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NORWEGIAN TEST METHODS FOR WIND AND RAIN PENETRATION THROUGH WINDOWS

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Synopsis

The severe climate of Norway, characterized by high winds and heavy rain, motivated the Norwegian government to engage in an extensive window test program as part of a joint building research effort of four Scandinavian nations. In this paper, two participants of this Norwegian program give an analysis of general meteorological data and climatic factors of particular importance in window design. The authors describe different types of air-flow and rain penetration apparatus and give an account of results obtained with this equipment in preliminary and full scale tests of window structures with standardized dimensions. The authors conclude the paper by establishing window requirements adapted to Norway's particular weather conditions as an intermediate result of their research program which was still under way at the time of this symposium.

During recent years it has become more and more obvious that many of the window types used in Norway are not satisfactory. There are several reasons for this: The demands of living comfort have increased, the glass area is larger in modern architecture, more multistory buildings are being constructed, and more exposed regions are used for housing development. At the same time, lack of detailed knowledge has hampered the efforts to improve the situation.

As a consequence, the Norwegian Building Research Inst. (NBRI), when it was established in 1949, found it necessary to give the window problems a high priority on its research program. The work was started a few years later as part of a joint Scandinavian project sponsored by the building research institutions of Denmark, Finland, Sweden, and Norway. The NBRI undertook the task of investigating penetration of wind and rain through windows. Since then, such investigations have been carried out more or less continuously at the Institute's laboratory in Trondheim.

One of the reasons for assigning this part of the program to Norway was its geographical location. The country stretches from the 58th to the 71st parallel of latitude and its long coast faces the North Atlantic and Arctic oceans (Fig. 1). The climate is, therefore, rather severe in most regions, and high winds combined with heavy rain have always been important factors to be considered in house design. Practical experience, and especially the experience gained from

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failures, has furnished a considerable amount of useful information. In addition to this, the NBRI had previously carried out extensive tests of wind and rain penetration through different types of wood frame and masonry walls.

The investigation was planned and proceeded along the following lines:

As the first step, an analysis was made of all available data on the climate and the individual climatic factors. Based upon this, suitable test apparatus was designed and test conditions stipulated.

Parallel to this, the NBRI started a survey of current window types all over the country. At the same time, an attempt was made to collect information about the behavior of the windows.

The laboratory tests can be divided into two groups, preliminary tests and full scale tests. Because casement windows and pivoted windows are predominant in the Scandinavian countries, only these types were included in the test program.

In the preliminary tests, the air leakage through the joint between window frame and wall was investigated. A study was also made of the different kinds of locking devices and the force these devices can provide on the window stops. The values obtained in this way were then used for testing the air flow through the joint between sash and frame.

The full scale tests were carried out on windows with the standardized dimensions of 120 by 120 cm. The investigation was carried out in both wind and rain apparatus and included reproducibility of tests, variations from specimen to specimen of the same kind, influence of aging, and effect of weather stripping. A great number of different types of windows was tested. The full scale tests also yielded valuable information about water penetration in the joint between frame and wall.

The last part of the program comprised an evaluation of the test results compared to field experience. An attempt has

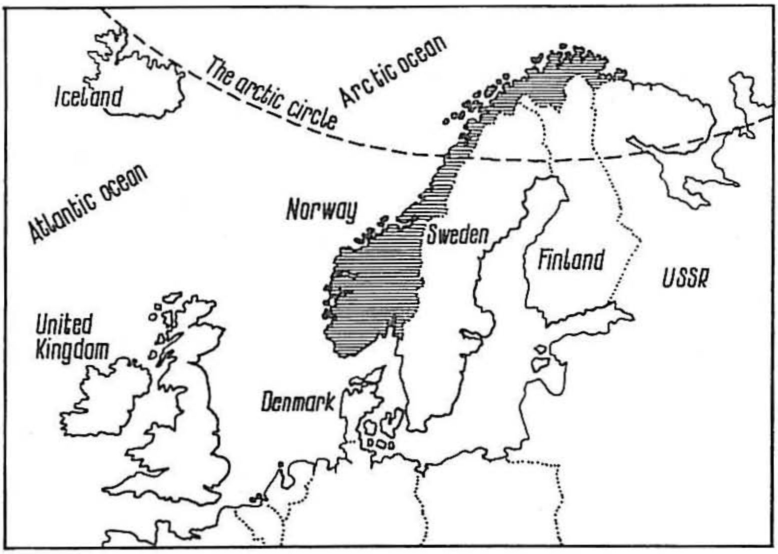

FIG. 1.—Map of Northern Europe.

been made to establish quality requirements for windows and to clarify the main principles to be followed in first class window design.

CLIMATIC FACTORS

The ordinary observations from the meteorological stations give a good general idea of the Norwegian climate. Large regions of the country have 40 or more days a year with wind of at least gale force, that is, with wind velocity higher than 15 m per sec. On days with this type of weather, the wind almost always blows from the sea and is, as a rule, accompanied by large amounts of rain. The temperature remains mostly only a few degrees above the freezing point. Very cold and clear weather is also quite frequently combined with strong winds, in this case from the east.

At the Technical University in Trondheim, measurements of wind-driven rain have been made daily since 1937 with the Holmgren directional rain gage shown in Fig. 2. The gage registers simultaneously the vertical precipitation and the horizontal rain component from the four cardinal directions. Since 1951, similar gages have been in regular use at four meteorological stations along the coast of Norway.

The records from Trondheim show huge differences during the year and from year to year. In extreme cases, the amount of horizontal rain from a single direction (west) has been more extensive than the vertical precipitation for several consecutive months. The most severe attacks are, however, of a far shorter duration, lasting from a few hours up to two to three days. There is a definite connection between these short attacks and the great majority of reports concerning rain penetration and rain damage.

For shorter periods of time, the wind-driven rain was automatically recorded with a pluviograph. In this way, more detailed data can be obtained as indicated in Fig. 3 where the amounts of rain in a 12-hr period are plotted in intervals of 10 min. The highest values thus observed in Trondheim have been 7 liters per sq m in 1 hr and approximately 50 liters per sq m in 24 hr. It must be assumed that the maximum values along the west coast of Norway are appreciably higher than this.

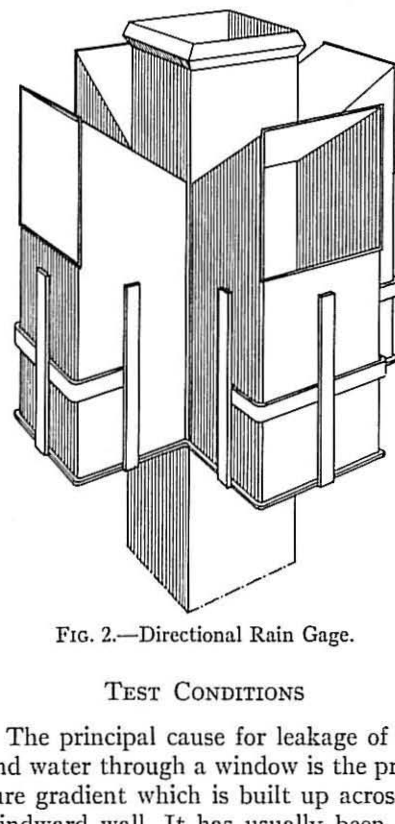

FIG. 2.—Directional Rain Gage.

TEST CONDITIONS

The principal cause for leakage of air and water through a window is the pressure gradient which is built up across a windward wall. It has usually been assumed that the approximate magnitude of this superpressure can be computed from the equation:

$$p = \frac{v^2}{16}$$

where p is the superpressure in kg per sq m and v the wind velocity in m per sec. Wind velocity observations are the average values from 10-min measuring time during which instantaneous maxi-

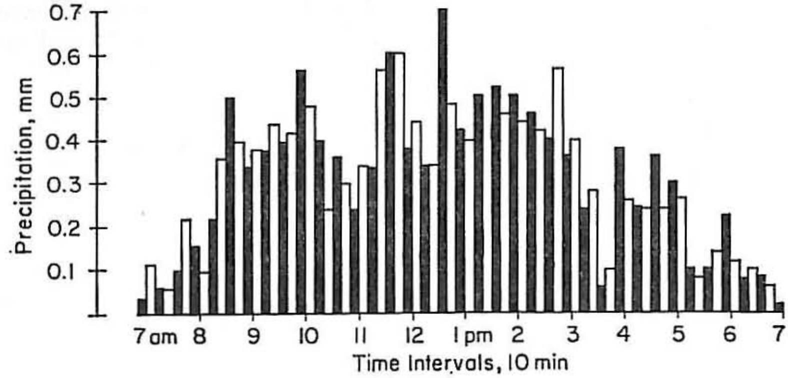

FIG. 3.—Precipitation Measured in Trondheim During 12 hr of Driving Rain in Western Direction.

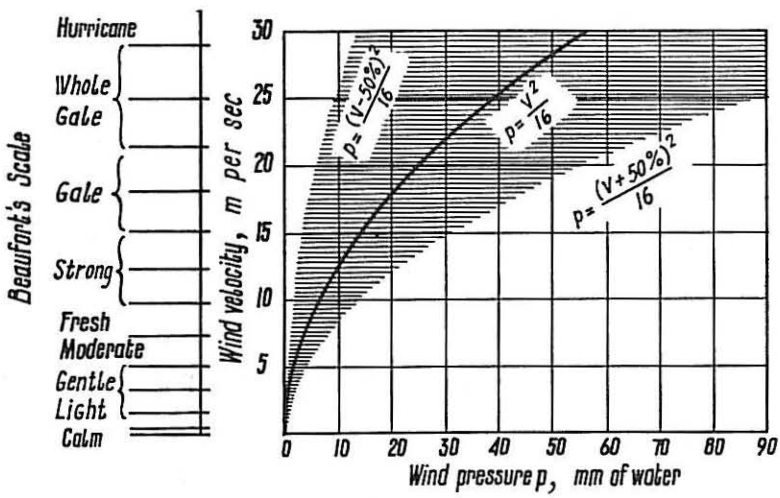

FIG. 4.—Wind Pressure *versus* Wind Velocity.

mum and minimum values can be some 50 per cent higher and lower (Fig. 4).

Several observations of superpressure across real walls have been made at NBRI in Trondheim. The observations seemed to verify this equation. At a wind velocity of 17 m per sec, for instance, maximum superpressure values slightly higher than 30 kg per sq m were recorded in readings taken at infrequent intervals over several months. During the same period, pressure gradients close to 50 kg per sq m were also observed. Information gathered from other parts of Norway strongly indicate that pressure differences as high as 150 kg per sq m are not unusual in the country's most exposed regions.

On the basis of what was learned about

climatic exposure, the design of wind and rain apparatus was started. It was considered necessary for the laboratory equipment to meet the following requirements:

The air superpressure in the two apparatus should be adjustable from zero to a maximum value well above the highest wind pressures normally occurring in exposed regions. It was assumed that static pressures could be used during tests.

The test specimens in the rain apparatus should be exposed to amounts of water corresponding to high but real values of wind-driven rain. Preliminary tests had shown that excessive waterflow was to be avoided because joints and cracks which stayed dry even in the heaviest rain in the field became covered with water if the flow was exaggerated. Thus, the pressure gradient would be disturbed, making the test results valueless.

The water should be applied in the forms of drops having sizes, horizontal velocity, and angle of incidence approximately like real raindrops. In this way the water, during the tests as in the field, would be able to enter the broader cracks and joints. For the same reason, the angle of incidence had to be adjustable in both the horizontal and vertical planes. The drops should be able to hit any exterior point of the test specimen, even the underside of projections.

TEST APPARATUS AND PROCEDURE

Based upon the test program and the test conditions described above, three different apparatus were designed; two for the air flow measurements, the third for the rain penetration tests.

Small Air-Flow Test Apparatus:

This apparatus consisted of an open box with the test specimen forming the lid. It was placed in a horizontal position with the opening facing up. The box was given an optimal airtightness by means of a sheet metal lining on the inside. A soft rubber gasket sealed the joint between the box and the specimen. To

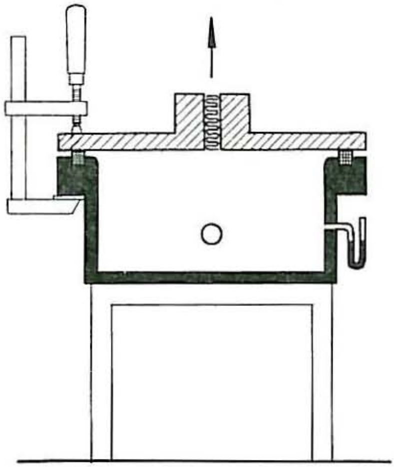

FIG. 5.—Small Air-Flow Test Apparatus for Single Joints.

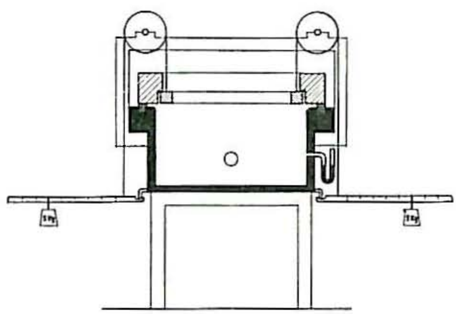

FIG. 6.—Small Air-Flow Tests Apparatus for Pressure Effect from Locking Devices.

check the tightness of the setup, a metal covered spare lid was used. The test specimen was 62 by 115 cm.

The air flow tests were carried out by inducing an air pressure drop across the specimen. This was obtained by blowing air under constant pressure into the box. The superpressure was registered by differential manometers and the air flow was measured at the inlet. The equipment for control and measurements was the same as in the large air flow test apparatus. The small unit was used for the preliminary tests.

Figure 5 shows the equipment for testing the joint between the window frame and the wall. In this case, the specimen was a split slab with an adjustable joint between the two parts of the slab. The length of the joint was 115 cm. Its width and depth could be varied. The slab was made air-tight except for the test joint and was fastened to the box by means of C-clamps. Air flow through joints was measured at a pressure drop varying from 10 to 70 kg per sq m in the following sequence: 10, 30, 50, 70, 60, 40, and 20 kg per sq m.

Figure 6 shows the apparatus when used for testing joints between the sash and the frame. The specimen was a wood casement window with single stop on the frame. The sash was facing down and the desired pressure of the sash against the frame was obtained by a system of weights and levers. This load was given an upward direction by transferring it *via* wires over frictionless wheels resting on an axle above the sash. The wheels could slide along the axle and thus the number of load points as well as their location could be varied along the sash rail. The flow measurements were carried out at the same air pressure drop intervals as described above. The loads simulating the pressure forces from locking devices were varied from 5 kg to 50 kg per point at 5-kg intervals. The weight of sash and glass was counterbalanced. The four joints along the perimeter of the sash were tested separately by sealing the three others with a caulking material. In addition, the four joints were all tested simultaneously.

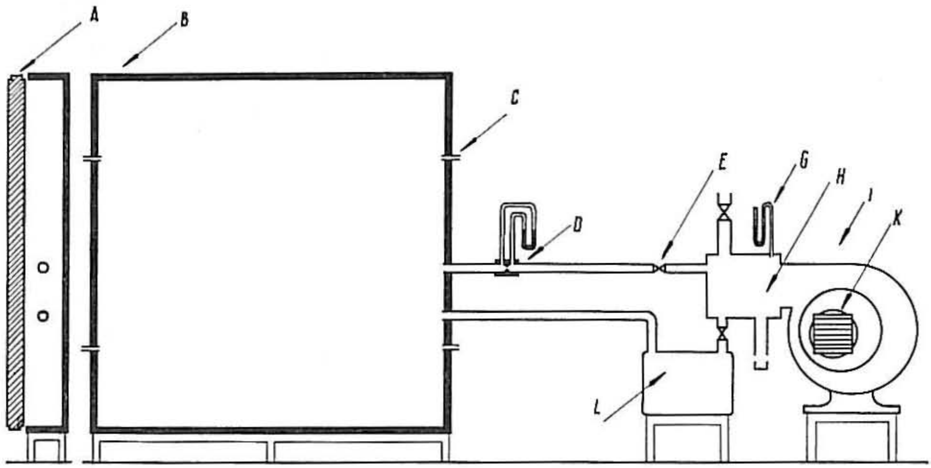

FIG. 7.—Large Air-Flow Test Apparatus.

Large Air-Flow Test Apparatus:

This apparatus was built upon the same principles as the small unit and had a vertical test area of 185 by 185 cm. It was equipped with an inspection window which allowed checking of the specimen from inside the chamber. It also had a spare panel for checking the tightness of the apparatus itself. Both chamber and check panel were metal covered (zinc with soldered joints).

Figure 7 is a schematic presentation of the large apparatus. The equipment for air supply and measurements consisted of a centrifugal fan connected to a plenum. From the plenum, air could be let into the chamber through one of two different channels, depending on the tightness of the specimen. The low-capacity channel led through a gas flow meter. A flow-measuring device, based upon the pressure differences across interchangeable orifices, was built in the high-capacity pipe. The air superpressure was measured by differential manometers with an accuracy of 0.1 kg per sq m. Outlets for measurements of pressure distribution in the joints and air spaces of the test specimen were also connected to the same manometer panel. Control of the superpressure was obtained by an adjustable air inlet on the fan and by valves in the two channels.

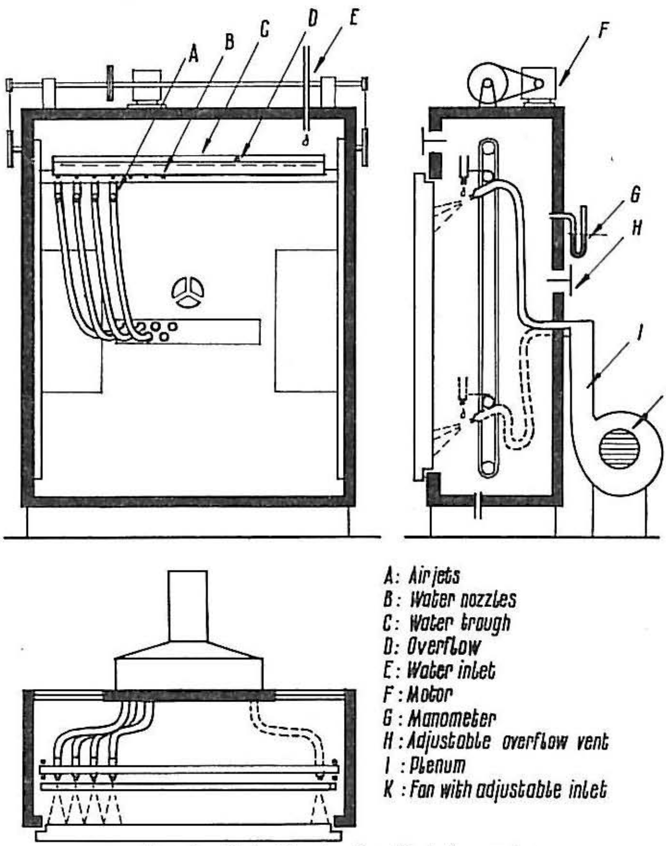

FIG. 8.—Rain Penetration Test Apparatus.

Since the apparatus was designed for use in both window and wood frame wall investigations, the test area was set to 185 by 185 cm. This area represented a wood frame panel three stud spaces wide

(2 ft spacing) and two fire-stop spaces high. However, the windows tested were normally 120 by 120 cm. It was therefore necessary to build the windows into spare test panels or masking frames with the correct exterior dimensions to match the apparatus and with an opening related to the size of the window.

During tests, a single problem or subject was isolated in every case. Thus, the main joints involved in the window program, the one between window frame and the wall and the other between the sash and the window frame, were tested separately. In the full scale tests on window surrounds, the sash was left out and replaced by an aluminium pane fitting directly in the window frame with caulked joints. In this case, the masking frames were complete wood frame walls. When testing joints between the sash and the frame, the masking panel was covered by sheet metal and the joints between frame and wall were sealed by caulking compound all around the window. This also applied to the tests on rain penetration.

Rain Penetration Test Apparatus:

Figure 8 is a sketch of the rain test apparatus. The test chamber was very similar in size and construction to the air flow test unit. The rain apparatus was built primarily for the window tests but, to make it possible to test the same specimens in both apparatus, the test areas were kept alike. The purpose of the chamber was only to maintain the desired superpressure—complete airtightness was not required. Air was fed into the chamber through 16 flexible hoses leading from a plenum outside the chamber. A centrifugal fan was connected directly to the plenum. Inside the chamber, the hoses led to 16 air jets pointing towards the specimen and attached to the under side of a horizontal axle parallel to the panel. Supported by the same axle and parallel to it was a water trough with 16 water nozzles fixed to the bottom just above the air jets.

Drops of water with an approximate diameter of 5 mm were formed by the nozzles. When these drops fell into the concentrated air stream from the jets, they were split into a large number of droplets of varying sizes and blown against the specimen. By means of an overflow, the water was kept at a constant level in the trough. This level and the opening of the nozzles determined the amount of water. The air jets could be adjusted to any desired angle in the horizontal and vertical projection thus forcing the simulated driving rain in the desired direction.

The velocity of the drops and the superpressure in the chamber could be regulated independently by an adjustable air inlet on the fan and by variable overflow vents in the chamber. To provide for a uniform spray over the entire test panel, the axle carrying the spray equipment was mobile and travelled up and down at a constant rate of one cycle every 25 sec per sq m per hr.

The amount of water normally used was 9 liters and the rain angle downwards was 30 deg with the horizontal. Pressure differences were varied from 10 to 70 kg per sq m. The test procedure was normally a stepwise progression with increasing pressure differences. The remaining test factors were kept constant. The pressure drop intervals were usually 10, 20, 35, 50, and 70 kg per sq m and the exposure time was 5 hr at every pressure step. In some cases, the spray equipment was kept in a certain position to give extra load on a specific part of the window. If desired, some of the water nozzles could be masked out.

CONCLUSION

The research work, which is continuing, has so far included a considerable number of preliminary tests and approximately 75 full-scale window tests. During the progress of the research program, there has been a marked trend in the work from general investigations towards the solving of more specialized problems. Whereas most of the time formerly was spent in studying principles common to large groups of windows, more work is now done on analyzing individual constructions. The reason for this is that more and more manufacturers send their new types of windows to the laboratory for testing before they introduce them on the market.

This has made it necessary to establish certain quality requirements with regard to wind and rain tightness. As far as Norway is concerned, there are very few local variations in the preference of windows, and a new construction may be used anywhere in the country. The quality requirements must, therefore, principally be based upon the most severe conditions and not upon the average climate.

Figure 9 shows tentative evaluation curves suggested by the NBRI for the air penetration of windows. The curves may seem severe, but they are prepared on the basis of the following considerations: Air leakage through a window is undesirable both because it increases the heat loss from the house and because it usually occurs in the form of a concentrated and unpleasant draft. The increased heat loss is frequently considered rather insignificant. A simple calculation shows, however, that a leaky window in severe climate can easily cause higher heat loss through air penetration than through the sum of heat transmission and radiation. In a country like Norway where heating costs are high, this fact is quite important.

Even where the total leakage is small, currents of cold air emerging from a window may be a real nuisance. The majority of complaints about windows refer to just this kind of defect. Therefore, the evaluation also has to consider possible drafts noticed during the test. The corners of the sash-frame joint, the hinges of pivoted windows, and the locking devices are frequently weak points in this respect.

The requirements suggested for rain tightness are also rather severe, but they too are based upon practical considerations. No water should be allowed to leak through the window during the test,

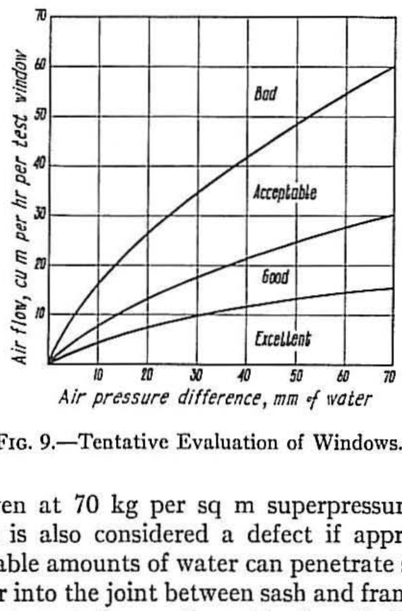

FIG. 9.—Tentative Evaluation of Windows.

even at 70 kg per sq m superpressure. It is also considered a defect if appreciable amounts of water can penetrate so far into the joint between sash and frame as to wet the weather stripping. If this water freezes during a sudden temperature drop, the weather stripping may be ruined the next time the window is opened. Cavities and pockets which can stay full of water for a long time should definitely be avoided.

It is evident that requirements like those mentioned above can be valid only within a single country. Since the superpressure increases with the square of the wind velocity, even small changes in climate can make a large difference.

From one country to another, there are also significant dissimilarities in building practice, customary heating systems, housing habits, and cost of heating. All those factors and several others have to be taken into consideration before quality requirements for windows are established.

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