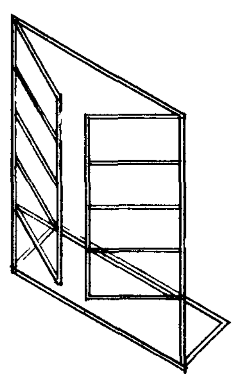
PROJECTED (5)



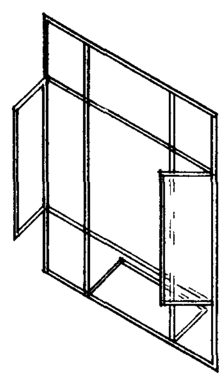
HOPPER VENTS (6)



CANOPY (7)



CASEMENT & VENT (8)



FIXED GLASS & VENTS (9)

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WINDOW TYPES

0-13