

E 487

Bibliotheek Hoofdkantoor TNO
TNO's-Gravenhage
INSTITUUT VOOR MILIEUHYGIENE
EN GEZONDHEIDSTECHNIEK TNO
publikatie nr. 486
DELFT - SCHOEMAKERSTRAAT 97 - POSTBUS 214

C.I.E. T.C.-4.2
Eclairage du Jour
Daylighting
Tageslichtbeleuchtung

25 JUNI 1975

SYMPOSIUM

BAIES

VITREES ET LEURS FONCTIONS DANS LE CONCEPT
ARCHITECTURAL

WINDOWS AND THEIR FUNCTIONS IN ARCHITECTURAL
DESIGN

FENSTER UND IHRE FUNKTION IN DER BAUPLANUNG

compte rendu de session
proceedings
tagungsbericht

TEKNIK UNIVERSITETE - ISTANBUL 22 - 27.10.1973

Publication du Comité National Belge de l'Eclairage (C.N.B.E.)
Galerie Ravenstein, 3, 1000 Bruxelles - Tél. 511.60.90.

5.4. - Acoustical aspectsWINDOWS AND NOISE (*)

by J. van IERLAND

CONTENTS

	<u>page</u>
6.2.1. Introduction	0 1
6.2.2. Reducing outdoor levels	0 1
6.2.3. Factors in the sound insulation of windows	0 2
6.2.4. Selection of window type	0 5
6.2.5. Improving existing windows	0 6
Literature	0 7
Figures and tables:	
6.2/1 Approximate average level difference ($\bar{D}$) for various types of windows [4]	0 9
6.2/2 "Insulation values" of various types of glazing [5]	
6.2/3 Recommended window types with regard to road traffic noise, according to type of room and location [4]	010
6.2/4 Recommended classes of insulation (5....0) with regard to road traffic noise, according to type of room, type of road and distance [3]	011
6.2/5 Classification of windows according to insulation [3]	012
Annexes:	
6.2 A Noise rating and critical indoor levels	014
6.2 B Some acoustical concepts	018

(*) Paper prepared as a draft contribution to Chapter 6.2 of International Recommendations on Daylighting being worked out by Committee T.C.-4.2.

6.2.1 Introduction

An important function of a building is: to offer a shelter, amongst other things, against external noise. In this respect, windows may be relatively weak spots. The paragraphs which follow concern possibilities to provide quiet without sacrificing the pleasure of adequate daylight and a view outside. They apply to both, edifices which still have to be built and those which need correction or adaptation to either increased noise or increased requirements.

Many disappointments have taught that attention to noise problems should be paid from the first stage of design of a building till the maintenance of its windows.

The following may be applied without excessive calculations. The reader is expected to be somewhat familiar with fundamentals of acoustics, a short refresher of which is given in the annexe 6.2 B. In critical situations calculations and possibly measurements may be needed for proper decision as to the required insulation. The methods will not be dealt with here, as they require judgment to an extent which can only be got from intensive training and experience. In view of communication with experts, some general information is provided in the annexe 6.2 A on criteria for indoor levels of intruding sounds.

6.2.2 Reducing outdoor levels

Excessive problems of insulation may be prevented by reducing the burden of sound upon windows. Possibilities may be found in: noise abatement at the sources; regional and town planning; selection and design of the building site; screening the building or its windows; adequate layout of the building.

As a rule, limitation of the noise in the environment of the (future) building will be beyond the power of the designer or the principal. In those special cases where it is within their competence, noise abatement should start at the sources.

Both in the selection and the planning of the site the distance of the building to possible noise sources should be considered. Doubling the distance yields an improvement of 6 dB(A) for a point source, and approximately 3 dB(A) for a line source (such as continuous road traffic).

The effect of screening is in the order of 10 dB(A); under favourable conditions it may be as large as 20 dB(A). Screening is most effective with higher frequencies. Four types of screening may be distinguished:

- a) by separate screens, such as walls. Size and distance have to be adapted to those of the source and of the part of the façade to be screened [6, 16].
- b) by projecting or recessed parts of the façade, such as balconies etc. However, it should be kept in mind that such devices, whilst screening one window, may reflect sounds towards other windows. This effect may be reduced by the application of absorbing material.
- c) by the building itself: by proper layout of the building and adequate position of rooms and windows which are critical with regard to external noise.
- d) by other buildings, which are less critical from the angle of noise. This may be applied in the design of a larger, e.g. industrial, complex and especially in regional and town planning.

In the structural plan already, attention should be paid to the prevention of noise passing from one room to the other along (opened) windows.

6.2.3 Factors in the sound insulation of windows

6.2.3.1 Sealing

Adequate sealing is a first condition for sound insulation. Other things being equal, the insulation of a normal openable single window, when closed, is approximately 8 dB less than of the well-sealed window. The reduction can be even greater in the case of double windows as the combined effect of window and gaps depends mainly upon the latter [7].

6.2.3.2 Mass per m²

The airborne sound insulation of a glass pane (of infinite size) depends upon its mass per m² (m), i.e. approximately upon the thickness (h), the relation being: $m \approx 2,5 h$ (kg/m²; mm).

Up to a certain frequency (vide next paragraph), doubling the mass per m² yields approximately 4...5 dB more insulation ("mass law").

6.2.3.3 Bending stiffness

From a certain frequency - called critical frequency, f_c - onward, the insulation is much (up to 15 or 20 dB) less than might be expected according to the mass law. This is due to the projected wavelength of the incident sound being equal to that of free bending waves within the pane. This effect is called "coincidence effect". As far as possible the critical frequency should be larger than the relevant frequencies. Its value depends upon the bending stiffness of the pane, which again depends upon h :

$$f_c \approx \frac{12\,000}{h} \quad (\text{Hz; mm})$$

Because of this effect, there is no use - with regard to common road traffic noise - in applying single glazing with $h > 10$ or 12 mm, i.e. with coincidence frequencies $< \text{appr. } 1000 \text{ Hz}$. The marginal effect of increasing the thickness beyond 10 mm is shown in the left part of Fig. 6.2/2. Where more insulation is required, double or possibly laminated glazing should be applied. Laminated glass allows an increase in thickness without the corresponding lowering of the critical frequency [8]. For double glazing, vide par. 6.2.3.6.

6.2.3.4 Area

The effect of halving the window-size - in the case of well sealed windows in a well insulating façade - is 3 dB. In many practical situations it will be less.

6.2.3.5 Angle of incidence

By and large, the insulation decreases with increasing angle of incidence (with the normal of the pane). As a consequence, levels of traffic noise in rooms on higher floors are higher than might be expected on account of the larger distance.

6.2.3.6 Double glazing

In case of double panes (thicknesses h_1 and h_2 , distance d) the insulation is poor near the resonance frequency (f_r) of the system (glass-air-glass). For lower frequencies it is much the same as that of one pane with thickness $h = h_1 + h_2$. Above the resonance frequency the effect of the air space increases strongly. Therefore it is important that thicknesses and distance of the panes are such that the resonance frequency is low as compared with relevant frequencies.

According to [14], p. 500, in IS-units (kg, m s) the resonance frequency

is found from:

$$f_0 = 60 \sqrt{\frac{1}{d} \left(\frac{1}{M_1} + \frac{1}{M_2} \right)} \approx 1,2 \sqrt{\frac{1}{d} \left(\frac{1}{h_1} + \frac{1}{h_2} \right)}.$$

It follows that the common type of double glazing (with panes of 4 mm and a distance of 8 or 10 mm) - effective as it is for thermal insulation - is poor as regards sound insulation: the resonance frequency is about 200 Hz, the frequency of maximum power of road-traffic sound.

In view of the coincidence effect (par. 6.2.3.3) it is recommended that $h_1 \neq h_2$. Vide Fig. 6.2/2 and 6.2/6.

Insulation of double glazing is much improved in all frequencies by increasing the air space. Especially for good results in the lower frequencies a large air space (e.g. 15 cm) is required.

To some extent insulation may be improved by the application of sound absorbent material to the edges of the air space. The effect is small for the lower frequencies. With road-traffic sound a gain of 2 dB(A) may be expected [5].

6.2.3.7 Frame

With openable windows without gaskets the insulation is better to ^{the} extent that the frame section is larger. With sealed windows or windows with gaskets the insulation is virtually independent of the type of frame. Gaskets are more easily applied with wooden frames and nowadays they must be considered part of their construction.

6.2.3.8 Edge mounting

With regard to the effect of various methods of edge mounting, findings show considerable differences. These may be due to the fact that elastic materials may lose their damping effect if not applied with due care [7].

6.2.3.9 Ventilation openings

For the middle of the room the average level difference ¹⁾ $(\bar{D})$ of an open window is 10 ± 5 dB, depending upon the size of the opening. Near the window it is virtually zero. Apart from very low requirements as regards insulation, and apart from situations where sufficient fresh air

¹⁾ Vide annexe 6.2 B9.

may be applied by opening windows during quiet periods, special provisions will be needed for ventilation.

A common single window - either openable or sealed, and with, say, 4 mm glazing - may be combined with a small ventilation opening (possibly with a powered fan). When this is closed the average level difference of the combination is 18 to 20 dB, approximately equal to that of an openable window. When it is open, this will result in a reduction by one or two dB.

Where (sealed) windows with heavy or possible double glazing are required, the same ventilation system would spoil their effect. For such cases a solution may be found in a double window with small staggered ventilation openings (the outer one possibly with a powered fan) and with absorbent material on the edges of the air space. The average level difference will be at least 30 dB when the system is closed [6, 17]. In all cases of forced ventilation - whether simple as those mentioned above or part of a larger installation - its effect on the balance of sounds from outside and those originating within the interior should be considered.

6.2.4 Selection of window type

Often an expert analysis will be needed for the proper solution of insulation problems. For ordinary situations graphs, tables and recommendations in practical terms are available as aids to designers. This applies especially for a very common kind of outdoor noise, i.e. road traffic noise.

Table 6.2/1 shows differences between the levels outside near the window and inside on some distance of the window for various window types. The values, having been determined for diffuse sound fields (whereas most outdoor noise is directional) and for certain practical conditions of application, are approximations, mainly for the purpose of comparison.

Figure 6.2/2 allows a comparison of effects in dB(A), for standardized road traffic noise, obtained with various types of glazing in well sealed windows [5].

Table 6.2/3 shows a simple system for the selection of adequate window types as regards road traffic noise [4]. Another such system [3] consists of two tables: the required class of insulation is found from figure 6.2/4, and subsequently figure 6.2/5 shows the types of windows within that class. Both systems are based upon a classification of rooms, locations and window constructions. Rooms which are not mentioned may be dealt with by analogy. Attention is called to differences in both classifications of rooms. As is indicated by the presentation, because of underlying assumptions, accuracy is limited to approximately ± 5 dB.

The reader is referred to [8] for elaborate documentation on insulation values of windows.

6.2.5 Improving existing windows

According to paragraph 6.2.3 the main possibilities for improving the insulation of windows are:

- better sealing
- thicker glazing
- applying an extra window or increasing the distance between panes

For optimal results their application should be balanced. Without adequate sealing other measures will not be effective. Perfect joints between wall and frame and around the glass are a first requirement. For windows without gaskets (older types of wooden frames; possibly also metal frames) fitting and adjusting may be improved; gaskets may be applied (e.g. PVC, neoprane, aluminium). In windows with gaskets, replacement of the latter may be necessary. Injection of elastic gaskets may be considered. For the adequate application of thicker glass, double windows or increased air space, principles will be found in paragraph 6.2.3. In such cases attention should be paid that the construction is adapted to the increased weight and that building regulations are respected.

Literature:

1. ISO/R 1996. Assessment of noise with respect to community response; may 1971.
2. COMAPI/CSTB. L'isolation phonique et thermique, Compte rendu du VIIIe colloque. Cahiers du CSTB-no 128, avril 1972.
3. VDI 2719 (Draft) Sound insulation of windows, 1972 (in German).
4. British Standard Code of Practice; CP 3: Ch III, Sound insulation and noise reduction, Part 2, 1972.
5. W.A. Oosting, The sound insulation of single and double glazings with respect to traffic noise, Proc. AICB Congress "Noise 2000", 1970.
6. D.P. Turner (ed). Windows and Environment, Pilkington Bros Ltd., 1969.
7. P.T. Lewis, Real windows; Ch VII in: T. Smith et al, Building Acoustics; British Acoustical Society. Spec. Vol. no 2, New Castle u.T. 1971.
8. J.A. Marsh, The airborne sound insulation of glass, Applied Acoustics, 4 (1971), p. 55, 131, 175.
9. Th.J. Schultz. Community noise ratings, Applied Science Publ. London 1972.
10. J.A. Godfrey et al, Double glazing and double windows. Building Research Station Digest no 140, H.M.S.O. april 1972.
11. ISO R 140, Field and Laboratory measurement of airborne and impact sound transmission. 1960.
12. ISO R 717, Rating of sound insulation for dwellings, 1968.
13. A. Eisenberg, Sound insulation of windows (in German), Berichte aus der Bauforschung, Heft 63, (1969), p. 25.
14. L.L. Beranek (ed), Noise and Vibration Control, Mc Graw Hill, New York, 1971.
15. An., Methods for increasing the sound insulation of the glazed parts of a building. Compagnie de Saint-Gobain, (without year).
16. W.E. Scholes and J.W. Sargent, Designing against noise from road traffic; Applied Acoustics 4 (1971), p. 203.

17. R.D. Ford and G. Kerry, The sound insulation of partially open double glazing, *Applied Acoustics*, 6 (1973) p. 57.

Table 6.2/1: Approximate average level differences ($\bar{D}$) for various types of windows. [4]

Construction	$\bar{D}$ 1)
	dB
Wide-open window	about 5
Slightly open single window	10 - 15
Closed "openable" single window	18 - 20
Sealed single window (3...4 mm glass)	23 - 25
Sealed single window (6 mm plate glass)	27
Sealed single window (9 mm plate glass)	30
Ventilated double window (5 percent area of "indirect" ventilation)	15 - 20
Closed "openable" double window (any weight of glass, with an air-space of 200 mm and absorbent-lined reveals)	30 - 33
Sealed double window (4 mm glass with an air-space of 200 mm and absorbent-lined reveals)	40
Sealed double window (6 mm plate glass with an air-space of 200 mm and absorbent-lined reveals)	42
Sealed double window (4 mm glass one side and 6 mm plate glass other side, 200 mm air-space and absorbent-lined reveals)	42 - 43

1) The values include some allowance for transmission by other parts of the façade and for flanking transmission, with normal traditional construction.

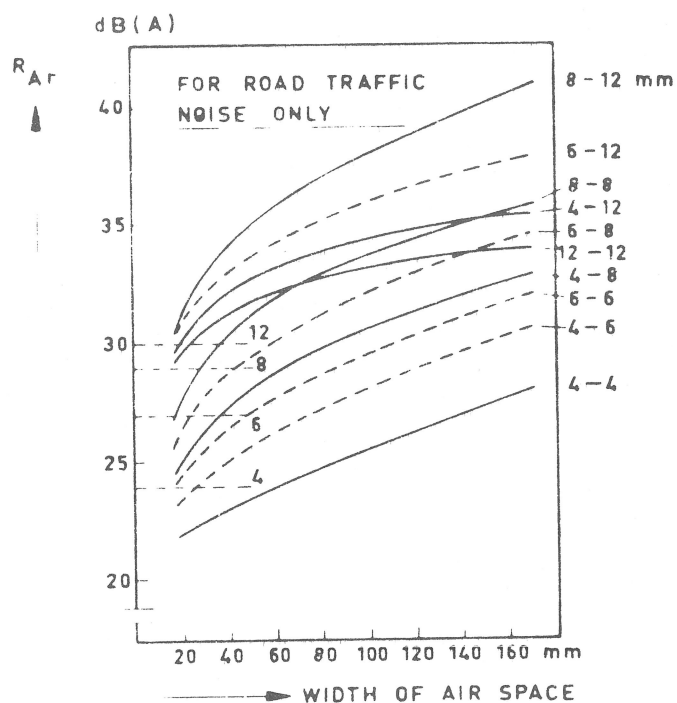


FIG. 6.2/2 "INSULATION VALUES" OF VARIOUS TYPES OF GLAZING.
 THE VALUES (R_{Ar}) APPLY FOR THE A-WEIGHTED LEVEL
 OF ROAD TRAFFIC SOUND, STANDARDIZED ACCORDING TO [5]
 PARAMETER: THICKNESS OF PANES

Table 6.2/3: Recommended window types with regard to road traffic noise according to rooms and locations [4].

Room	Location				
	A/B	C	D	E	F/G
Lecture theatre etc.		Double	Double	Sealed heavy	Sealed light
Bedroom	Double	Double	Sealed heavy	Sealed light	Openable light
Living room	Sealed heavy	Sealed light	Openable light	Openable light	Openable light
Classroom	Double	Sealed light	Openable light	Openable light	Open
Executive office	Sealed heavy	Sealed light	Openable light	Openable light	Open
General office	Openable light	Openable light	Open	Open	Open

Where:

- A Arterial roads with many heavy vehicles and buses
- B (i) Major roads with heavy traffic and buses
(ii) Side roads within 15-20 m of A or B (i) groups roads
- C (i) Main residential roads
(ii) Side roads within 20-50 m heavy traffic routes
(iii) Courtyards of blocks of flats screened from direct view of heavy traffic
- D Residential roads with local traffic only
- E (i) Minor roads
(ii) Gardens of houses with traffic routes more than 100m distant
- F Parks, courtyards, gardens in residential areas well away from traffic routes
- G Places of few local noises and only very distant traffic

Table 6.2/4: Recommended classes of insulation (5.....0) with regard to road traffic noise according to types of room, types of road and distance [3].

	distance	type of room			
	m	A	B	C	D
Main road in city;					
close building; high tr. density		5	5	4	3
spaced building; med. to high density		4	4	3	2
Motor highway; high traffic density	25	5	4	3	2
	80	4	3	2	1
	250	2	1	0	0
Motor highway; medium traffic density	25	4	3	2	1
	80	3	2	1	0
	250	1	0	0	0
Main through route	8	3	2	1	0
	25	2	1	0	0
	80	1	0	0	0
Main road	8	2	1	0	0
	25	1	0	0	0
	80	0	0	0	0

Where:

- A residential rooms in dwellings, hotel rooms, patients rooms
- B class rooms, private offices, study rooms, libraries, conference rooms, lecture rooms, rooms for medical investigation or treatment, churches, auditories
- C Offices for two or more persons
- D large offices, restaurants, shops,
- 0 5 classes, applied in table 6.2/5

Table 6.2/5: Classification of windows according to insulation¹⁾ [3]

class

- 0 - window with gaps, either with single glazing or "thermal" double glazing²⁾
- 1 - window without gasket, with thermal double glazing
- joint window³⁾ without gasket, $\Sigma h = 6 \text{ mm}$
- 2 - sealed window or window with gasket; 6 mm pane or thermal double glazing
- joint window, with gasket and $\Sigma h = 6$
- 3 - sealed window or window with gasket; 12 mm pane or multiple thermal glazing
- joint window with gasket; $\Sigma h \geq 9 \text{ mm}$; distance $d = 4 \dots 5 \text{ cm}$
- 2 separate windows without gaskets⁴⁾; $\Sigma h \geq 6 \text{ mm}$; $d \geq \sim 10 \text{ cm}$
- 4 - joint window with special sealing; $\Sigma h \geq 9 \text{ mm}$; $d \geq 6 \text{ cm}$
- 2 separate windows, with gaskets; $\Sigma h \geq 6 \text{ mm}$; $d \geq 10 \text{ cm}$
- 5 - joint window, acoustically disconnected, with special sealing, $\Sigma h \geq 9 \text{ mm}$, $d \geq 10 \text{ cm}$
- 2 separate windows, with special sealing; $\Sigma h \geq 9 \text{ mm}$; $d \geq 15 \text{ cm}$

¹⁾ The classification is based upon the airborne sound insulation index I_a . Vide annexe B, paragraph 9. It increases in steps of 5 dB from $\leq 24 \text{ dB}$ (class 0) to 45 ... 49 dB (class 5).

²⁾ Two panes, sealed, with air between them, distance $d \approx 1 \text{ cm}$

³⁾ Two single windows with co-axial hinge on common frame; distance $\geq 100 \text{ mm}$

⁴⁾ Either in separate frames or in common frame; independent hinges

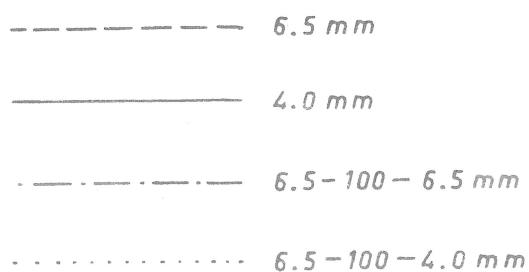
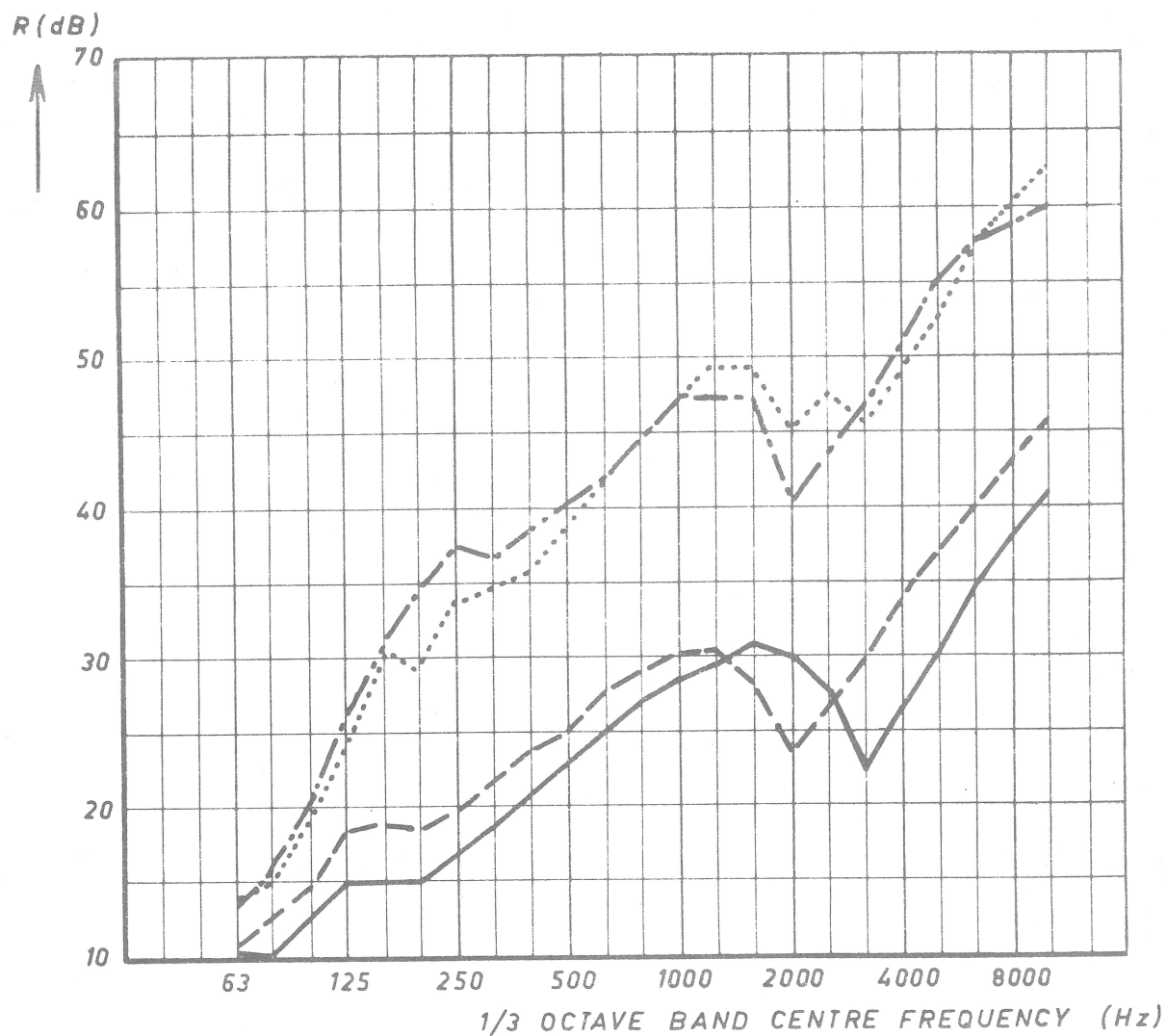


FIGURE 6.2/6 EFFECT OF GLASS THICKNESS ON TRANSMISSION LOSS (R) OF WINDOWS [7]

ANNEXE 6.2 ANoise rating and critical indoor levels

In critical situations, calculations and possibly measurements may be needed for proper decision as to the required insulation. Discussion of the methods is considered outside the scope of this chapter, as their application would require intensive training and experience. Basic data are criteria for indoor levels from intruding sounds¹⁾. Therefore, some information on this subject is given below. From a great variety of rating procedures only two, recommended by ISO [1], are discussed.²⁾

For many applications it will be sufficient to check whether the indoor levels will not exceed certain critical values when a window type (and façade) with certain insulation characteristics is applied in an environment characterized by certain levels outdoors. On other occasions it may be necessary to find out the insulation requirements for a given combination of external levels and critical indoor levels. In the first case it will usually be sufficient to apply A-weighted levels, whereas in the second case a spectral analysis may be needed to find out which frequency interval is critical.

6.2 A1 Rating without spectral analysis; "rating sound level"

In view of prediction to what extent a sound may interfere with activities or rest, it is attributed a "rating sound level", (L_r) according to:

$$L_r = L_A + C_1 + C_2$$

where

L_A = A-weighted sound level

C_1 = 5 dB when the noise is impulsive (as with hammering) or when it contains pure tones (as with a circular saw) or both. $C_1 = 0$ in all other cases.

C_2 is found from a table according to the duration of the sound as a fraction (p) of the relevant time period. C_2 varies from 0 for $0,05 < p < 1$ to -30 for $p < 0,002$ (This part of the recommendations has been criticized: the effect of time upon annoyance is more complex; in certain circumstances

1) This applies for proper window design in individual cases. It is understood that from the point of view of noise prevention critical values

for outdoor levels are more relevant.

2) This selection is on formal reasons only. For other procedures vide e.g. [3, 16].

it may even be in a direction opposite to the suggested one).

For sounds which fluctuate to such an extent, that no fixed value of L_A can be attributed, L_r may be found from

$$L_r = L_e + C_1,$$

where L_e is the "equivalent sound level", calculated from a time analysis of L_A according to the equal energy principle [1].

The rating sound levels L_r may be compared with relevant criteria. For the time being the building designer has to do without international criteria on indoor levels. The quoted recommendations [1] - for purposes of zoning and dealing with complaints - are primarily concerned with outdoor levels. An appendix ("2") shortly deals with criteria for indoor levels. The abstract in the table below may serve as a guide to designers. For the sake of adequate interpretation we quote from [1] that

- in a supposed community, "no-","sporadic-" or "widespread complaints" (i.e. with regard to noise from outdoors) must be expected when the criterion is exceeded by resp. 0, 5 or 10 dB(A).
- the criterion for noise from outdoors in residential premises, usually "should not be set below 20 dB(A)".

CRITICAL VALUES OF RATING SOUND LEVELS (L_{rc})

type of room	L_{rc} dB(A)
- workshop, according to intended use	45 ... 75
- large typing hall	55
- larger restaurant	45
- larger office, meeting room	35
- residential premises in residential districts, at night	20 ¹⁾

6.2 A2 Rating with spectral analysis; "noise rating number"

From any level L - for the octaves in the range 31,5 to 8000 Hz (centre frequencies) - a corresponding level L' is calculated, according to

$L' = L + C_1 + C_2$, where C_1 and C_2 are chosen according to paragraph A1.

Subsequently a "noise rating number" (NR-number) is attributed to the spectral distribution of L' , by means of figure 6.2 A/1, the NR-number being the number corresponding with the lowest curve that is not exceeded. Interpolation may be applied, but the result will easily suggest more accuracy than can be accounted for, because of approximations in both the rating system and the determination of L values.

The criteria for the NR-numbers are 5 units lower than those for the rating sound levels in dB(A). Vide par. A1.

When the critical value is exceeded it is easily to be seen from figure 6.2A/1, which frequency range is critical for improvement of the situation.

OCTAVE BAND PRESSURE LEVEL

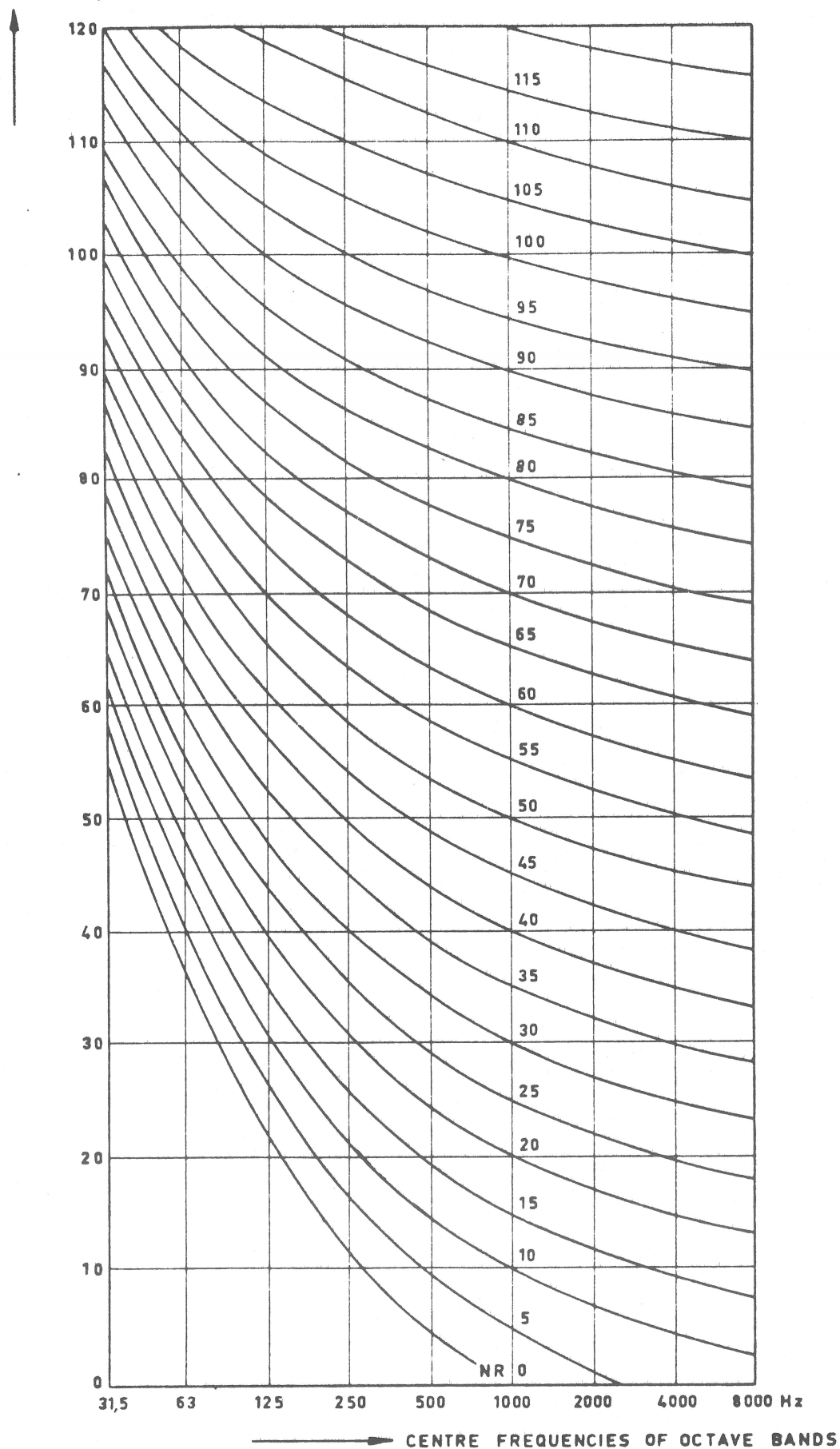
dB re $2 \cdot 10^{-5}$ N/m²

FIG. 6.2 A/1 NOISE RATING CURVES

SOME ACOUSTICAL CONCEPTS

6.2 B1 Sound is experienced when the ear is stimulated by pressure fluctuations within a certain range of frequencies and intensities. The human ear responds to frequencies from about 20 Hz (or c/s) to about 20 000 Hz; in terms of pitch: a range of ten octaves (10^3 being approximately equal to 2^{10}). As regards audible intensities: the smallest perceptible values are in the order of 10^{-12} W/m²; hearing without pain (though not without discomfort, neither - on the long run - without hearing damage) is possible up to about 100 W/m². This range of intensities may be expressed as a factor 10^{14} , "14 decades", "14 log units", or, in the acoustical terminology: 140 decibels (dB), one decibel being $\frac{1}{10}$ of a log unit.

6.2 B2 As a rule the intensity of sound waves is characterized by a dimensionless numeral, called sound level (L). It indicates to what extent the intensity (I) exceeds a certain reference value (I_0). It is defined by

$$L = 10 \log \frac{I}{I_0} \text{ (dB)}.$$

For single sinus waves (pure tones) intensity varies with the square of the sound pressure variation (p).

$$L = 10 \log \frac{I}{I_0} = 10 \log \frac{p^2}{p_0^2} = 20 \log \frac{p}{p_0} \text{ (dB)}$$

where p_0 is the pressure variation corresponding with I_0 .

6.2 B3 For many applications, such as sound insulation, we are only interested in sound level differences, which means that the reference value is not relevant.

$$L_1 - L_2 = 10 \log \frac{I_1}{I_0} - 10 \log \frac{I_2}{I_0} = 10 \log \frac{I_1}{I_2} = 20 \log \frac{p_1}{p_2} \text{ (dB)}$$

For other instances the reference value has been standardized as $p_0 = 2 \cdot 10^{-5}$ N/m² (i.e. approximately the pressure variation which corresponds with the auditory threshold at 1000 Hz for the standard ear). Where this reference value is applied, the sound level is called "sound pressure

$$L_{\text{re } 2.10^{-5} \text{ N/m}^2} = 20 \log \frac{p}{2.10^{-5}}$$

or shortly:

$$L = 20 \log \frac{p}{2.10^{-5}}$$

- 6.2 B4 However, waves with the same value of L may differ as regards their acoustical effect or their interference with rest or activities. For this reason a full description of a (steady) complex sound requires a spectral analysis, i.e. a statement or graph of values of L for various frequency ranges. According to the required accuracy these may be intervals of e.g. one, $\frac{1}{2}$ or $\frac{1}{3}$ octave.
- 6.2 B5 For fluctuating sounds the full physical description requires a time analysis, in terms of levels $L_{f,p}$ which in the frequency range (e.g. octave) with central frequency f , are exceeded during p percent of the time (p e.g. 5, 10, 50, 90).
- 6.2 B6 For many practical situations the complex characterization of sounds and insulations by a spectral analysis can be avoided by the use of a certain weighting circuit in combination with the sound level meter. This circuit, like the ear, reduces the relative weight of low frequencies. The resulting values of L , called "A-weighted sound levels" (L_A) and expressed in dB(A) show a good relation with human responses of the kind mentioned above.
- 6.2 B7 It is a rather common error, to confuse insulation and absorption. Applying absorbing material to a wall will not reduce the sound transmitted. (Under unfavourable conditions the insulation may even be worse.) The only effect will be reduction of the sound reflected by the wall.

6.2 B8 Within the field of insulation, distinction has to be made between two types of intruding sound, depending upon whether or not they are transmitted within air before the transmission in the barrier. They are called respectively "airborne sound" and "impact sound". Impact sounds are for instance sounds caused by hammering in other rooms of the building or by knocking upon a window. With regard to the sound insulation of windows only airborne sounds are relevant.

6.2 B9 Some of the numerals, applied to characterize building materials or elements with regard to airborne sound insulation are:

- the "level difference", D

$$D = L_1 - L_2$$

where L_1 level in the source room

L_2 level in the receiving room

D depends not only from the barrier, but also from the reverberation time (T) in the receiving room. Therefore,

- the "normalized level difference", D_n , is defined by:

$$D_n = D + 10 \log 2T$$

Both D and D_n depend upon the size of the barrier. Therefore the material as such may be characterized by:

- the "sound reduction index", or "transmission loss", R

$$R = L_1 - L_2 + 10 \log \frac{S}{A}$$

where S is area of the test specimen and A the absorption in the receiving room, R is measured in the laboratory i.e. with the exclusion of flanking transmission. The same measurement in practical situations yields a lower value: R' .

All the above numerals depend upon frequency. Procedures for their spectral measurement are recommended in [11]. For many purposes it is sufficient to know average values for 100 ... 3200 Hz:

- $\bar{D}$, $\bar{D}_n$, $\bar{R}$ or $\bar{R}'$

- the "airborne sound insulation index", I_a computed from deviations

of R from a standard distribution (with respect to sound insulation between dwellings). [12]

The above (B9) applies to diffuse sound fields, and therefore, for example, to sound insulation between rooms. In the case of windows and outdoor noise additional complications occur, due to the directional character of the outdoor sound. On this subject we must refer to the literature [3, 8, 13, 16] .